FEMC

Forest Ecosystem Monitoring Cooperative

Long-Term Monitoring Update 2017

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 - 2017

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Acknowledgments

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Introduction

The Forest Ecosystem Monitoring Cooperative (FEMC, formerly the Vermont Monitoring Cooperative) was established in 1990 as a partnership among the USDA Forest Service, the State of Vermont Agency of Natural Resources (VT ANR) and The University of Vermont (UVM). The mission of the FEMC is to facilitate 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 more than 215 collaborators in its 28-year history. These projects, conducted across the state of Vermont and the larger northern temperate forest region have investigated 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 datasets that characterize 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, and an analysis of the long-term patterns and trends in the data. These updates thus provide a relevant and timely source of information on the current state of the region's forested ecosystems.

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 is growing daily. As an organization, the 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 allow us to 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 interns 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. From 2008 to 2013, the plots were measured on a 3-year rotation.

Hemispherical canopy photo at long-term plot in the Lye Brook Wilderness Area (2017).

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. 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.

2017 in Summary

Crown Health

In 2017, for all selected tree species, mean dieback decreased compared to 2016. Only one species, red oak, showed elevated dieback (8.9%) levels compared to the long-term trend (1991-2017). Overall dieback across all species was 9.6%, which is lower than the mean in 2016 (12.2%), but still represents an increase compared to the long-term average (8.1%). While any one year can have events that stress trees (e.g., drought, insects, disease), multiple years of increased dieback can be cause for concern.

For most tree species, crown transparency decreased (e.g., improved) in 2017 compared to 2016. At 14.9%, average crown transparency was lower in 2017 than in 2016 (20.7%), and lower than the long-term average (20.5%). The only species that did not exhibit a decrease in crown transparency were red oak and white ash.

Red oak showed an increase in live crown ratio in 2017, indicating an overall trend of increased foliage relative to total height. Conversely, other species (American beech and eastern hemlock) exhibited a decline in live crown ratio. In 2017, the average live crown ratio across all species was 50.7%, which is slightly lower than the 2016 value (52.7%) and the long-term average (51.5%).

Table 1. Crown health metrics (dieback, transparency, and live crown ratio) in 2017 and compared to the long-term mean. 'Dif' column indicates the difference between 2017 and the long-term mean, with red values showing a decline in health (one standard deviation), blue shows an improvement, and no color indicates no change.

Species	Dieback (%)			Transparency (%)			Live crown ratio (%)		
	2017 mean	Long-term mean	Dif	2017 mean	Long-term mean	Dif	2017 mean	Long-term mean	Dif
American Beech (Fagus grandifolia)	11.33	9.43	1.90	15.68	22.38	**-6.70**	56.21	59.90	**-3.69**
Balsam fir (Abies balsamea)	12.88	12.18	0.70	10.72	19.28	**-8.56**	60.74	69.57	-8.83
Eastern hemlock (Tsuga canadensis)	6.68	4.31	2.38	13.27	21.84	**-8.57**	63.70	82.03	**-18.33**
Eastern white pine (Pinus strobus)	7.60	7.86	-0.26	16.20	20.81	**-4.61**	47.02	47.79	-0.77
Northern red oak (Quercus rubra)	8.89	4.76	**4.13**	18.89	17.32	1.57	46.35	34.17	**12.18**
Paper birch (Betula papyrifera)	11.40	9.85	1.55	16.00	23.21	**-7.21**	41.75	41.99	-0.24
Red maple (Acer rubrum)	9.10	7.17	1.93	15.22	20.11	**-4.89**	47.07	48.74	-1.68
Red spruce (Picea rubens)	6.63	6.74	-0.10	9.48	17.03	**-7.55**	50.82	51.65	-0.83
Sugar maple (Acer saccharum)	8.24	6.10	2.14	12.33	17.33	**-5.00**	52.82	55.54	-2.72
White ash (Fraxinus americana)	12.94	8.55	4.39	17.06	19.19	-2.13	40.67	37.25	3.42
Yellow birch (Betula alleghaniensis)	8.39	7.26	1.13	15.10	18.93	**-3.83**	55.03	54.95	0.08

In 2017, we saw high regeneration of red maple, sugar maple, yellow birch, and striped maple (Figure 1). However, overall there was a decrease in regeneration of selected tree species relative to 2016 (Figure 3). As some tree species produce heavier and lighter seed years, annual fluctuations in seedling densities are expected to some degree. Since 2014, we have seen a high density of red maple seedlings in the FHM plots; however, in 2017 the mean density of red maple decreased (5,767 seedlings per hectare) compared to 2016 and was comparable to densities of sugar maple (5,540 seedlings/ha) and balsam fir (4,526 seedlings/ha) seedlings (data not shown). Compared to the previous two years, American beech regeneration was slightly depressed. Yet, American beech seedlings were still a considerable component of the understory, though in slightly lower densities than in 2016.

For dominant and codominant trees measured in 2017, balsam fir dominated the plots (438 trees), followed by sugar maple (318) and red maple (206) (Figure 1). 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 2017 there were some uncommon species detected in the plots, including black gum and basswood.

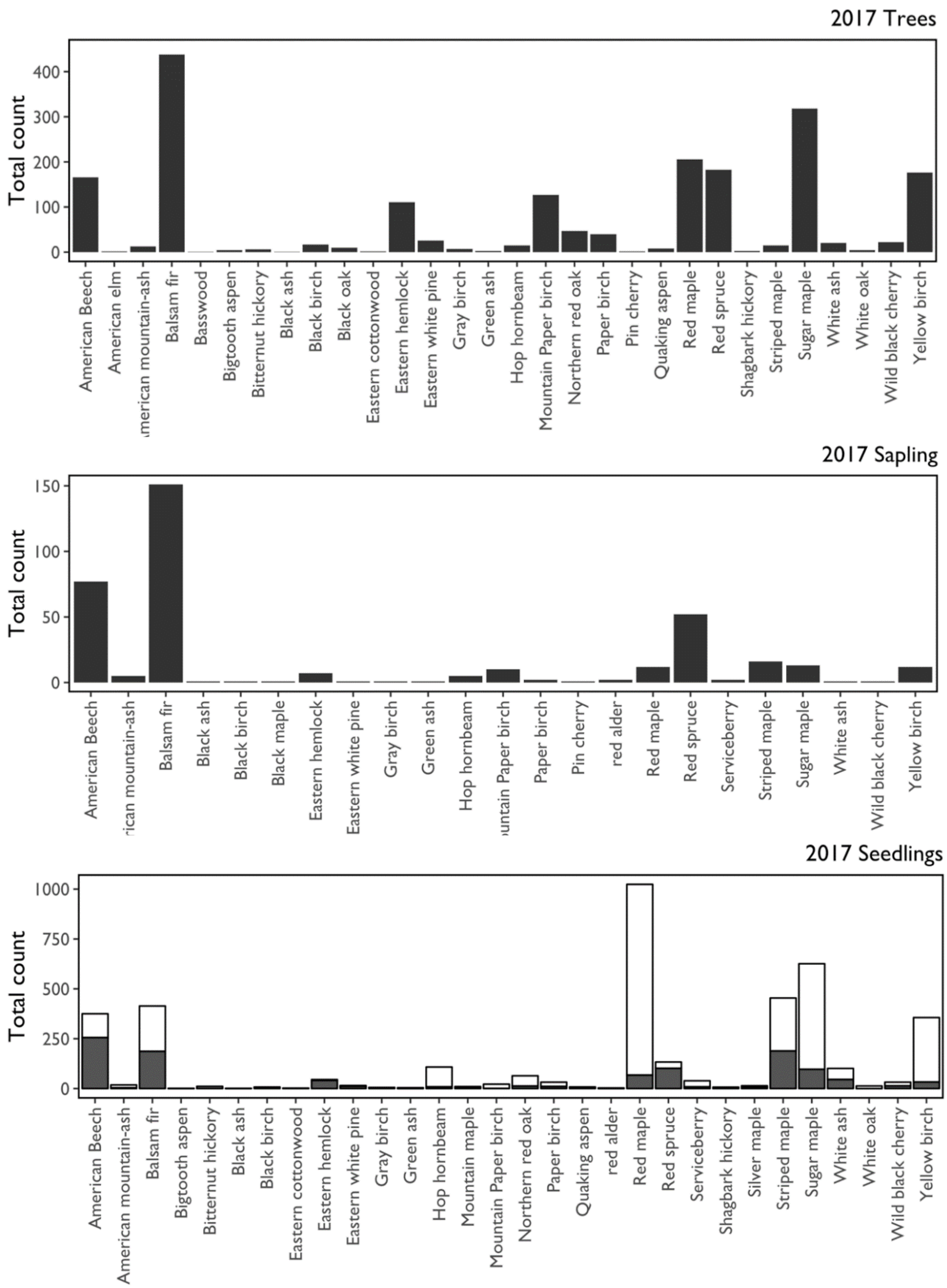


Figure 1. Species composition of all dominant and codominant trees greater than 5 in. diameter (top), saplings between 1 in. and 5 in. diameter (middle), and seedlings less than 1 in. diameter (bottom) tallied across the 2017 FEMC Forest Health Monitoring plots. For seedlings, class 1 seedlings (<12 inches tall for hardwoods and <6 inches tall for softwoods) are depicted in white and class 2 (all seedlings <1 in. diameter that are not included in class 1) in gray.

Forest Health

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 2). 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. For nearly all species, crown health in 2017 worsened

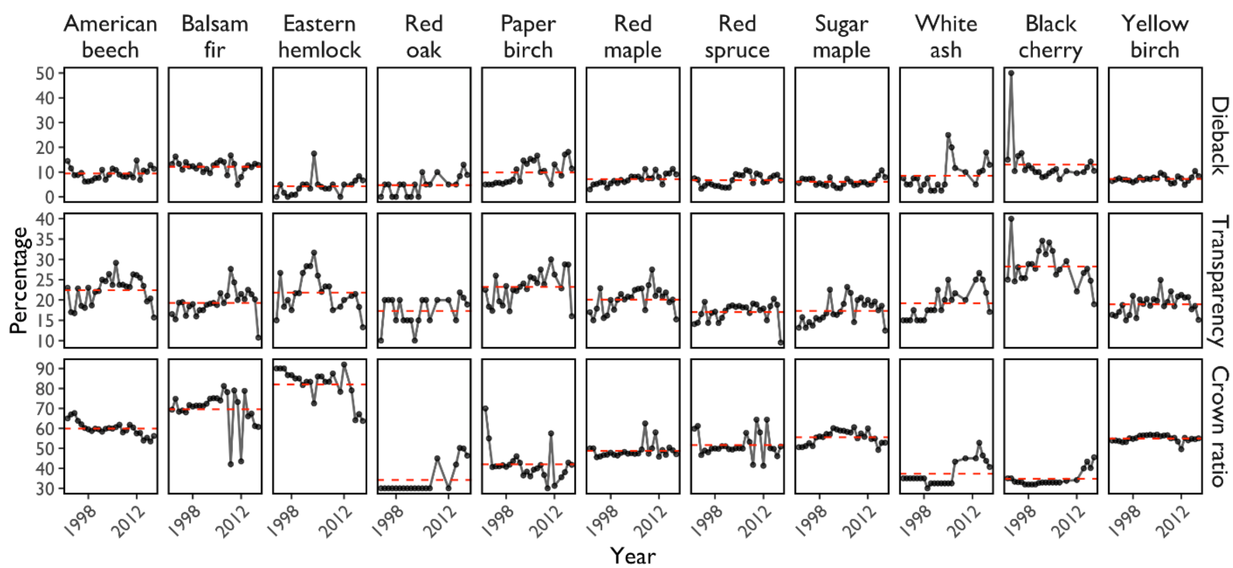


Figure 2. Tree crown health metrics: percent dieback, percent crown transparency, and live crown ratio (percentage of tree with foliage) for 11 dominant tree species in Vermont. Red dashed line shows the long-term mean (1993-2017) for that species and metric.

compared to 2016 measures. (Figure 2). The FEMC will continue to monitor these species to understand how changing environmental conditions are altering forest health or competitive relationships.

Regeneration trends over time on a subset of plots

Total seedling density across a subset of the total plot network (19 plots) showed that balsam fir and American beech dominated, however, seedling densities of sugar maple were also high (Figure 3). Seedling patterns vary dramatically across plots due to the broad geographic and elevational range of the locations, which span many forest types. 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.

Looking only at established seedlings (class 2 seedlings: hardwoods >12 inches tall, softwoods >6 inches tall, Figure 3), trends in overall abundance of established seedlings on Mt. Mansfield plots fluctuate, with 2017 appearing similar to some previous assessments and different from others. 2017 shows an increase in established seedlings for sugar maple over the most recent 10-year period, but still a much lower representation than found in the early 1990s. Paper birch and red maple made up a larger proportion of seedlings than in previous years.

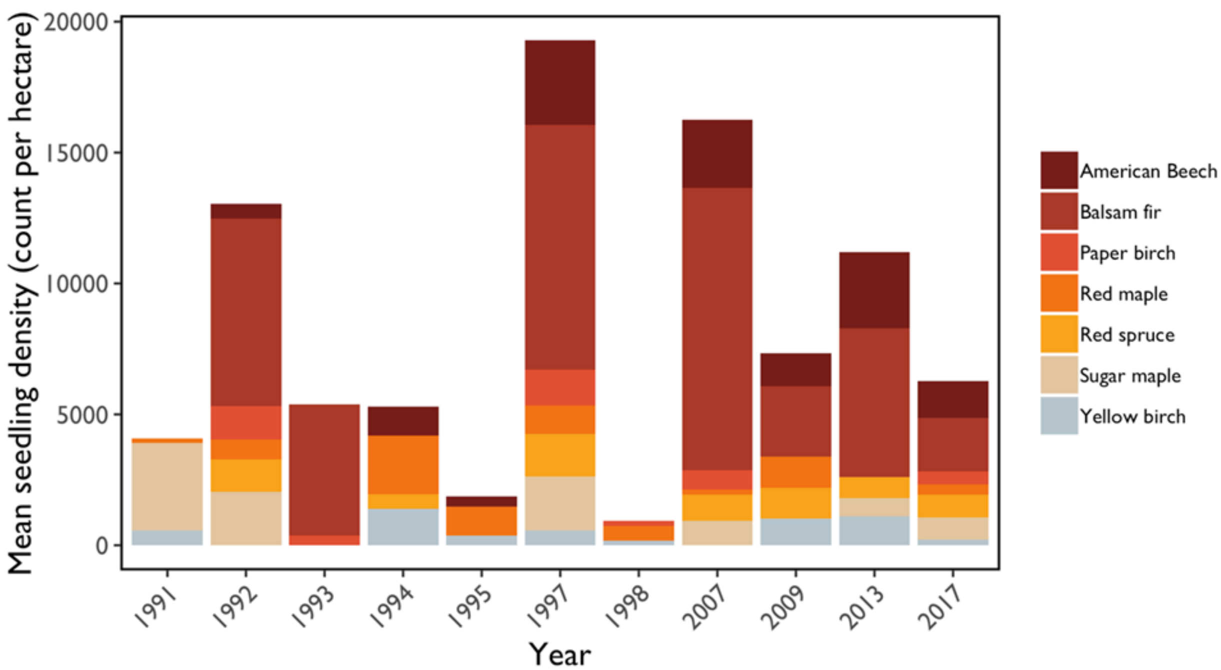


Figure 3. Mean seedling density (count per hectare) for selected species assessed at a subset of 19 FEMC forest health monitoring plots. Note that seedling counts were not assessed each year.

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.

Forest Health

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 trends continue to show declining tree crown health for white ash and paper birch, while others species continue to remain stable. Sugar maple regeneration is on the decline as red maple regeneration is inclining.

Acknowledgements:

Special thanks to Josh Halman from the Vermont Forest Parks and Recreation Department for reviewing and editing the Forest Health Section of the 2017 FEMC Long-Term Monitoring Update.

Additional Resources

VT Forests, Parks and Recreation Vermont Forest Health Highlights 2017
https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2017%20VT%20Forest%20Health%20Highlights.pdf

VT Forest Insects and Disease Conditions 2017
https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2017%20Vermont%20Forest%20Insect%20and%20Disease%20Conditions%20Report%20FINAL%20updated.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 Vermont'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 in the future.

The Data

The Data Insect and Disease Surveys (IDS) (formerly, 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 survey data 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 IDS across the US.

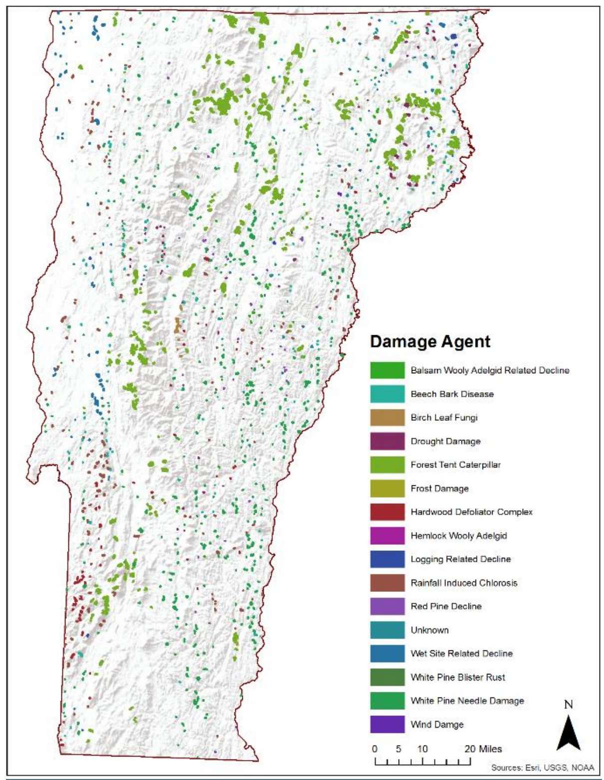


Figure 4. Locations of 2017 mapped forest disturbance from Vermont aerial detection surveys. Disturbance polygons were increased in size for visibility. Only those damage agents with the highest occurrence are shown.

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.

2017 in Summary

In 2017, 39,873 hectares (98,555 acres) of forest disturbance were mapped in Vermont, which is just over 2% of Vermont's forestland. This is an increase from 2016 when 32,737 ha were mapped, and is much lower than the long-term (1995-2017) average of 102,499 ha/year.

A forest tent caterpillar found in Vermont.

2017 marked the second year of a forest tent caterpillar (*Malacosoma disstria)* outbreak, with 24,515 ha of damage mapped during the season, an increase over the 9,197 ha mapped in 2016. Outbreaks result in defoliation of hardwood trees and usually last several years. White pine needle damage was the second most widespread damage, with 6,650 ha mapped (Figure 4), but this value represented only half the white pine needle damage area mapped in 2016.

Rainfall-induced chlorosis was the third-most common damage type, resulting from the wetter-than-normal spring and early summer, largely affecting sugar maples. Symptoms attributed to drought were much less common than in 2016 (VT FPR 2017) 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 2017 although they caused damage elsewhere in the northern Forest region (MA, ME, NH, NY, and VT).

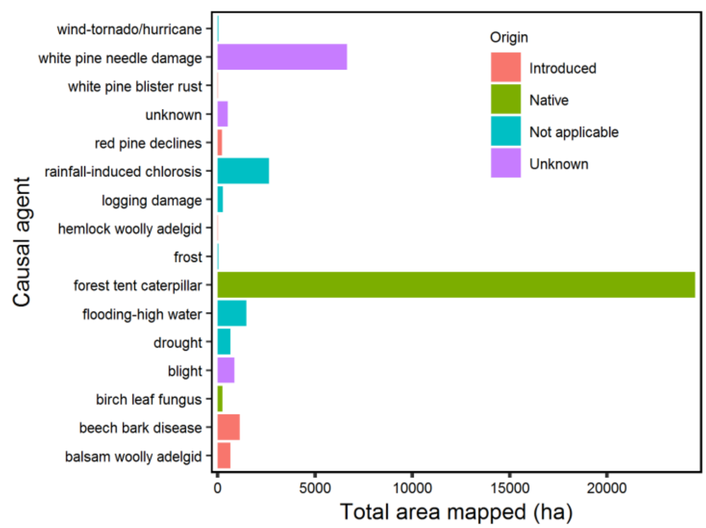


Figure 5. Area (in hectares) of mapped 2017 disturbance by causal agent according to Vermont aerial detection surveys. Color corresponds to the agent's origin.

More complete results of the 2017 Vermont ADS effort can be found in the 2017 report, *Forest Insect and Disease Conditions in Vermont* (VT FPR, 2017).

Long Term Trends

Summing all disturbances per year (1995-2017) 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 23-year period: beech bark disease and birch defoliator complex (Figure 7).

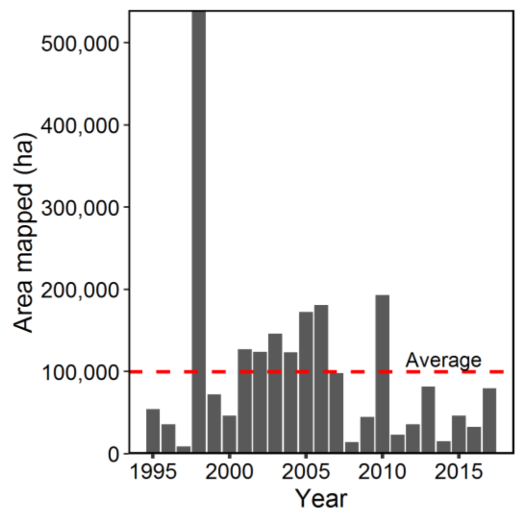


Figure 6. Annual area mapped as disturbed (grey bars; hectares) during statewide aerial detection surveys in Vermont. Red dashed line indicates the average disturbance (1995-2017).

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 (394,829 ha), birch defoliator complex (324, 807 ha) and forest tent caterpillar (301,715ha).

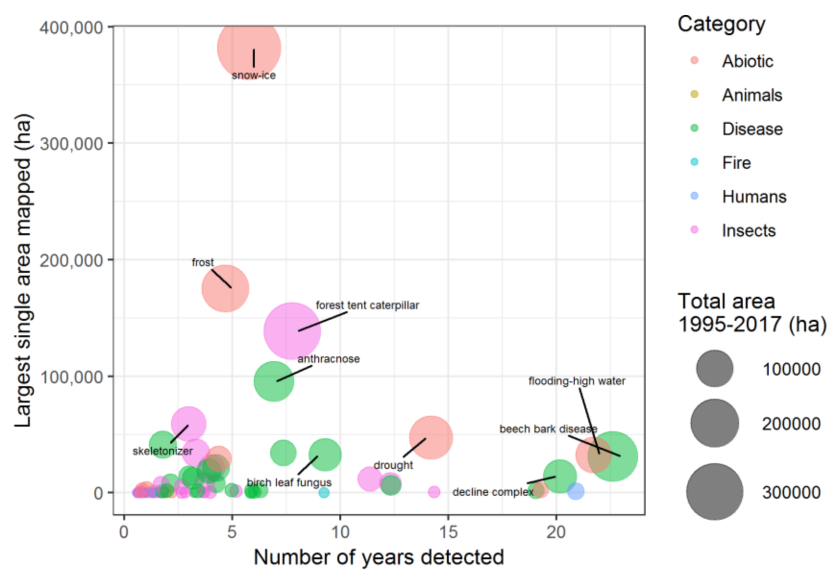


Figure 7. Mapped disturbance agents in aerial detection surveys from 1995-2017 plotted by the frequency (number of years detected) and largest single area mapped (ha; e.g., largest polygon) attributed to agent. Circle size corresponds to the total area recorded for that agent over the twenty-one-year 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 23-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

Insect and Disease Survey 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 specific species, such as ash (*Fraxinus* spp.) with the continued spread of emerald ash borer. 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.

In 2017, there was less disturbance than the Vermont average (1995-2017). The most damaging disturbance agents in 2017 were forest tent caterpillar, white pine needle damage, and rainfall-induced chlorosis.

Additional Resources

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). 2017. Forest Insect and Disease Conditions in Vermont: 2017. Report. Available online at: https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2017%20Vermont%20Forest%20Insect%20and%20Disease%20Conditions%20Report%20FINAL%20updated.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 better understand how changes in climate are impacting forested ecosystems.

The Data

Current FEMC data sets include visual assessments from 1991 to present of sugar maple (*Acer saccharum*) 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 670 m (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 26-year period.

2017 in Summary

The day-of-year of first bud break in 2017 for sugar maple (DOY 119) was earlier than the long-term average (DOY 125) (Figure 8). Full leaf out (DOY 139) was similar to the long-term average, but occurred two days earlier compared to 2016. The transition from bud break to full leaves was longer than normal, taking 20 days compared with the long-term average of 15 days. At lower elevations, maximum fall color occurred 4 days earlier than the long-term mean. Full leaf drop came just 1 day earlier than the long-term mean. At higher elevations, peak color was more delayed (5 days later than the long-term mean), and full leaf drop was 1 day earlier than the long-term mean.

Long Term Trends

Spring phenology in 2017 was similar to the long-term mean and 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 trees). 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).

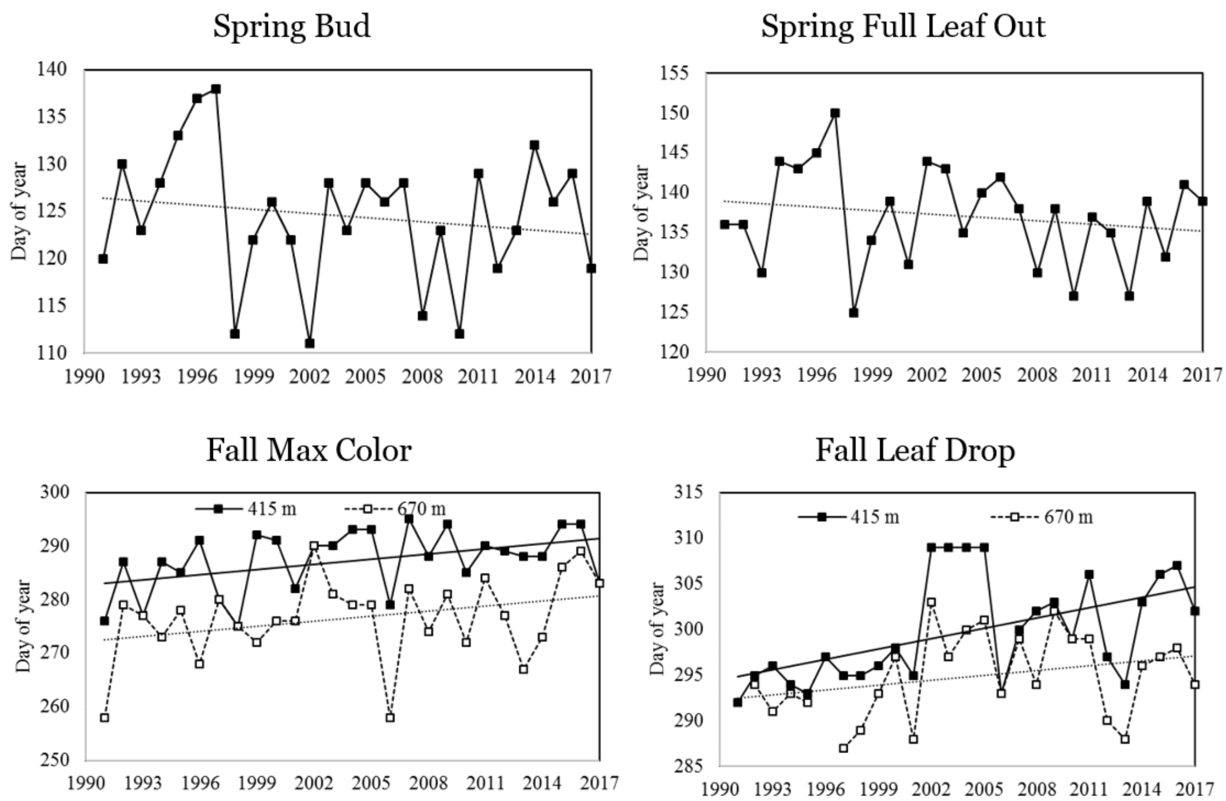


Figure 8. Long-term trends in the timing (mean day of year) of spring and fall phenological events for sugar maple from 1991 to 2017. Spring bud burst (top left) and full leaf out (top right) are assessed yearly at lower elevation (415m), with linear trend line shown. Fall maximum coloration (bottom left) and leaf drop (bottom right) yearly data are shown for sugar maple at two elevations (415m and 670 m) as well as a linear trend line in both.

In the fall, significant trends towards later fall color and leaf drop at lower elevations continued to be observed (Figure 8). The delay of maximum fall colors at low elevations showed consistently later peak foliage over time, culminating in an average delay of 8 days across the data record. Fall leaf drop showed a similar 10-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 that other work has suggested that climate change induced warming 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.

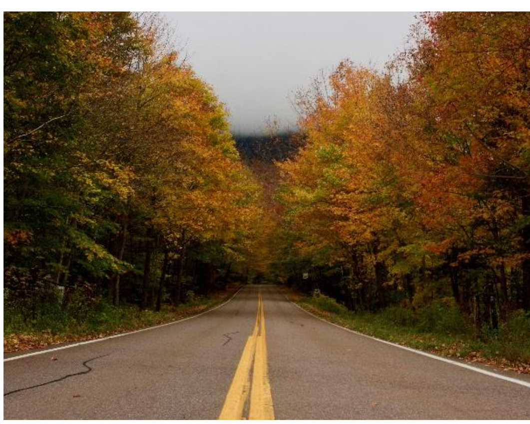
These trends toward earlier springs and later falls are consistent with trends reported in earlier analyses of the FEMC data set (see https://www.uvm.edu/femc/attachments/project/999/reports/SugarMapleSpringPhenology_Mansfield2010.pdf)

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 these changes may affect forested ecosystems. There are possible implications for water cycling, 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 tourism 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

The ecological consequences of atmospheric acid deposition have been well studied in the Northeast. 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^{2-}) 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.

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

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^+).

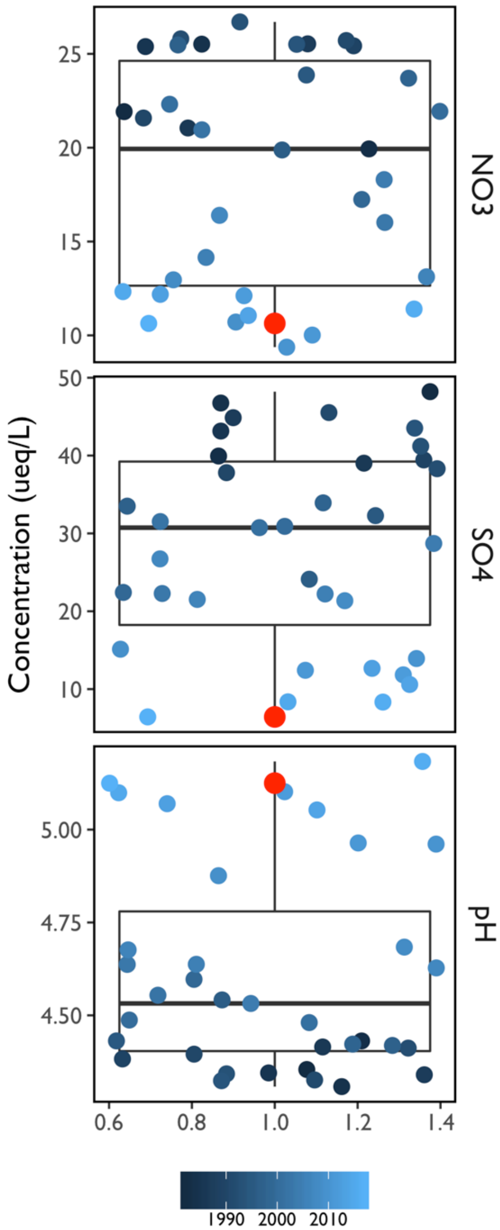


Figure 9. Mean annual deposition of nitrate (NO3), sulfate (SO4), and pH displayed with quantile box plots. The most recent year's measurements (2017) are indicated in red, and shades of blue correspond to the year, with lighter values corresponding to more recent data. Solid horizontal line indicates 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.

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

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.

2017 in Summary

For all three metrics of acid deposition (NO_3, SO_4, pH), 2017 continued the trend of reduced pollution concentrations over historical measurements (Figure 9).

While mean deposition of NO_3 in 2017 was not the lowest value observed in the record (Figure 9), it was the third lowest at 10.64 μeq/L, and was a considerable decline from the record high of 28.13 μeq/L in 1985. Further, for every year in the most recent decade (2006 on), precipitation contained the lowest measured concentrations of NO_3.

In 2017, we saw the lowest concentration of SO_4 in the record (6.43 µeq/L), continuing a four-year streak of record lows. This is a dramatic decline from the historical high of 48.20 µeq/L in 1982. For the second year in a row, deposition of SO_4 fell below that of NO_3.

The average pH was the second highest on record at 5.13, which indicates that precipitation in the form of rain, snow, or ice is continuing to be less acidic when compared to historic records. 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 acidic 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, SO_4 accounted for about 66% of the acidity in precipitation, while NO_3 contributed the other 33%. According to the U.S. EPA National Emissions Inventory 2014 Report V2, national emissions of the precursor pollutants of SO_4 and NO_3 have decreased substantially since 1990 levels. Nationally, sulfur dioxide (SO_2) emissions have decreased by 88% since 1990, while emissions of nitrogen oxides have decreased by 58%. While the stress imposed by sulfate deposition has been greatly reduced, it is unclear how the continued deposition of nitrate 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). Sulfate deposition has fallen from nearly 50 µeq/L to less than 10 µeq/L (Figure 10).

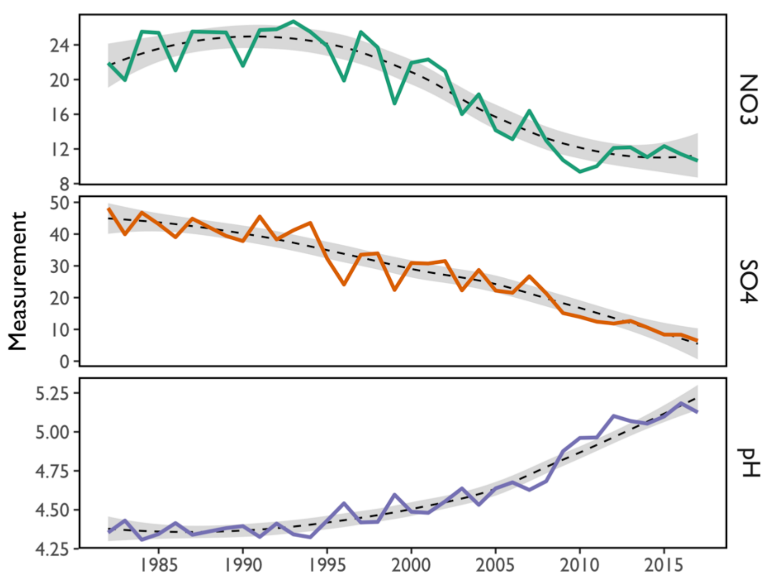


Figure 10. Long-term precipitation chemistry showing annual mean concentrations (ueq/L) of nitrate (NO_3) and sulfate (SO_4), and mean pH (solid colored lines). Black dotted line shows trend (LOESS function) with 95% confidence intervals (grey shading).

More modest changes 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, including the implementation of low sulfur fuel oil standards for heating oil.

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 tenfold decrease 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.

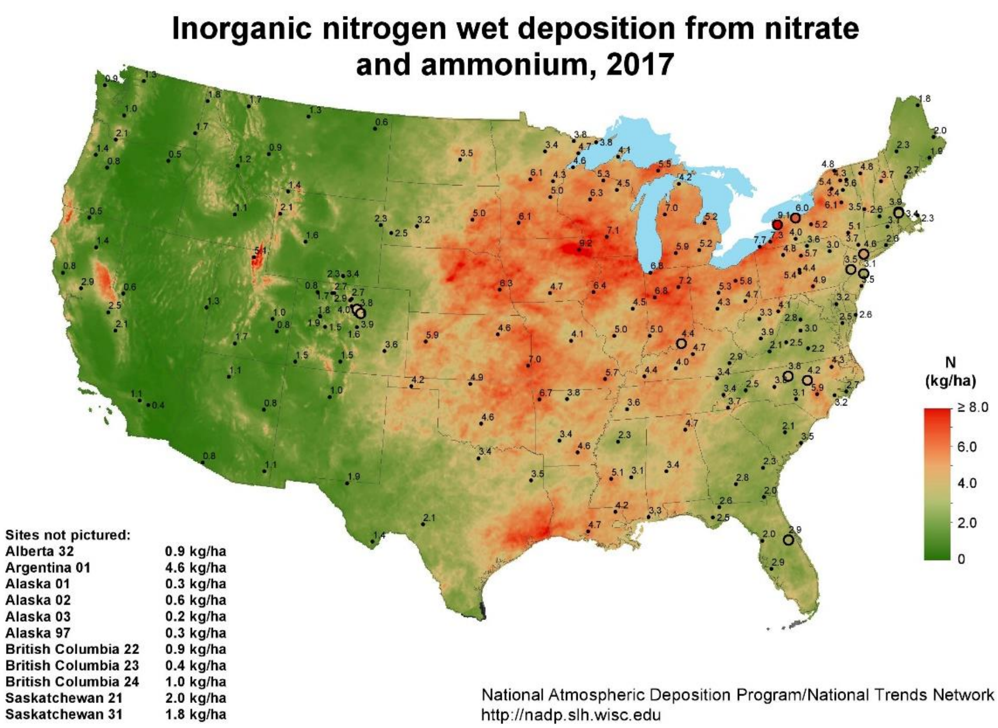
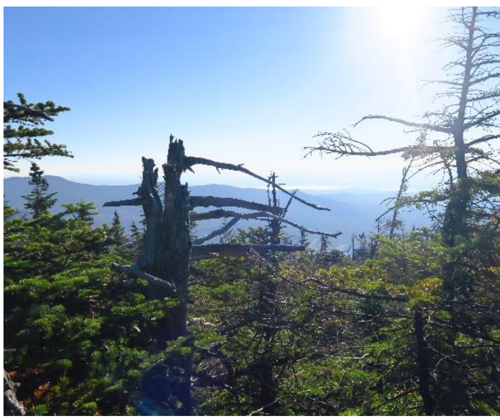


Figure 11. Spatial distribution of total inorganic nitrogen wet deposition from nitrate and ammonium (kg/ha) across the continental US in 2017. Source: NADP.

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 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 2017. The average pH of precipitation was 5.13, 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/

2014 National Emissions Inventory Report, Version 2: https://www.epa.gov/sites/production/files/2018-06/documents/nei2014v2_tsd_09may2018.pdf

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

Mercury Deposition

Mercury Deposition Network automated sample collector

Mercury Deposition Network Monitoring at VT99

Mercury (Hg) 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 100 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, how mercury bioaccumulates in birds and amphibians, how mercury levels are influenced by elevation, and how falling leaves contribute to deposition. 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.

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 (site ID: VT99). 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.slh.wisc.edu/mdn/)

2017 in Summary

Mercury monitoring at FEMC's air quality site VT99 for 2017 shows slightly lower mercury (Hg) deposition than average for the 13-year record, higher than 2015 and roughly equal to 2014 (Table 2). 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 2017, precipitation-weighted mean concentration was lower than average for the record, while the maximum recorded concentration in a single sample was well below historical average. In 2017, Vermont registered lower concentration and deposition averages than most sites elsewhere in the United States (Figure 12).

Table 2. Annual mercury (Hg) measurements from VT99. The color scale represents the lowest (green) and highest (red) values for a given metric between 2005 and 2017. Note that data for 2008 have been 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	132.0	11.6
2008			
2009	5.3	33.6	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	5.3	11.4	7.2
2015	4.9	21.0	6.1
2016	5.8	21.3	7.3
2017	5.3	11.7	7.4
Overall Mean	**5.8**	**46.5**	**7.9**

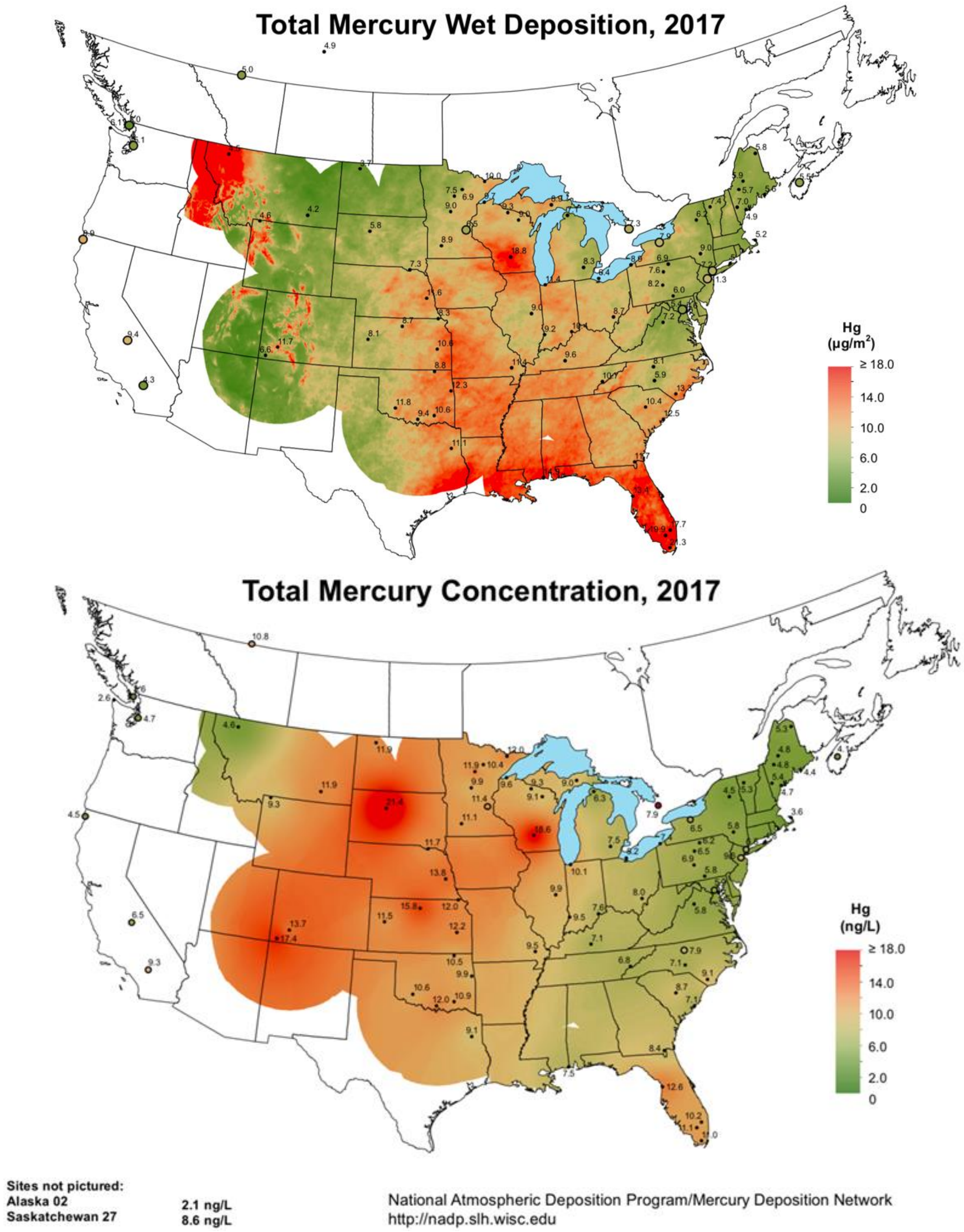


Figure 12. Estimated concentration and deposition of mercury in precipitation across the United States in 2017. Total mercury deposition is the amount deposited from the atmosphere on the landscape, and is used to assess the consequences on the ecosystem. Mercury concentration varies with the amount of precipitation, and is used to determine pollution sources and other atmospheric possesses.

Hg

Mercury Deposition

Long Term Trends

Over 13 years of monitoring at VT99, 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 also climbed from 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 (e.g., higher than 41% of sites). In 2017, we saw deposition that was similar to the long-term average (higher than 42% of other MDN sites).

Table 3. Comparison of total mercury (Hg) deposition (µg/m^2) at national MDN network sites and VT99. For the national mean deposition, only those MDN stations that met yearly quality criteria were included; however, the total number of reporting stations includes all stations, even those that did not meet quality criteria. The percentiles for VT99 compared to the national sites are shown in the bottom row. Red colors indicate greater percentiles (e.g., higher values than other sites) and greens indicate lower percentiles (lower values than other sites).

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Overall mean
Total # of reporting stations	95	104	112	117	125	133	112	113	116	120	116	112	85	112.3
National mean deposition	9.2	9.3	8.7	9.7	8.6	9.0	10.2	8.8	9.9	9.5	8.9	9.1	9.0	9.2
VT99 mean deposition	7.4	7.9	11.6	--	6.3	8.4	9.6	6.1	8.1	7.2	6.1	7.3	7.4	7.8
VT99 percentile	34%	38%	85%	--	35%	49%	48%	14%	44%	31%	27%	41%	42%	41%

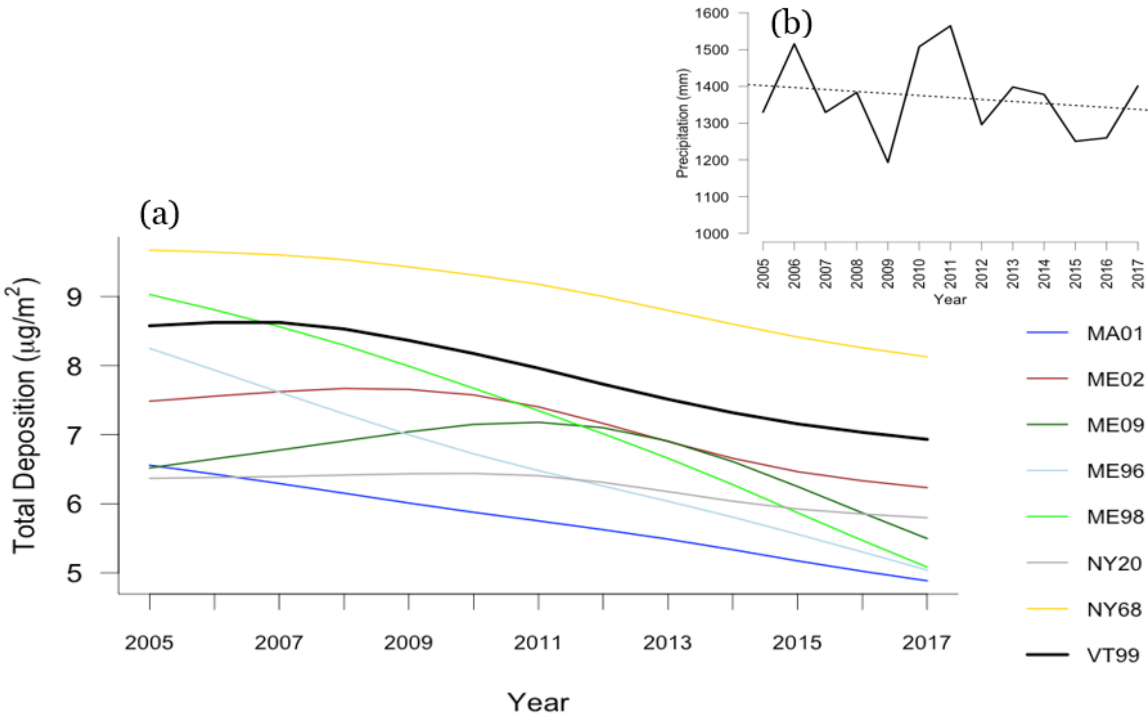


Figure 13. (a) Total mercury (Hg) deposition (μg/m²) by year for MDN monitoring sites in the northeastern US (Massachusetts, Maine, New York, and Vermont) with comparable years of data collection, displayed as spline-smoothed lines. Inset (b) displays the precipitation (mm) record at the sites, which shows little trend over the same period.

Indeed, a regional trends analysis using NADP MDN data (Figure 14) provides further signs of regional differences for VT99. Different time 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 concentrations. While five years is too short for a definitive trend, these results may suggest that VT99 has been more influenced by global sources compared to other MDN sites due to its relatively high elevation and the absence of nearby coal utility boilers (Weiss-Penzias et al. 2016).

Implications

In the long term, mercury deposition levels have decreased dramatically with the amendments to the Clean Air Act in 1990 (Kamman and Engstrom 2002). This legislation identified mercury as a toxic pollutant to be controlled to the greatest possible extent. However, as we have seen in Vermont, mercury deposition has not declined like other air pollutants.

Historically, sulfate emissions were 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 to mercury. In the northeastern region, mercury concentrations have not fallen as precipitously as expected. This suggests that mercury deposition in Vermont is not associated with regional sulfate emissions and may have other sources. Indeed, it is possible that the mercury falling in Vermont originates from overseas.

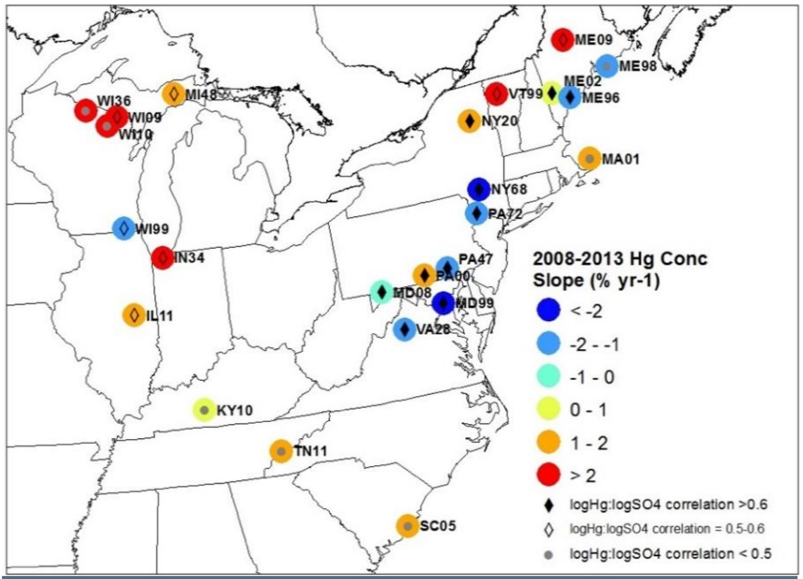


Figure 14. Annual rates of change in precipitation-weighted mean residual mercury (Hg) concentration over the period 2008-2013 for co-located MDN and NTN sites in the northeastern U.S. Symbols indicate the site-specific linear correlation coefficients (R) obtained from a regression between weekly log Hg and weekly log SO42- concentrations (not residuals) over the 2008-2013 period.

The atmosphere is the main pathway for mercury into Vermont's ecosystems. It has been estimated that more than half of atmospheric mercury deposition falls in a dry form. Dry deposition is more difficult to measure than wet deposition (e.g., falls with precipitation); however, NADP is committed to expanding its network of mercury dry deposition sites. Unfortunately, the FEMC had to terminate its Atmospheric Mercury Network (AMNet) site to assessed dry deposition on Dec. 31, 2015; therefore, dry deposition rates have to be inferred from wet deposition rates.

Mercury persists in the environment and continues to be cycled through the various storage pools (i.e., soils, air, biota). The continued low-level input and occasional spikes in mercury deposition will likely drive cumulative increases in mercury in Vermont's forests moving forward. Forest ecosystems and the organism that live there are particularly sensitive to these inputs (Driscoll *et al.* 2007, Gay 2016, pers comm, Weiss-Penzias *et al.* 2016). Conifers tend to have higher concentrations of bark and foliar mercury (Yang et al. 2018). Fish mercury burdens are one way to track these trends and in Vermont, and 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 ecosystem mercury is critical. Mercury cycling and bioaccumulation is complex process that is not fully understood.

As of October 2018, the Environmental Protection Agency's Mercury and Air Toxics Standards (MATS), which implements emissions reductions of toxic air pollutants, like mercury, from existing and new coal and oil-fired power plants, is under review by the EPA. If MATS continues in its current form, we should see a continued downward trend in mercury deposition from regional sources in Vermont and the Northeast.

Conversely, greater global mercury emissions 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.

In 2017, Vermont saw one of the lowest maximum concentrations of mercury in the 13-year record. However, Vermont's mercury deposition has not been decreasing as quickly as hoped, highlighting the role of monitoring for identifying patterns regional and global of mercury pollution.

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Yang Y., Yanai R.D., Driscoll C.T., Montesdeoca M., Smith K.T. 2018. Concentrations and content of mercury in bark, wood, and leaves in hardwoods and conifers in four forested sites in the northeastern USA. PLoS ONE 13(4): e0196293. https://doi.org/10.1371/journal.pone.0196293

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 causes a range of adverse effects on human health and sensitive vegetation. Ozone forms from photochemical reactions between air pollution emissions of nitrogen oxides and volatile organic compounds (VOCs). The US EPA sets and periodically revises national ambient air quality standards (NAAQS) 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 was promulgated by EPA in 2015 and is based on the highest 8-hour average 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. With preliminary 2018 data now available, the three-year average design value can be compared to the other sites, which averages similarly to, and in-between, the concentrations monitored at Bennington and Underhill (see Figure 15).

O_3

Ozone

2018 in Summary

The most recent 2018 4th highest maximum and 3-year average data for Bennington, Rutland, and Underhill are summarized in Table 4 below. All of the monitored design values are below (i.e. in attainment of) the 70 ppb level of the current primary health standard.

Table 4. 2018 and 3-year average ozone concentrations in northern and southern Vermont.

	2018 4th Highest 8-hr Maximum	2016-2018 Avg. 4th Highest 8-hr Maximum
Underhill	**62 ppb**	**60 ppb**
Bennington	**65 ppb**	**65 ppb**
Rutland	**63 ppb**	**63 ppb**

Long-Term Trends

Long term trends in ozone in northern (Underhill) and southern (Bennington) Vermont, as well as the recent record for Rutland, 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.

O_3

Ozone

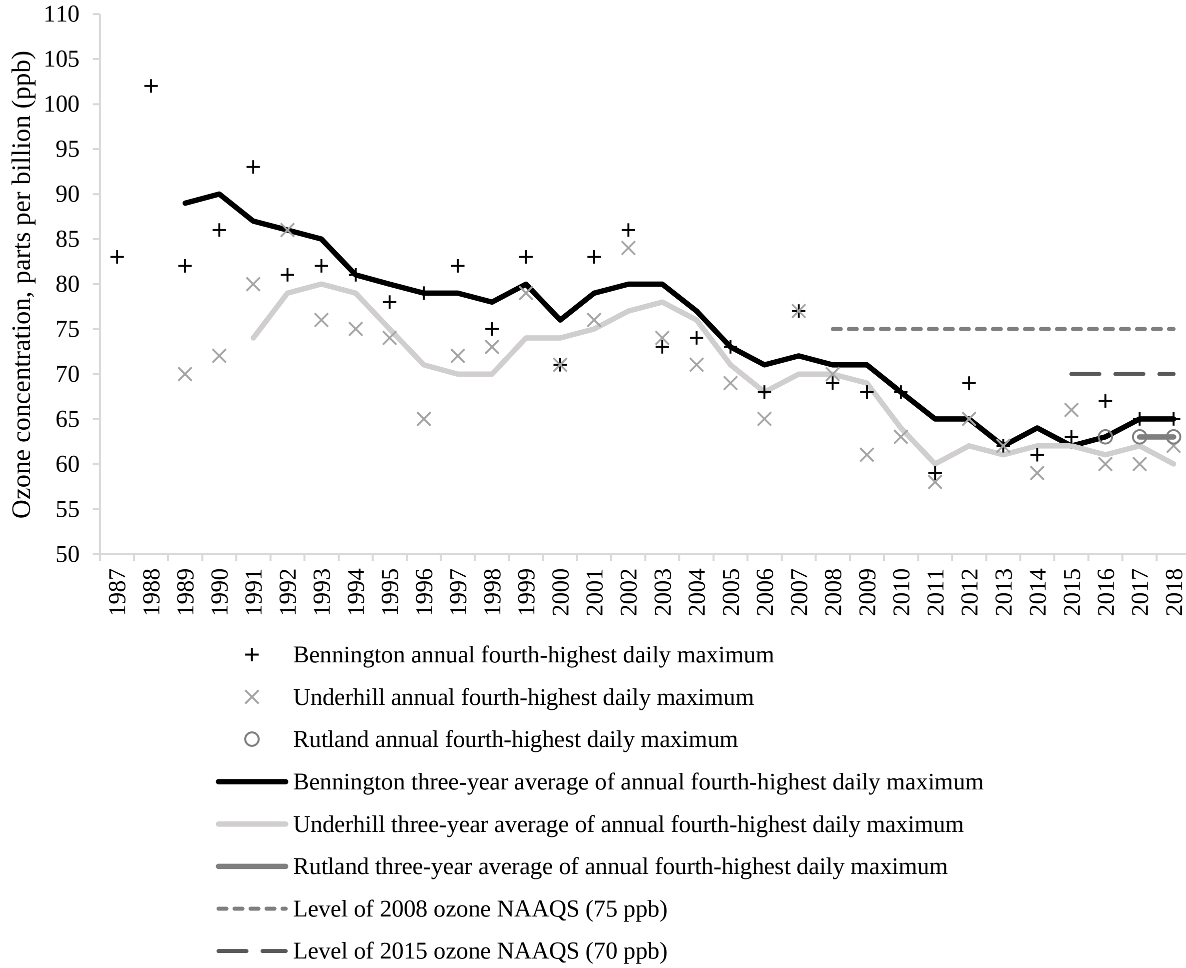


Figure 15. Vermont trends in ozone concentration. Data in the figure above are illustrated for the period 1987 to 2018 at the Bennington, Rutland, and Underhill ozone monitor locations. Note that 2018 averages are preliminary and subject to change.

O_3

Ozone

Implications

Substantial improvements have been observed in Vermont ozone concentrations over the past 20 years. These reductions reflect effective controls on emissions of VOCs 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 (VOCs 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 forest environment. 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

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

FEMC Project Database Links

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

Climate

Climate Monitoring in Vermont and the Northeast


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. In addition, the Northeast Regional Climate Center (NRCC) provides detailed information on trends in climate and weather for the Northeast.

Weather and climate are related but very different phenomena. Weather is the condition of the atmosphere (precipitation, temperature, etc.) over the short term, while climate refers to long-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.

The Data

Continuous meteorological observations are taken at seven FEMC sites from the shores of Lake Champlain to slopes of Mt. Mansfield. To add temporal and spatial depth to our summary, we expanded the climate summary for 2017 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 NRCC. 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[1] .

[1] http://www.nrcc.cornell.edu/regional/narrative/narrative.html

2017 Vermont Summary

Overall, 2017 had variable temperatures for Vermont, with above-normal average temperatures recorded at the Mount Mansfield weather station in five months and below-normal in seven months (Table 5). Superlative temperatures across the state are in Figure 16.

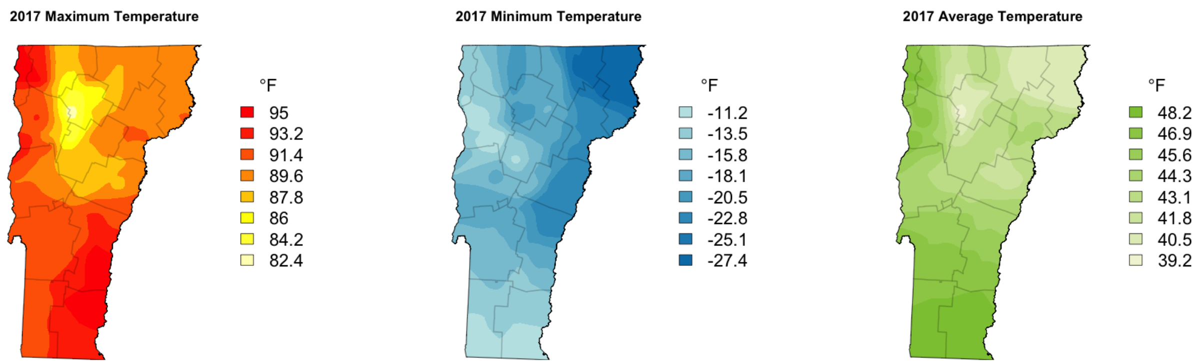


Figure 16. Annual maximum, minimum, and average temperature across the state based on data from 33 weather stations.

The annual statewide average temperature was approximately 1°F above the average for the last 30 years, and matches the predicted value based on the last 30 years of record keeping (Figure 17). Although, 2017 was another warmer than normal winter for Vermont at an average of 24.8° F (ranked 3rd warmest on record), it was colder than the record high average of 26.6° F in 2016.

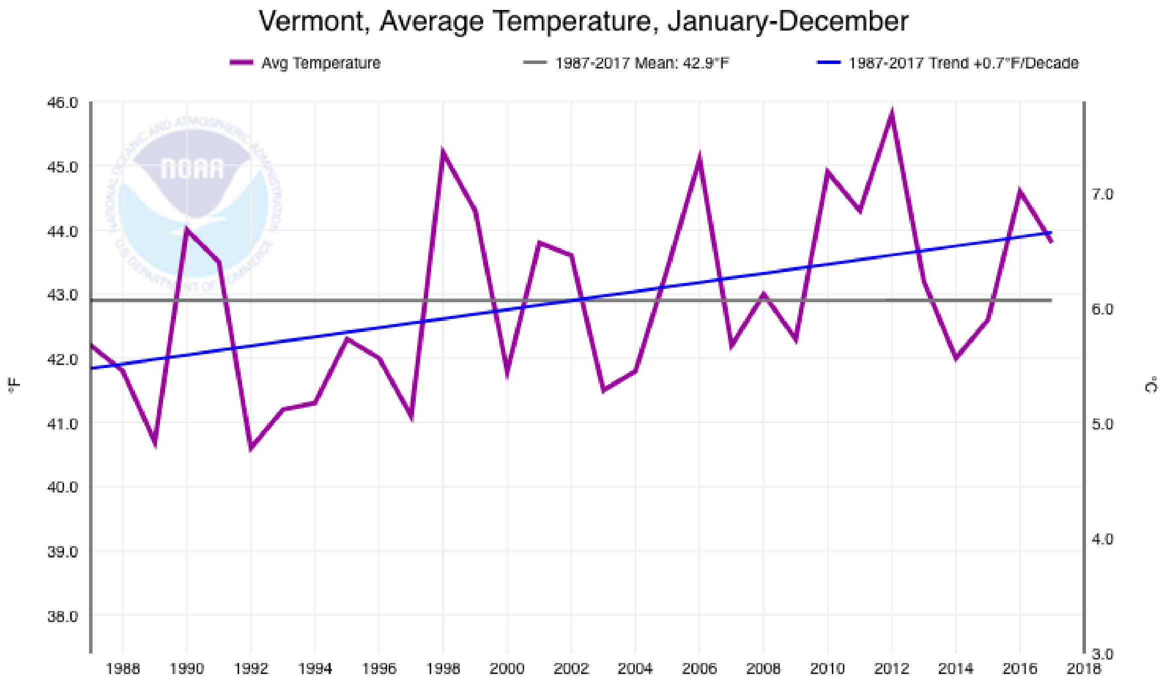


Figure 17. Annual average temperature history, with long term average and 30-year trend. Figure credit: NOAA National Centers for Environmental information, Climate at a Glance: U.S. Time Series, Average Temperature, published November 2017 (http://www.ncdc.noaa.gov/cag/).

2017 Regional Summary

Temperature

The climate pattern in the Northeast during 2017 is generally one of warmer than normal temperatures (Table 5) with extreme local precipitation events (Figure 19). Most areas emerged from a warm winter to a cool spring. Although there were local extreme snow events, the winter did not follow a single trajectory across the region.

The region's average temperature was 48.8°F, which was 1.5°F above normal (Table 5). Nine out of twelve states ranked 2017 among their top ten warmest years on record.

The year started with a warmer than normal winter: winter 2016-17 was the fifth warmest on record for the Northeast with an average temperature of 30.6°F, 4.7°F above normal. Five out of six New England states each had at least a fifth warmest winter on record, while Maryland, New York, Pennsylvania and West Virginia all had at least their third warmest winters. Snowfall varied across the region, with five states (Maine, New

Climate

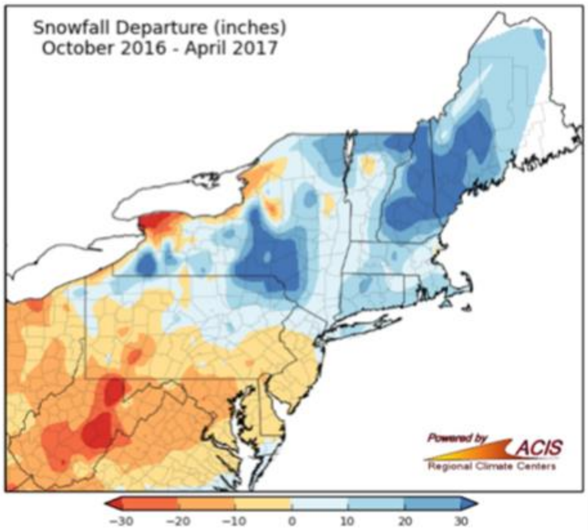
Hampshire, New York, Pennsylvania and West Virginia) receiving above average snowfall (Figure 18).

Table 5. Average temperature in 2017 for the 12 states in the Northeast (°F). Table credit: NOAA, Northeast Regional Climate Center at Cornell University.

State	Average	Departure	Rank	Coolest	Warmest
Connecticut	50.9	1.6	116	44.3 in 1904	52.5 in 2012
Delaware	57.6	2.2	122	50.9 in 1904	58.5 in 2012
Maine	42.4	1.1	114	36.5 in 1904	44.6 in 2010
Maryland	56.6	1.8	121	50.6 in 1904	57.5 in 2012
Massachusetts	49.5	1.4	112	43.3 in 1904	51.3 in 2012
New Hampshire	45.0	1.5	115	38.8 in 1904	46.6 in 2012
New Jersey	54.6	1.7	117	47.8 in 1904	55.9 in 2012
New York	46.9	1.4	113	41.1 in 1917	48.8 in 2012
Pennsylvania	50.6	1.7	117	45.2 in 1917	51.8 in 2012+
Rhode Island	51.5	1.5	116	44.8 in 1904	52.9 in 2012
Vermont	43.8	1.3	113	37.6 in 1904	45.9 in 2012
West Virginia	54.0	1.9	119	48.8 in 1917	54.3 in 2012+
Northeast	48.8	1.5	116	43.1 in 1917	50.1 in 2012

Rankings are for the 123 years between 1895 and 2017. 1=coolest; 123=warmest.
Departures are calculated using the 1981-2010 normals.
+ indicates extreme also occurred in one ore more previous years.

The 2017 spring was slightly warmer than average for the Northeast, with an average temperature of 46.0°F, 0.5°F above normal. Notably, several states had a very warm April, with record high temperatures in nine out of 12 states. The 2017 summer months were slightly cooler than average, with an average temperature of 67.3°F, 0.4°F below normal. The entire Northeast had cooler August than normal, with all 12 states experiencing temperatures ranging from 0.5 to 1.7 below normal. The cool summer was followed by the fifth warmest autumn on record with an average temperature of 52.4°F, 2.6°F above normal. Three of the New England states had record high average temperatures, while the others had their second highest autumn on record.



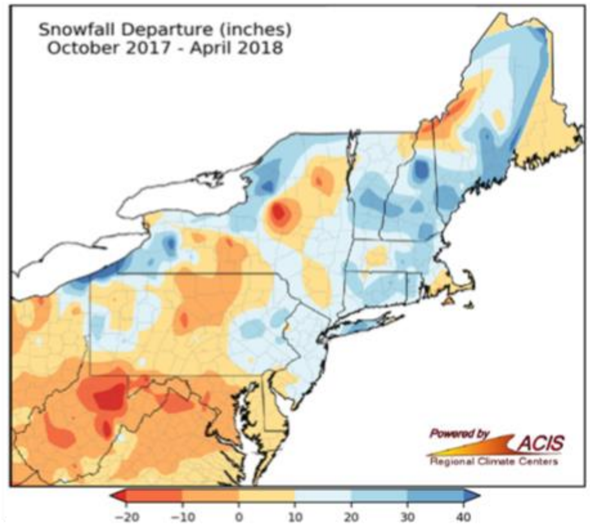


Figure 18. Regional snowfall departure from long-term normal for the winters at the beginning and end of 2017. The winter going into 2018 had variable snow accumulation across the region, while the winter at the beginning of 2017 saw more snow fall in the northeast and less snowfall in the southwest of the region. Note the different scales in the two maps. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University.

Rainfall

The Northeast wrapped up 2017 with an average of 46.35 inches of precipitation, 1.91 inches above the long-term average (Figure 19). Four states (Connecticut, Maryland, Massachusetts, New Jersey) were slightly drier (1.45-5.48 inches below average), while nine states had slightly wetter (0.02-3.20) than normal years. Notably, New York had one of its top ten wettest years (Figure 19).

Above-normal rainfall contributed to a cool and wet spring, and made 2017 the fifth wettest on record. Summer continued to be wet with 0.8 inches of precipitation above normal, while a dry autumn rounded out the year with below average precipitation.

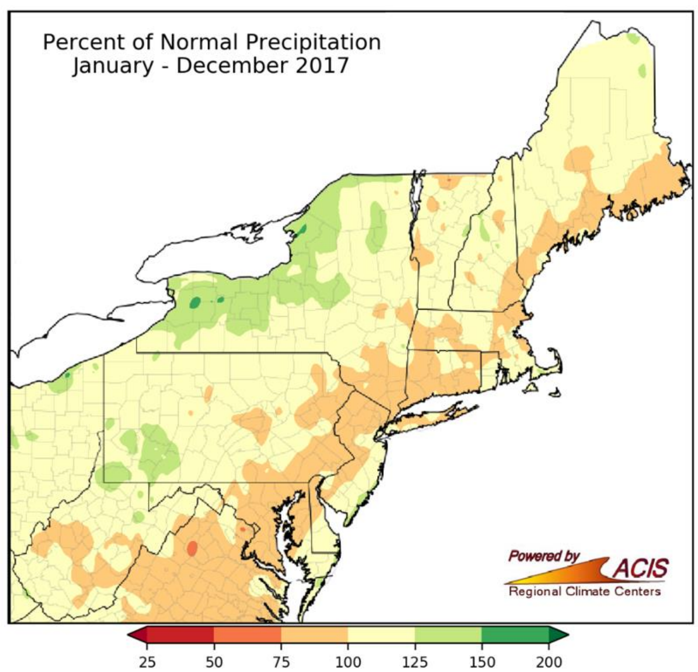


Figure 19. Across the 12 state region, the northeast saw below-average precipitation in 2017. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/monthly/monthly.html).

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 for forest ecosystem condition. The increase in extreme temperatures witnessed in 2017 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).

2017 meteorological measurements in the Northeast show increased variability, following local and national assessments indicating that temperatures have increased over the past several decades. These variable temperatures potentially increase vulnerability to species adapted to cold weather dormancy.

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.

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Additional Resources

Vermont State Climatologist: http://www.uvm.edu/~vtstclim/
Northeast Regional Climate Center (NRCC): http://www.nrcc.cornell.edu/
Northeast Regional Climate Center 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 up close photo by Chesapeake Bay Program.

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 2017 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 6).

Table 6. Population estimate of brook trout per each age class (YOY combined with yearling (1) and older fish (1++) per mile of each monitoring station in 2017.

Brook Trout	Ranch 1200'	Ranch 960'	West Branch 1550'	West Branch 1440'	West Branch 1410'
YOY/mile	603	472	1265	609	253
1++/mile	1465	1180	683	1324	1056
Lbs/acre	17.6	11.2	19.8	23.1	23.2

2017 in Summary

In 2017, natural reproduction of brook trout decreased at the two Ranch Brook stations and two of the three West Branch stations relative to 2016 populations but remained above 2014 estimates despite this decline. At the upper West Branch station, reproduction increased to numbers comparable to 2015, however the YOY counted per mile at the lowest West Branch station was the lowest observed since 2000. Overall reproduction was down nearly 38% from 2016. (Figure 20). Yearling and older brook trout increased by 17% at the Ranch 960' station but decreased by an average of 21% at the remaining 4 sites in 2017 (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 1700 trout per mile over the 21-year study. Wild brook trout populations vary considerably among and within streams due to differences in habitat conditions and localized land use effects while broad environmental variables may have significant temporal effects. While large fluctuations were observed for each age class both within and among the two study streams, no clear trends were evident.

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

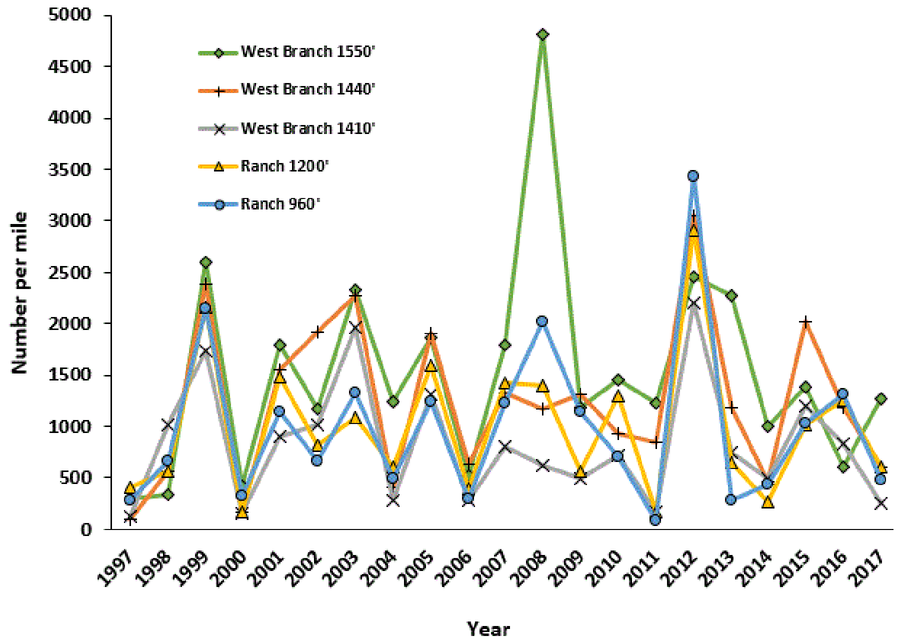

Figure 20. Vermont Department of Fish and Wildlife trout surveys: Young of year (YOY) expressed as number per mile, from 1997 through 2017.

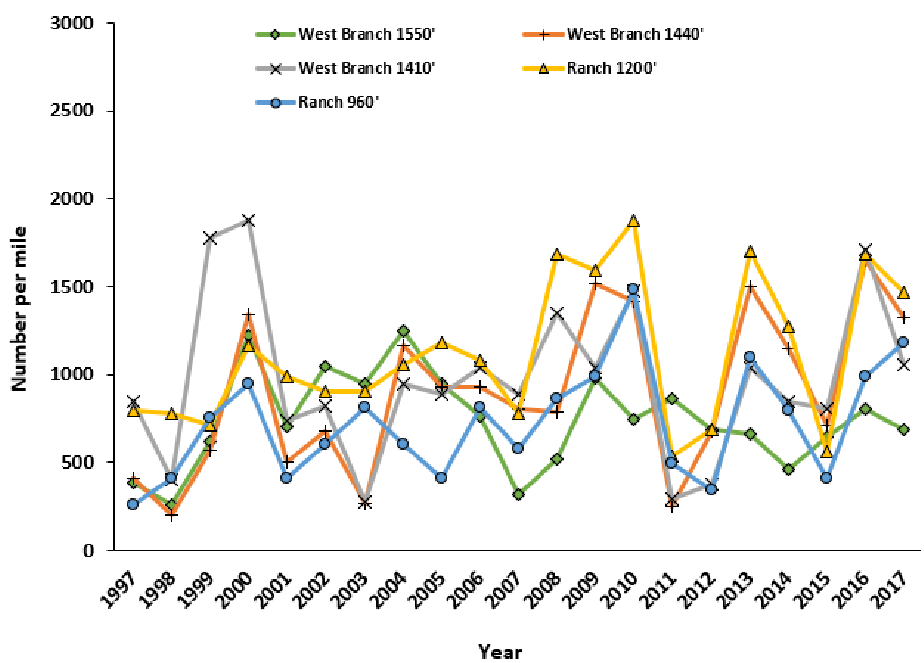

Figure 21. Vermont Department of Fish and Wildlife trout surveys: Yearlings and older fish, expressed as number per mile, from 1997 through 2017.

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 constructed 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 increases in flood frequency and stream temperatures predicted under climate change 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

In 2017, 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 26th consecutive field season on the Mt. Mansfield ridgeline. VCE also conducted Year 2 of a complementary study to monitor potential phenological mismatching between insectivorous songbirds and other trophic groups. 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 preservation of sensitive species.

VCE's John Lloyd and Kent P. McFarland preparing to measure a Bicknell's thrush captured on Mt. Mansfield.

The Data

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). These two study sites are part of VCE's long-term Forest Bird Monitoring Program (FBMP), which was initiated in 1989 with the primary goals of conducting habitat-specific monitoring of forest interior breeding bird populations in Vermont and tracking long-term changes (Faccio et al. 1998, 2017).

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

2017 in Summary

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 49 species detected over all survey years, respectively. In 2017, the number of individual birds and species richness declined at both UNSP and LBWA, continuing the long-term downward trends for both these metrics (Figure 22). The long-term trends for both number of individuals and species richness have declined slightly at both sites (Figure 22).

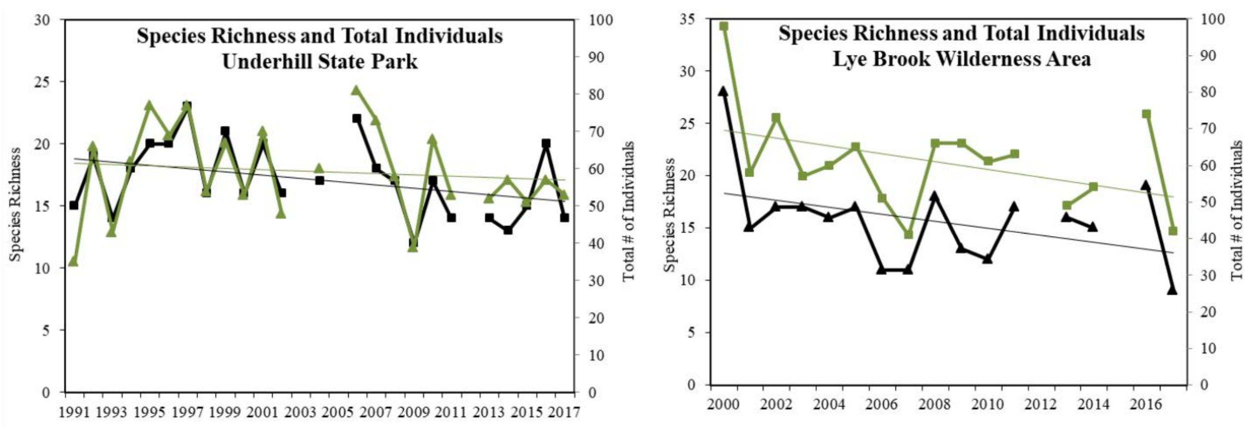

Figure 22. Annual totals and trends for species richness (black lines) and total number of individuals (green lines) detected at Underhill State Park, 1991 – 2017, and Lye Brook Wilderness Area, 2000-2017.

Long-term Trends

Mt. Mansfield Ridgeline – In 2017 there were 413 bird captures comprising 312 individuals of 30 species, including 263 new bandings, 52 returns from previous years, and 23 within-season recaptures.

Underhill State Park – Total number of individuals and species richness decreased from 2016, with 53 individuals of 14 species recorded, including a Swainson's thrush, the first since 2009. Among the nine most common species, five were above the 26-year mean, and four were below. Overall, 2017 counts of Ovenbird and Black-throated Green Warbler were the same as 2016; while the long-term trend for Hermit Thrush, Vermont's State bird, remained relatively flat (Figure 23). These results reflect the broader, 26-year trends observed for these three species in the statewide Vermont FBMP dataset, in which both Black-throated Green Warbler and Ovenbird significantly increased, while Hermit Thrush showed no trend (Faccio et al. 2017). A single Canada Warbler was again detected in 2017; this species is declining at a rate of 4.13% annually (R^2=0.634), representing the sharpest decline among the nine most commonly detected species.

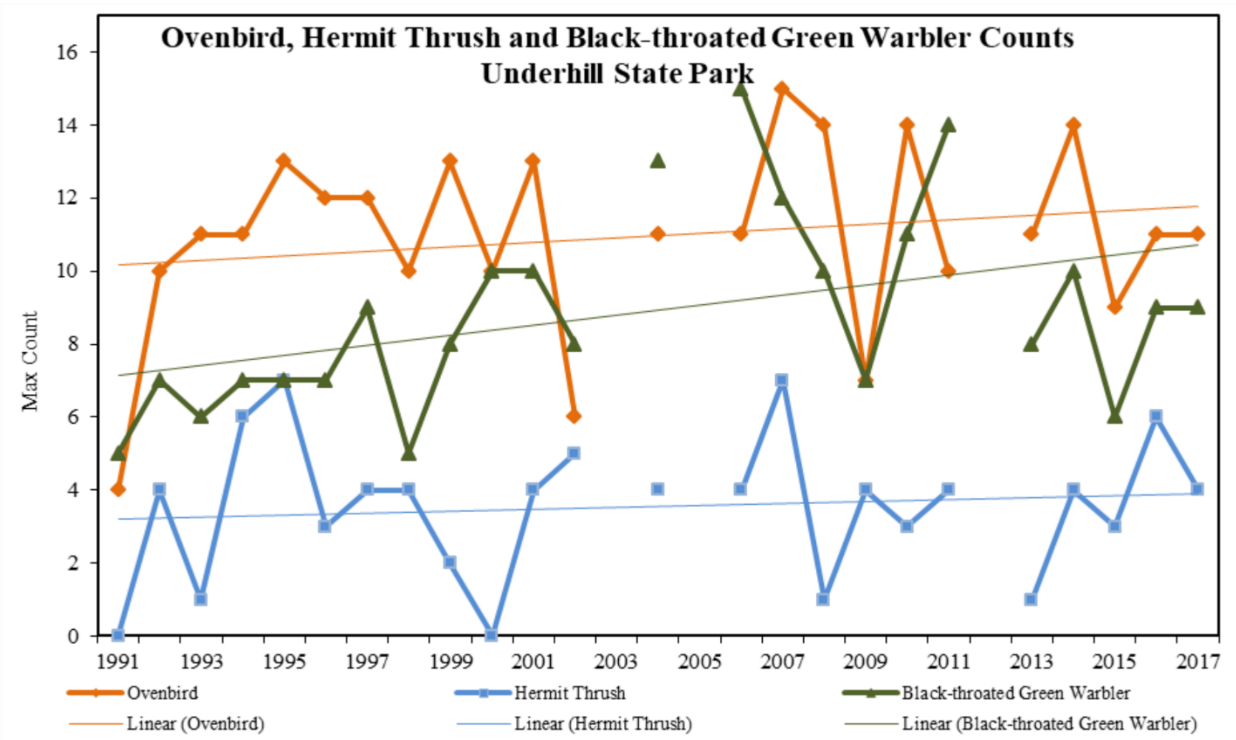

Figure 23. Twenty-six year data and trends for Ovenbird, Hermit Thrush, and Black-throated Green Warbler from annual surveys conducted at Underhill State Park, 1991-2017.

Lye Brook Wilderness Area – After relative abundance and species richness reached near-record levels in 2016, both metrics declined significantly in 2017, with relative abundance dropping to its second lowest level in the survey's 16-year history (n=42) and species richness its lowest (n=9) (Figure 24). Among the nine most common species, counts of all nine declined from 2016, and only Red-eyed Vireo remained above its 16-year average. The long-term trend for Black-throated Blue Warbler showed a moderate decline of -2.03% per year (R^2 = 0.224) (Figure 24), while Red-eyed Vireo showed a strong upward trend, increasing by 6.69% annually (R^2 = 0.311) (Figure 24), mirroring the significant statewide trend exhibited by VCE's 25-year study (Faccio et al. 2017).

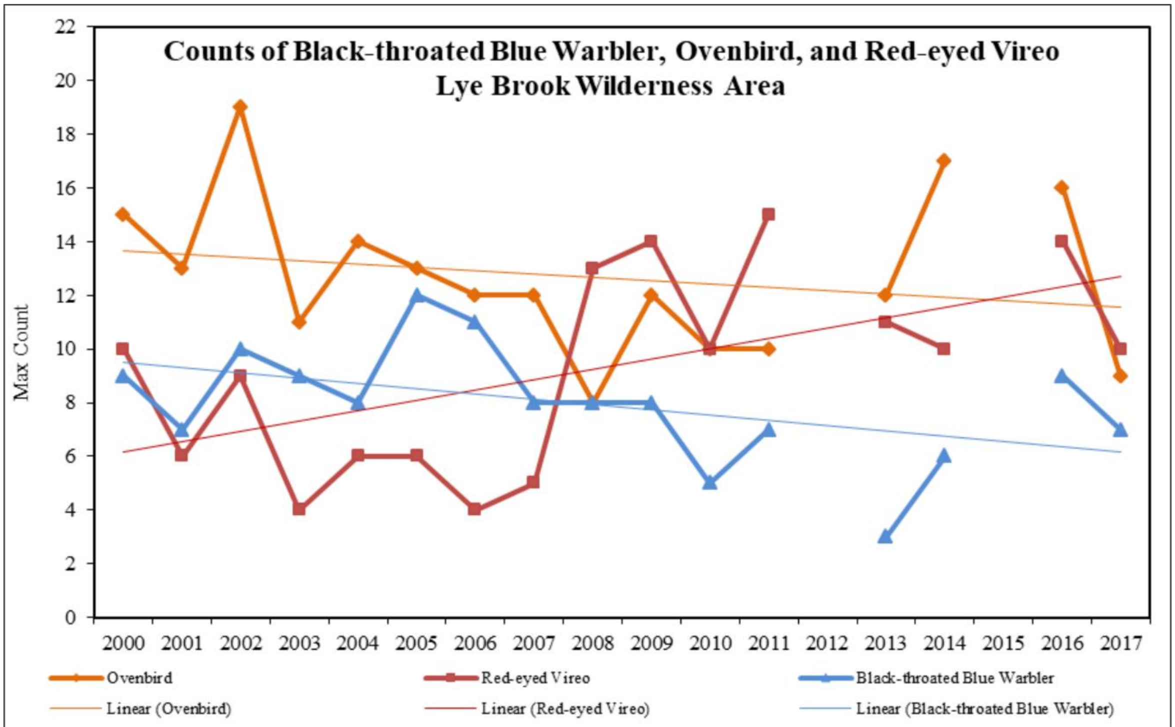

Figure 24. Twenty-six year data and trends for Black-throated Blue Warbler, Ovenbird, and Red-eyed Vireo from annual surveys conducted at Lye Brook Wilderness area, 1991-2017.

Implications

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. Also, year-to-year changes in survey counts may simply reflect natural fluctuations in abundance, differences in detection rates of observers and/or species, variability of singing rates due to nesting stage, and/or a variety of dynamic factors, such as predator or prey abundance, overwinter survival, effects of diseases such as West Nile Virus, and local habitat change.

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 statewide trends for these species during the 25-year study of the Vermont Forest Bird Monitoring Program (Faccio et al. 2017).

It is unknown which of the many anthropogenic stressors (e.g., habitat degradation and loss due to development, land use change, acid precipitation and other atmospheric pollutants, or changing climatic conditions) may be contributing to these population trends, but it is likely all have had impacts. In addition, migratory species, whether short- or long-distance Nearctic-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 stopovers 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.

Black-throated Green Warbler and Red-eyed Vireo show increasing trends at long-term sites. Canada Warbler shows a strong decreasing trend at long-term sites. These changes mirror findings statewide, and could represent the influence of many anthropogenic stressors and/or natural factors.

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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

Amphibians

Amphibian Monitoring on Mt. Mansfield

Wood frog (*Lithobates sylvaticus*) found on Mt. Mansfield in 2017.

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. 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.

In addition to intensive amphibian monitoring on Mt. Mansfield, data on all of Vermont's reptiles and amphibians are gathered for the Vermont Reptile and Amphibian Atlas. This includes inventory and basic natural history data on all reptiles and amphibians found within Vermont.

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 began 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. This report contains all data collected in the 2017 season, and the next report will follow the 2018 field season.

2017 in Summary

Overall, the total number of salamanders and frogs detected per trapping is higher than last year. Numbers were the highest ever detected for Spotted Salamander, Spring Salamander, Eastern Red-backed Salamander, and Wood Frog.


Spring salamander (*Gyrinophilus porphyriticus*) captured on Mt. Mansfield.

Spring Peeper captures continue to improve and this year resulted in the highest rate of catch (1.8 per trapping) since 1995. Although the long-term trend has not turned around yet, the increased number of adult Spring Peepers caught during the 2017 monitoring (mostly in early 2017) may signal the beginning of a recovery.

In 2017, the usual five caudate (salamander) species were caught as adults. In addition, we also caught adult Spring Salamanders (*Gyrinophilus porphyriticus*). Young of the following salamander species were also caught: Spotted Salamander, Eastern Newt, and Eastern Red-backed Salamander (Table 7).

In 2017, adults of all six of or our normally trapped anurans (frogs) were caught. Juvenile Wood Frogs were abundant (85). There were a few young Green Frogs (7) and Spring Peepers (4) but only one young American Toad and no young Pickerel Frogs or Gray Treefrogs (Table 7).

Table 7. Monitoring results from drift fences on Mt. Mansfield in 2017.

Common name	Scientific name	#of all ages	#of young of the year	% young of the year
Caudates (Salamanders)				
Spotted salamander	*Ambystoma maculatum*	52	5	10%
N. Dusky Salamander	*Desmognathus fuscus*	12	0	0%
N. Two-lined Salamander	*Eurycea bislineata*	13	0	3%
Spring Salamander	*Gyrinophilus porphyriticus*	10	NA	NA
Eastern Newt	*Notophthalmus viridescens*	26	5	19%
E. Red- backed Salamander	*Plethodon cinereus*	261	3	1%
Group totals		374	13	3%
Anurans (Frogs)				
American Toad	*Anaxyrus americanus*	22	1	5%
Green Frog	*Lithobates clamitans*	10	7	70%
Pickerel Frog	*Lithobates palustris*	1	0	0%
Wood Frog	*Lithobates sylvaticus*	203	85	42%
Spring Peeper	*Pseudacris crucifer*	32	4	13%
Group totals		268	97	36%
Amphibian totals		642	110	17%

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

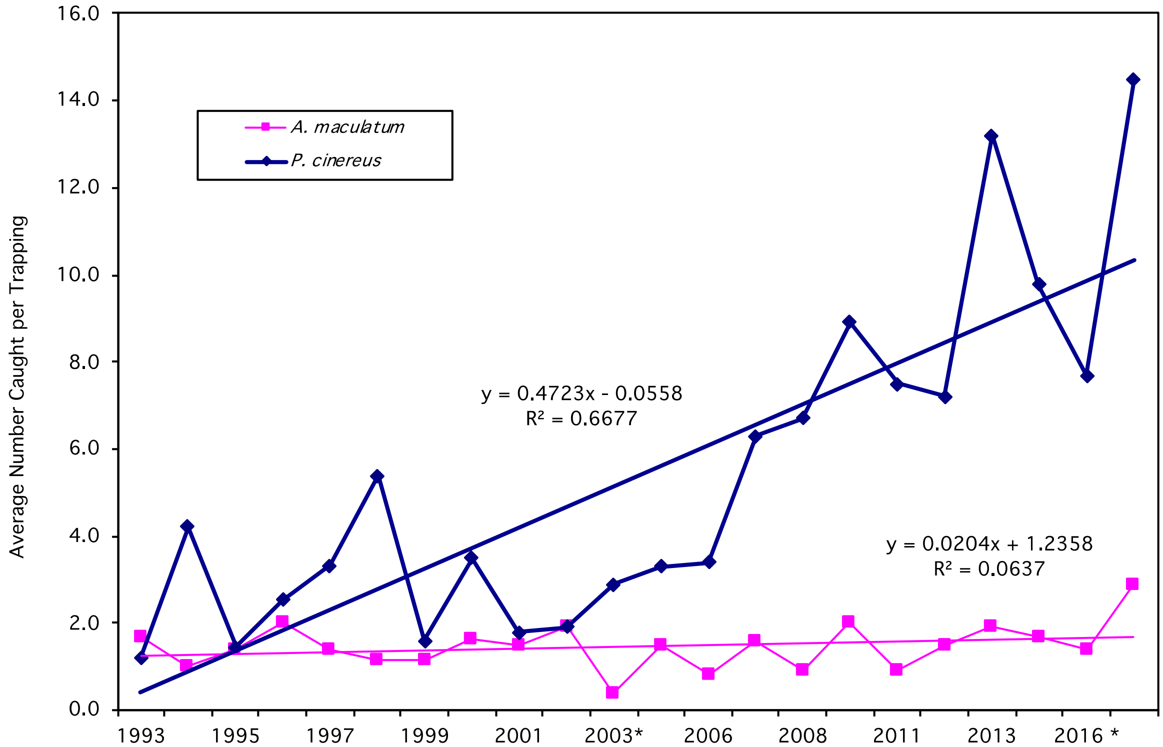


Figure 25. Spotted Salamander (*Ambystoma maculatum*) and Eastern Red-backed Salamander (*Plethodon cinereus*) population indices from 1993-2017 from Mt. Mansfield, Underhill, Vermont.

Long Term Trends

A few species show clear long-term increases (Eastern red-backed salamander, Northern two-lined salamander, and American toad), while most species population indices remain constant (Figure 25). 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

Northern two-lined salamander (*Bislineata dorsum*) found on Mt. Mansfield in 2017.

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.

Beginning with the 1995 report, we began documenting the number of young of the year (YOY). In 2017, young of the year made up 17% of those caught (Table 7). Over the course of the entire study (1995-2017) the average percentage of young of the year of total catch was 27.5%. Since the study's inception the young of the year have varied from 11% (2014) to 74% (2002). 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%. In contrast, Wood Frogs showed their lowest percentage of YOY in 2012 (4%) while Spotted Salamanders were at a fairly 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, winter kill and late season freezes in their 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 E. 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.

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 Green Mountain and Finger Lakes 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 2017 surpassed those of 2016 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

Long Term Biological Monitoring at Reference Streams

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 (110-1920 ft) and geographical separation. Most are in watersheds that have significant protection against impacts from anthropogenic activity, and all but one has a watershed with greater than 90% combined forest and wetland (based on 2011 land use/land cover data, Table 8). Five of these sentinel streams are included in the US Environmental Protection Agency (EPA) Regional Monitoring Network of high-quality reference streams throughout New York and New England (U.S. EPA, 2016).

Stonefly nymph, order Plecoptera.

By focusing on streams with negligible prospects for development or land use change, DEC hopes to be able to isolate long-term impacts related to climate change. Many of these streams have monitoring data going back to the 1990s, and all are currently being monitored on an annual basis for water chemistry, physical habitat, water temperature, and biological condition. Numerous sites are also being gaged for stream discharge, air temperature, and fish community health. Through this monitoring, one of DEC's key goals is to gain a better understanding of how climate-induced changes in water quality, temperature and hydrology lead to long-term alterations in biological communities.

One of DEC's longest running sentinel stream sites is at Ranch Brook in Stowe, Vermont. With a drainage area of 10 km² and an elevation of 1240 ft, it is one of the smallest and most pristine sentinel streams. Ranch Brook has a record of annual macroinvertebrate community data and a continually operated stream gage since 2000, and has served as a focal point for early analyses on the DEC sentinel network.

Table 8. 2011 land use/land cover data for sentinel streams and initial hydrologic gaging and temperature monitoring dates for each of sites.

Stream	Macro-invertebrate Stream Type*	Town	Drainage Area (km²)	Elevation (ft)	% Water/ Wetland	% Forest	First Date of Hydrologic Gaging	First Date of Temperature Monitoring**
Ranch Brook+	**SHG**	**Stowe**	**9.9**	**1240**	**0.0**	**98.3**	**USGS (2000)**	**A (2018), W (2015)**
Smith Brook	SHG	Rochester	4.6	1920	0.0	100.0		A (2018), W (2008)
Bingo Brook+	SHG	Rochester	23.5	1120	0.2	98.8	DEC (2015)	A (2018), W (2008)
North Branch Winooski River+	MHG	Worcester	28.8	967	5.1	92.6	DEC (2018)	A (2018), W (2013)
Winhall River+	MHG	Winhall	46.6	1470	12.5	87.2		A (2018), W (2008)
Moose River+	MHG	Victory	58.5	1318	1.4	98.4	DEC (2014)	W (2013)
Green River+	MHG	Guilford	65.9	671	2.7	89.4	USGS (1990)	W (2012)
White River	MHG	Stockbridge	510	715	1.0	92.7		W (2011)
Lewis Creek	WWMG	Ferrisburgh	208	110	8.0	63.9	USGS (1990)	A (2018), W (2009)
Nulhegan River	WWMG	Bloomfield	352	891	10.8	87.8		W (2009)
Alder Brook	HLG	Ripton	7.2	1335	4.5	95.1		A (2018), W (2016)
Bog Brook	SLG	Victory	48	1115	7.7	91.1		W (2016)

* SHG (Small High Gradient), MHG (Medium High Gradient), WWMG (Warm Water Moderate Gradient), SLG (Slow Low Gradient), HLG (Hybrid Low Gradient), ** Air (A), Water (W), + Part of the EPA region 1 Stream Regional Monitoring Network

The Data

Vermont DEC collects macroinvertebrate community samples from stream reaches during an annual index period that runs from September 1st through mid-October. Samples are sorted and identified in the laboratory, and 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 density, biodiversity, tolerance to pollution and ecological feeding habits.

Metric values are compared to established thresholds determined from historical statewide data. DEC recognizes five stream community types that result from variation in stream size, gradient, and habitat; Small High Gradient (SHG), Medium High Gradient (MHG), Warm Water Moderate Gradient (WWMG), Hybrid Low Gradient (HLG), and Slow Low Gradient (SLG). Metric thresholds can vary by stream type, and outcomes are used to determine an assessment rating for community health, using a tiered scale ranging from *Poor* to *Excellent* (VTDEC, 2017). In addition to assessment ratings, this report chooses to focus on three key macroinvertebrate metrics used in assessment determinations. Ephemeroptera, Plecoptera and Trichoptera (EPT) Richness is a measure of the diversity of water quality sensitive taxa (Ephemeroptera, Odonata and Trichoptera (EOT) richness is used in low gradient streams). Total Density is the number of organisms per square meter, and previous analyses at Ranch Brook suggest that this metric reacts strongly and quickly to extreme flow events. Biotic Index (BI) is a metric that demonstrates the macroinvertebrates community's sensitivity to pollution and/or enrichment, and is correlated with stream thermal regimes (Hilsenhoff, 1987; Hilsenhoff, 1988).

Abiotic data related to stream habitat is collected in conjunction with biology and is used to help explain biological community condition. While water quality and habitat data are collected annually, a primary focus at sentinel streams has been the collection of temperature and hydrological data. Several sentinel sites have been co-located with USGS gaging stations, and DEC has set up stream gages on several others. DEC scientists have also recently begun to use time-lapse cameras to help to visually monitor flow levels, and to track the mobilization of substrate during high flow events. Year-round water temperature data is collected at all twelve sentinel sites, and DEC has initiated an effort to add air temperature monitoring at many locations.

2017 in Summary

Figure 27 shows 2017 results for overall assessment ratings, as well as the results for three key metrics used to assess biological condition. Sentinel sites are grouped by stream type and are compared to average results from a statewide survey of randomly selected streams sampled from 2013 to 2017. Threshold values indicating minimum criteria for "Good" biological condition (Class B(2)) in Vermont streams is also displayed. Results from Ranch Brook include samples taken at both the beginning and end of the 2017 fall index period.

Ranch Brook, the primary case study for sentinel stream monitoring, received assessment ratings of *Very Good/Excellent* and *Excellent* for its two community samples in 2017. EPT richness at Ranch Brook (26) was significantly higher than the minimum criteria (16) for small high gradient streams, and moderate density and low BI scores indicate a high-quality stream with exceptional water quality. The fact that Ranch Brook (and other sentinel streams) have metric values relatively similar to statewide averages for randomly selected streams is indicative of the generally high quality of streams throughout Vermont. The high assessment ratings and metric values also show recent consistency in the community, which had shown instability in condition following several extreme flood events in the earlier part of the decade.

Only two of the sentinel sites received an assessment rating lower than Very Good in 2017, and both of these sites (Bingo Brook and Lewis Creek) had ratings limited by slightly elevated BI values. Density, EPT/EOT richness, and BI at all sites easily passed minimum thresholds. In general, all sentinel sites showed robust and healthy macroinvertebrate communities. The plots in Figure 27 also highlight a consistent pattern in Vermont reference streams, whereby larger and warmer streams often have naturally higher invertebrate densities and BI values, and medium sized streams often have the highest diversity.

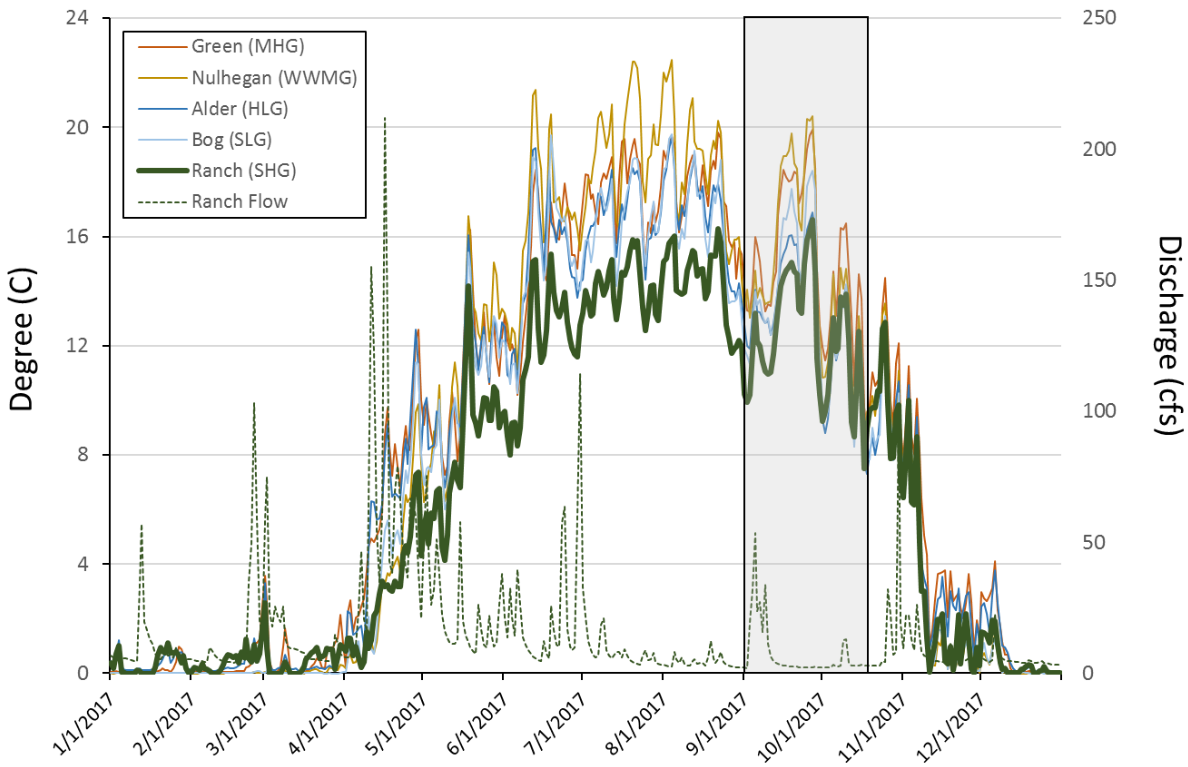


Figure 26. 2017 temperature (solid lines) and discharge (dashed lines) profiles for Ranch Brook, and temperature profiles for representatives from each of the other stream types. The shaded area represents the length of DEC fall index period for macroinvertebrate data collection (September 1st through October 15th).

Temperature and discharge profiles from 2017 are given for Ranch Brook, as well as temperature data from representatives for each of the other four stream types (Figure 26). Despite the sites being widely geographically separated throughout Vermont, closely corresponding trends in the temperature data are apparent, including a significant warming period during the middle of DEC's fall index period. The plot also demonstrates that SHG streams like Ranch Brook are the coldest stream type, with the larger MHG and WWMG streams occupying the other end of the temperature range. Flows at Ranch Brook were relatively stable throughout the summer leading up to, and during, the DEC index period. This likely contributed to the overall health of the biological community compared to previous recent years.

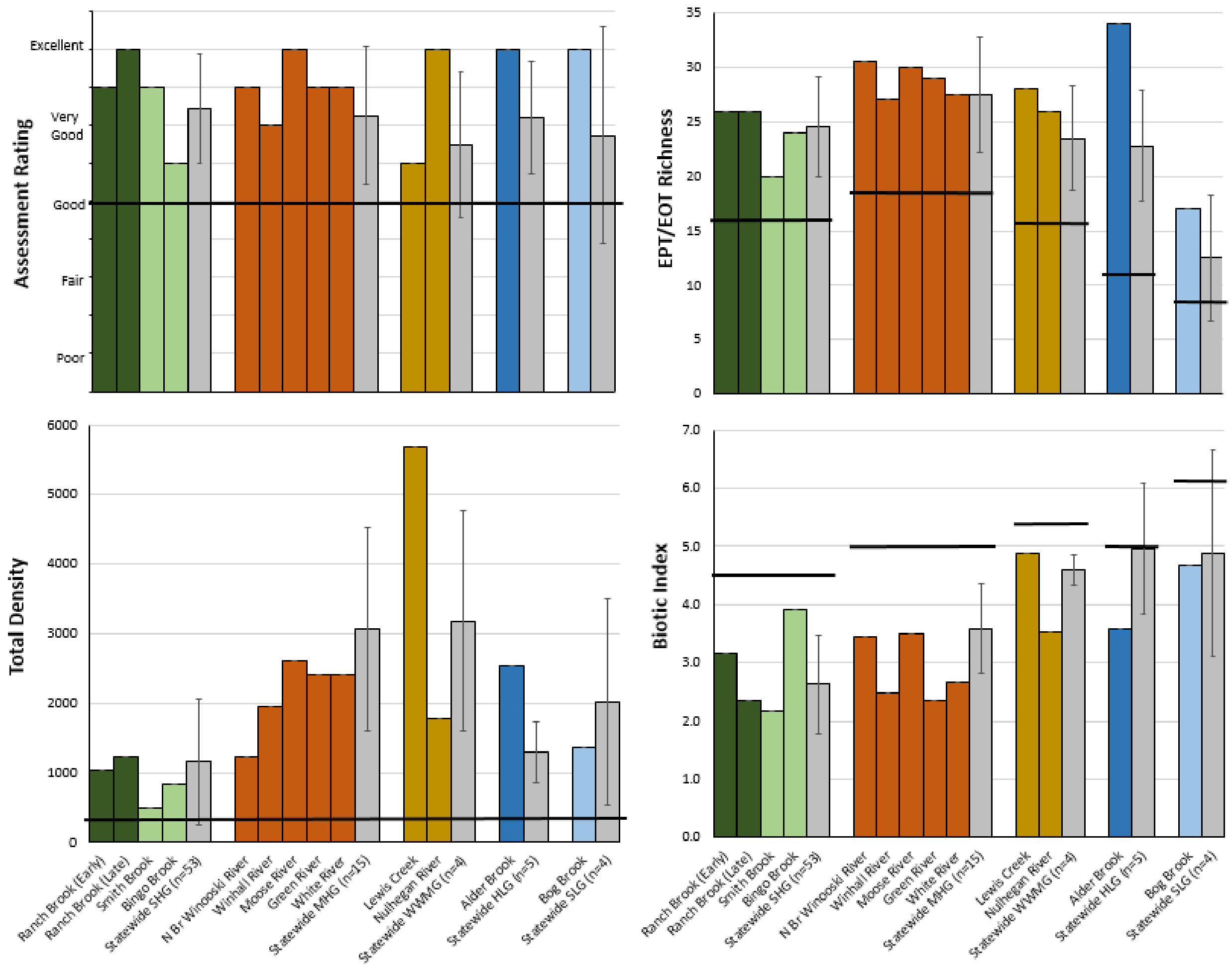


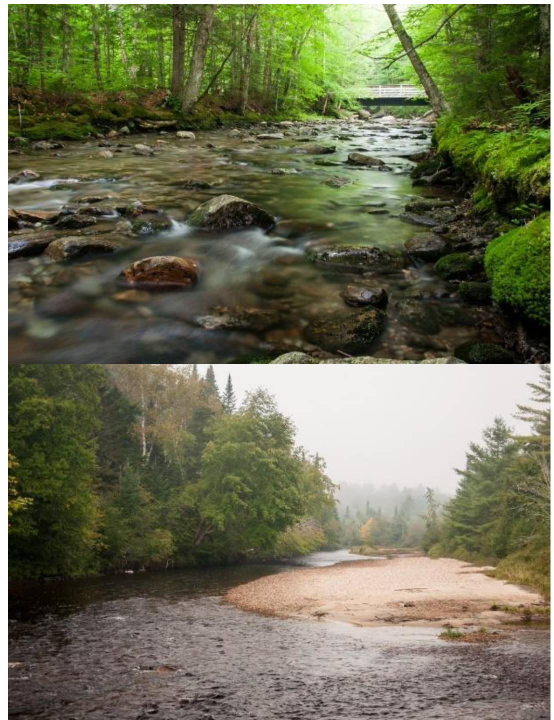
Figure 27. 2017 scores for overall assessment ratings and three biological metrics used to assess community health. Sentinel sites are grouped by stream type, and compared to streams from throughout the state. Horizontal black bars represent DEC's minimum acceptable criteria.

Long Term Trends

While several sentinel sites have been added by DEC since 2012 in an effort to increase the strength of the long-term monitoring program, eight of the sites have biological monitoring data going back to 2003 or earlier (Figure 28). Through this data set, DEC hopes to be able to observe any emergent trends that may be related to climate change or other large-scale factors.

The richness of sensitive EPT taxa appears to have remained relatively steady over time at most sentinel sites. Ranch Brook is a small and relatively low productivity stream. It has slightly lower EPT richness than most other sentinel streams, and all community samples since 2000 have had EPT richness between 20 and 26.

In contrast, macroinvertebrate density has typically shown more variability over time, and has reacted dramatically to high flow events. Tropical Storm Irene caused extreme flooding throughout Vermont in 2011, occurring immediately before the start of DEC's fall index period. Densities dropped up to an order of magnitude at most small and medium sized sentinel streams, and assessments at these sites generally received failing ratings due to abundances below DEC's minimum criteria. Densities rebounded in 2012, but some sites had lingering effects in subsequent years as macroinvertebrate communities continued to stabilize.



A visual comparison between a smaller sentinel stream site (top, Ranch Brook) with closed canopies and a larger site (bottom, Nullhegan River).

Ranch Brook experienced a series of high flow events between 2010 and 2013, with the three highest annual peak discharges on record occurring over this four-year period. This resulted in a series of lower than expected assessment ratings due to higher variability in density, BI, and distribution of feeding groups. This trend has appeared to stabilize with less extreme flow events over subsequent years.

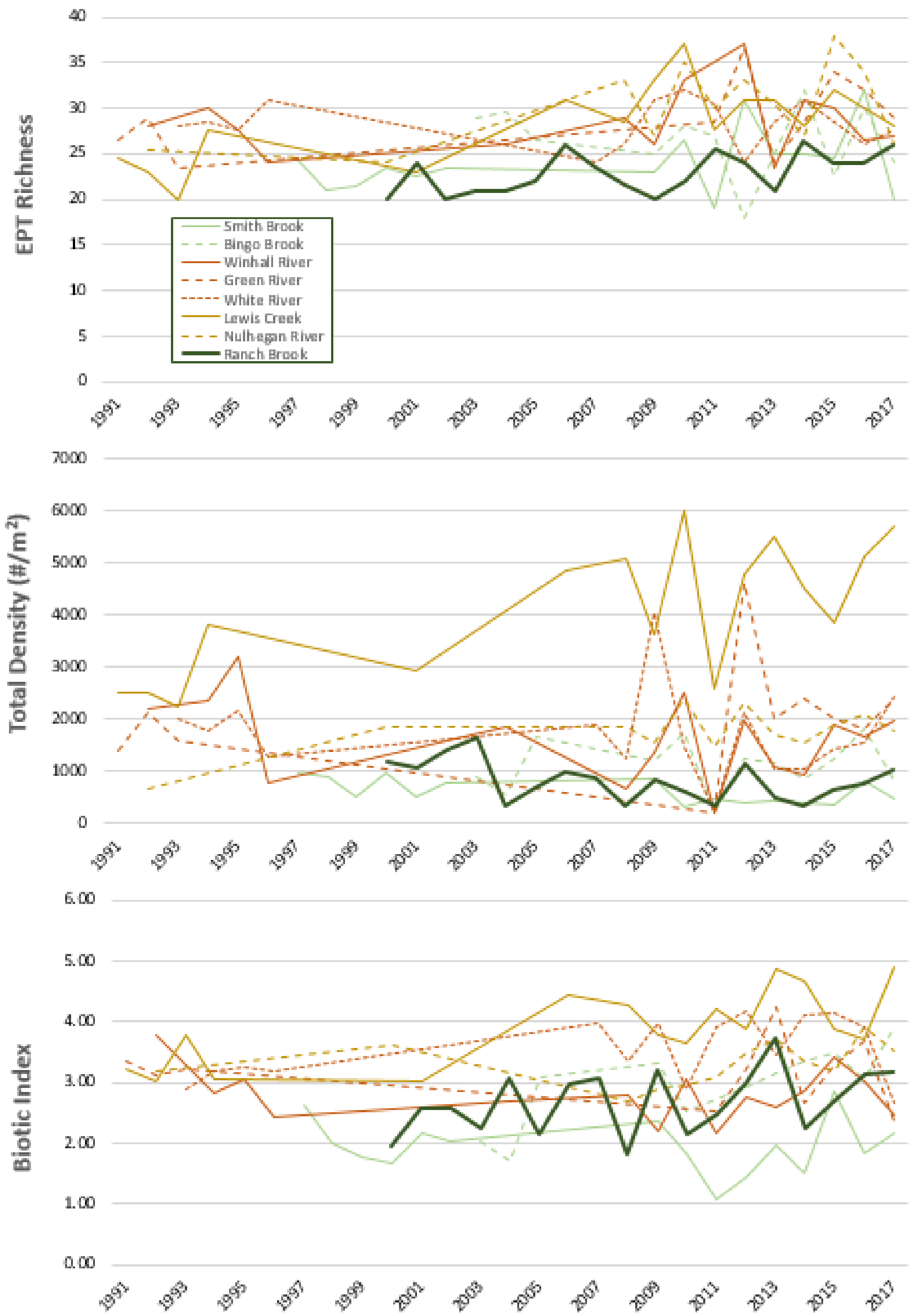


Figure 28. Long-term trends in macroinvertebrate richness and overall assessment rating. Two biological samples were collected in five different years, with these multiple sample collections typically separated by at least five weeks.

Implications

It will take a much longer period of record to fully understand how water quality, temperature and hydrology are influencing biological communities at sentinel sites. Only Ranch Brook has a continuously paired hydrological and biological record going back longer than 10 years, and most sites only have a water temperature record of 5-6 years. However, it is expected that as the monitoring records increase, patterns may begin to emerge that will help to understand how changes in hydrology (i.e. extreme flow events or drought) and warming temperatures may permanently affect these stream communities. Changes in reference condition due to climatic variables may eventually alter our immediate expectations of a healthy biological community. The monitoring of these sentinel sites, and other reference streams, is essential for DEC's ability to differentiate impacts caused by climate change versus more localized stressors.

Despite the limitations of the data set, some early patterns are helping our current understanding. The magnitude of flood events like that of Tropical Storm Irene can diminish biological health by dramatically reducing macroinvertebrate densities. The increased frequency of high flow events like those experienced at Ranch Brook may destabilize communities and lead to volatility in metrics and assessments over time. In an ecological context, the instability in community metrics is a direct result of changes in the populations that make up these communities. At Ranch Brook it seems apparent that the magnitude of the annual peak discharge is closely correlated to the relative abundance of the mayfly family Baetidae (Figure 29). Mayflies of this family are known to be early colonizers of disturbed substrates. Other species that depend on colder water may begin to be lost from these communities if average stream temperatures rise. Understanding the population dynamics and life history traits of taxa that vary with climatic variables will be necessary, and DEC hopes to further explore these questions.

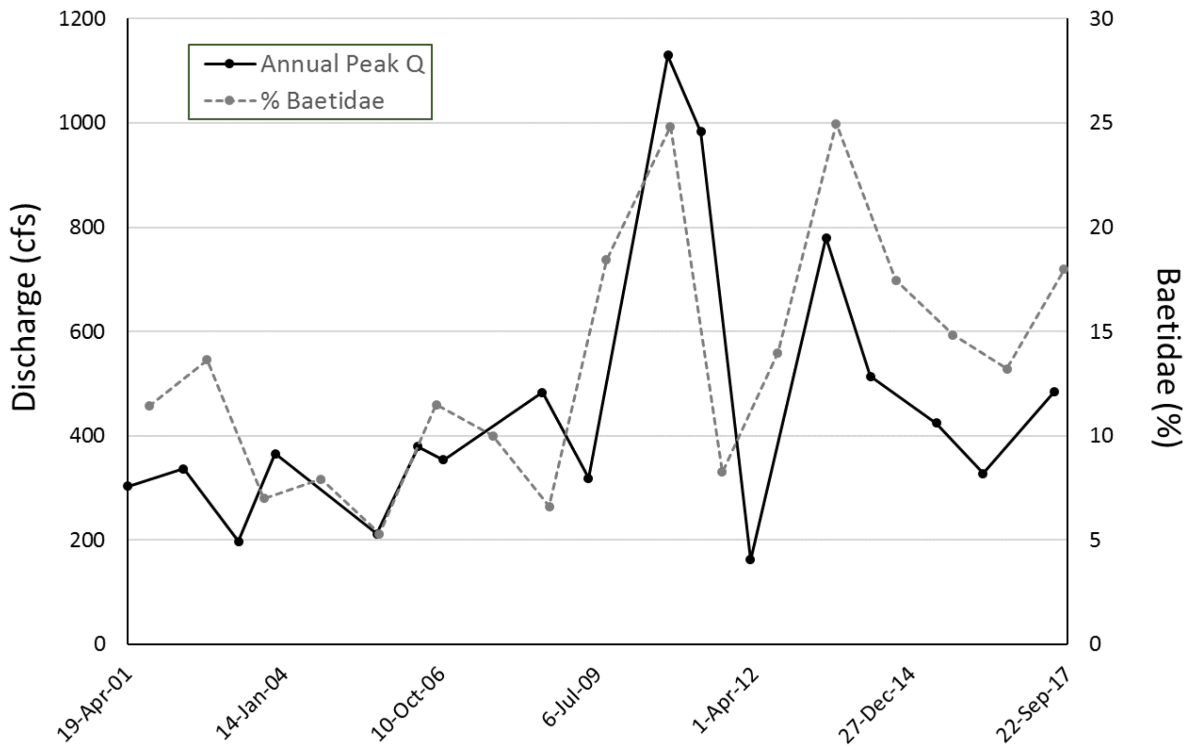


Figure 29. A comparison of annual peak discharge (Q, solid line), and the proportion of the macroinvertebrate community comprised of the mayfly family Baetidae (dashed line), an early colonizer of disturbed substrate.

Changes in hydrology and water temperature due to climate change are expected to cause dramatic changes to stream invertebrate communities.

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Additional Resources

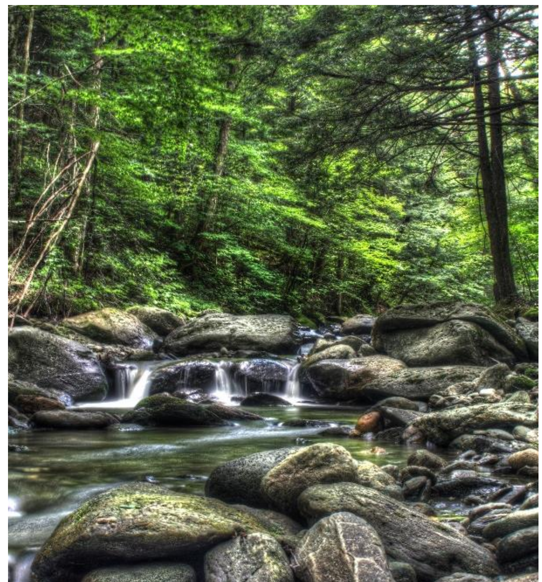
VT DEC Biomonitoring and Aquatic Studies
http://www.watershedmanagement.vt.gov/bass/htm/bs_biomon.htm

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



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

Since September 2000, the U.S. Geological Survey (USGS) 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 (watershed size 9.6 km^2) as the forested control watershed, and West Branch (11.7 km^2) as the developed watershed. The West Branch watershed contains nearly the entire extent of the four-season Stowe Mountain Resort. In the classic paired watershed approach, monitoring would have been conducted prior to any development, but the resort was established long before the study began.

However, the resort underwent a significant expansion during the course of the study, so the study design is appropriate to assess the effect of the expansion. This report on the Mt. Mansfield gaging is for Water Year (WY) 2017 (October 1, 2016 through September 30, 2017). The report interprets the WY17 streamflows in the context of the full 17-year record. Historic and near real-time streamflow data are available on the USGS website (links have been provided in the additional resources section follow this report).

In WY17, the gages were jointly funded through a cooperative agreement between the USGS, the Vermont Department of Environmental Conservation and the Forest Ecosystem Monitoring Cooperative (FEMC). 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 (UVM), Sterling College, Vermont Agency of Natural Resources, and others. In particular, Beverley Wemple and students at UVM 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 the monitoring of long-term hydrology patterns and water quality trends including: baseline conditions, trends in stream acid/base status, cations (Ca^{2+}, K^{+}, Mg^{+2}, Na^{+}, Si^{+}), anions (Cl^{-}, NO_3^{-}, SO_4^{2-}) 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*, also called* ***discharge****, is measured in volume per unit time. In the U.S. it is typically measured as cubic feet per second, or cfs (Figure 30). Throughout this report, we use runoff rather than streamflow.* ***Runoff*** *is the discharge divided by the area of the watershed, which allows for a direct comparison of the streamflow from watersheds of differing sizes. For example, if one watershed is twice the size of another and has twice the streamflow, the runoff of the two watersheds would be the same. Runoff is reported in depth per unit time -- the same as units precipitation which allows 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.*

2017 in Summary

Relative to the 17-year record, WY17 had above average runoff. WY17 (Oct 1 2016 to Sept 30 2017) featured low runoff in fall and winter, followed by above normal runoff in spring (Figure 30). This was likely due to a very rapid warmup in April of 2017 which caused fast melting of snow, followed by a wet start to summer. However, the wet, cool spring and summer ended in drought conditions across the state in the fall. In fact, the droughty conditions resulted in ground fires (i.e., where roots and organic matter catch fire and smolder) in Chittenden County, a relatively uncommon occurrence. During this period, Lake Champlain water levels were extremely low, causing hazardous navigation in shallow areas.

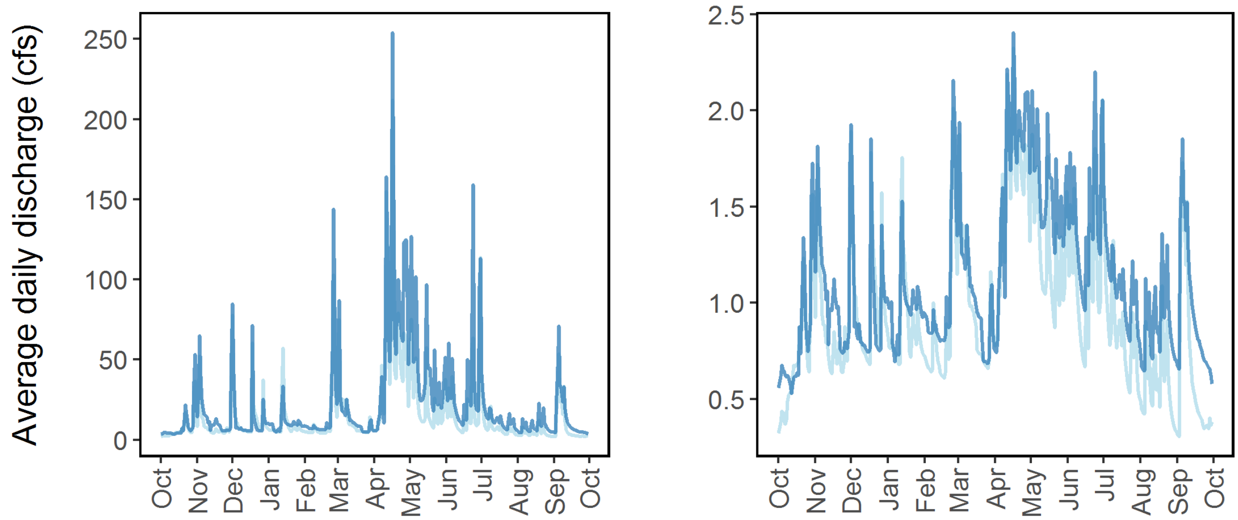


Figure 30. Streamflow at Ranch Brook (light blue) and West Branch (dark blue) gages for Water Year 2017 (Oct 1 2016 through Sept 30 2017) in linear untransformed (left) and $\log_{10}$ transformed (right) scales. The log scale better highlights the higher sustained base flow levels at West Branch (dark blue).

Overall, runoff in WY17 was greater than the long-term average (Figure 31). Compared to WY16, the cumulative runoff in WY17 was above average for the most of the year, particularly in the spring when runoff was either at or slightly above the long-term average. By May 2017, runoff from both Ranch Brook and West Branch were above the long-term average. Cumulative runoff at both sites continued to be above average for the rest of WY17 as well. The cumulative runoff patterns at the two sites in WY17 were similar to 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. (Note that water used for snowmaking at the Stowe Mountain Resort is extracted from West Branch upstream of the gage, meaning that when the snow melts, the water 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 WY17 at both sites was the greater cumulative runoff compared to the long-term record. Between October and Feburary of WY17, the area experienced above-average temperatures, followed by slightly below-average temperatures from March to August, with some extreme warm tempreatures experienced in September (Northeast Regional Climate Center, link in additional resources).

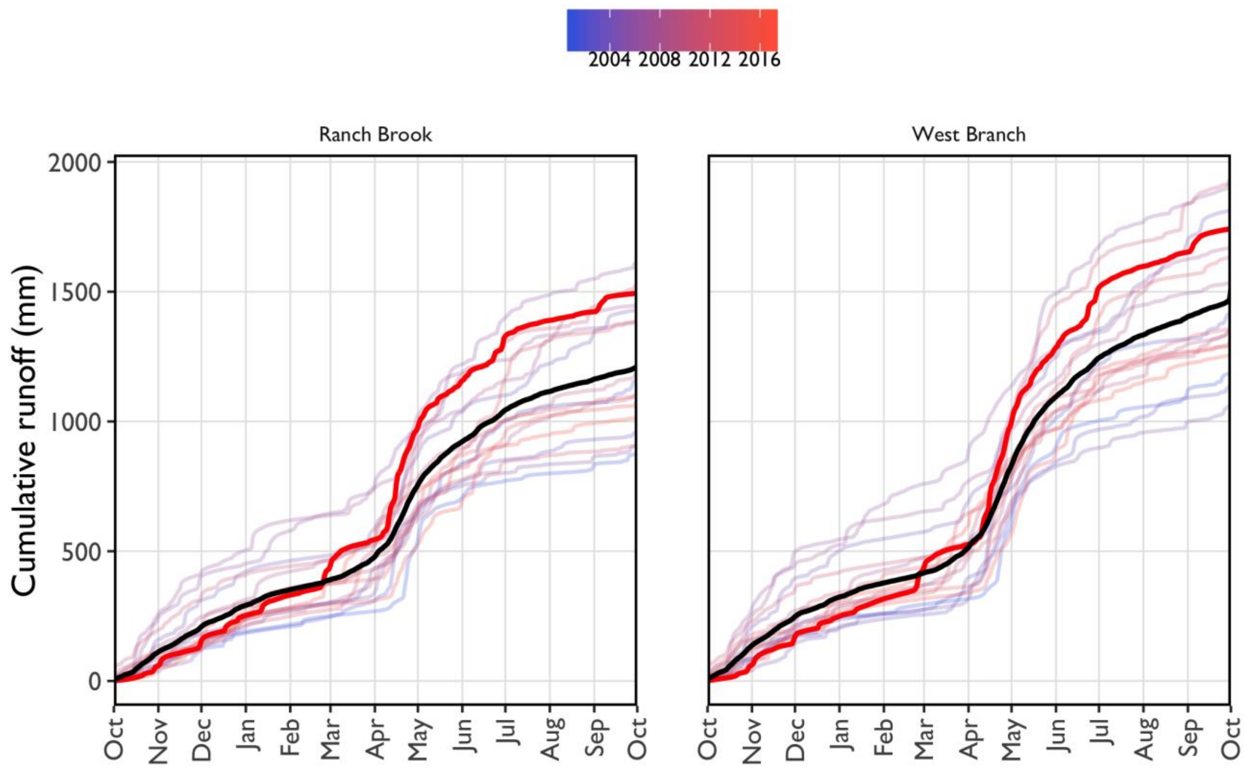


Figure 31. Cumulative runoff at Ranch Brook and West Branch based on the averages across the 17-year record (black line) and for Water Year 2017 only (red line). Faded lines show cumulative runoff for individual years (color denotes the year).

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 31 and Figure 32). Over the long-term, the average difference has been 22% greater runoff at West Branch. The Water Year 2017 differential was 17%, below the long-term average (Figure 32). Greater runoff at West Branch is what we would expect from the creation of open land and development; but 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.

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 33). Preliminary analysis suggests that the resort build-out had no clear impact on the hydrology, except for the low-flow regime. Construction of a new snowmaking pond with greater storage has lessened the need to draw water directly from the stream at low flows, thus enabling a higher sustained baseflow in late fall and winter.

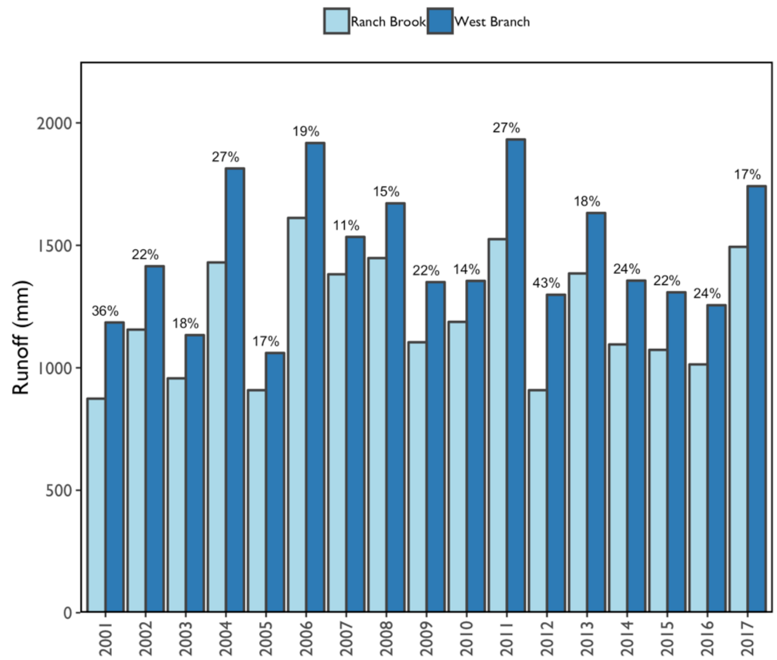


Figure 32. Annual runoff (mm) at Ranch Brook (light blue) and West Branch (dark blue) for the duration of study though the present report year (2001-2017). Percentage of greater runoff at WB relative to RB is given over each pair of bars.

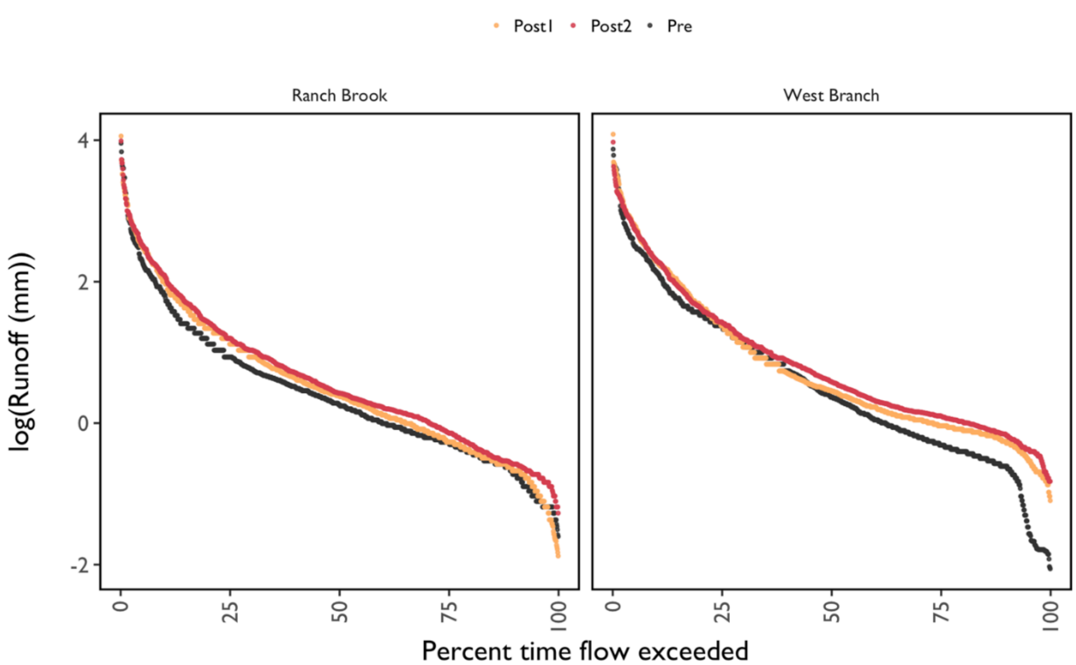


Figure 33. Flow duration curves for three three-year periods before and after the resort expansion, at Ranch Brook (left) and West Branch (right). Pre-expansion (WY01-03; black points), post-expansion 1 (WY12-14; orange points), post-expansion 2 (WY15-17; red points).

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.

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 snow making), can also adversely affect both aquatic and riparian animal and plant communities.

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

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

References

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

Additional Resources

Burlington National Weather Service data accessible at:

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

Northeast Regional Climate Center, accessible at:

http://www.nrcc.cornell.edu/regional/tables/tables.html

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 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, monitoring, analysis and reporting is conducted by the Department of Environmental Conservation (DEC), in partnership with FEMC.

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, silica, total phosphorus 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 of water quality in VT.

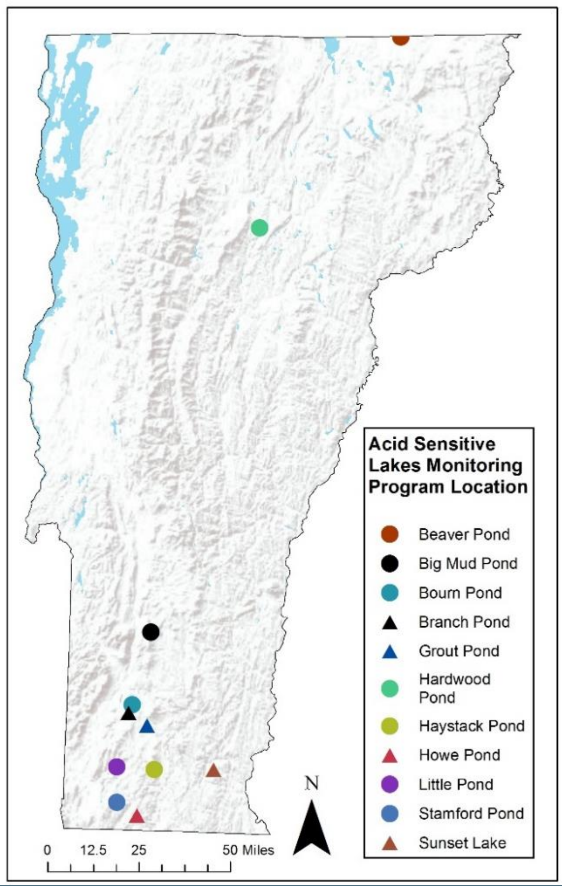


Figure 34. Locations of lakes/ponds in the Acid Lakes Monitoring Program in Vermont.

Project Lead: Rebecca Harvey

Staff Editor: Charles Nicholson & Alexandra Kosiba

2017 in Summary

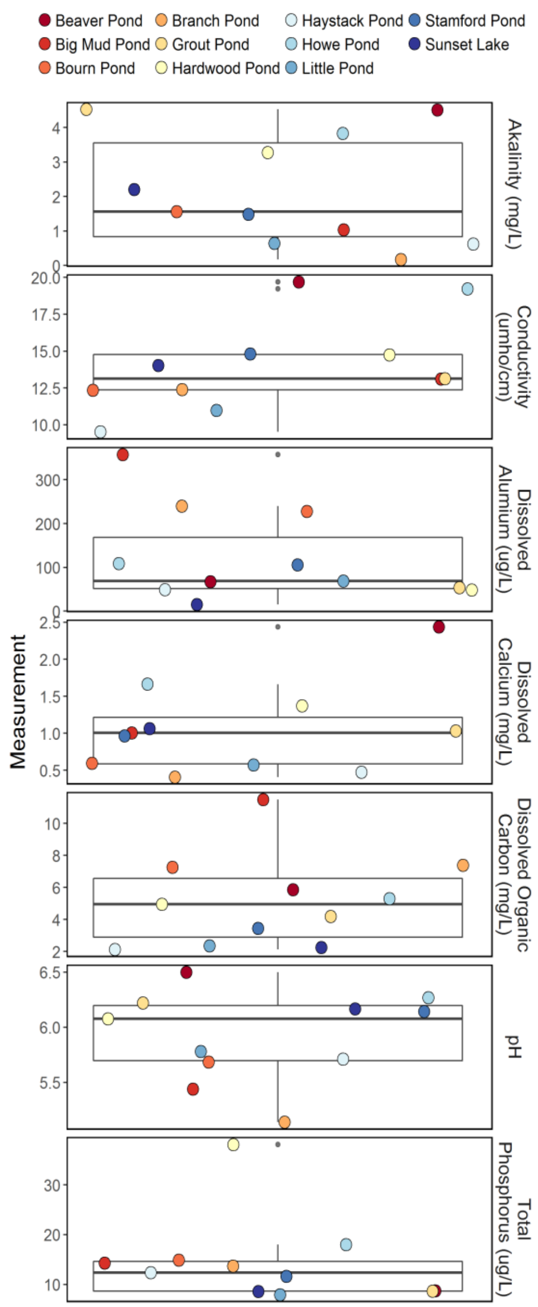


Figure 35. 2017 water quality measurements. Boxplot around points shows the mean (bold horizontal line) and extreme values (above or below vertical lines on top/bottom of box). Colors correspond to the 11 Acid Lakes in the monitoring program.

In 2017, we saw a range of values for water quality measurements in the 11 lakes and ponds in the Acid Lakes Monitoring Program (Figure 35) 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 acid lakes degraded slightly from 2016. This is most likely due to the increase in sulfur emissions and deposition in the northeast.

Average pH was 5.92, which is slightly lower than the average value in 2016 (5.94), a reversal of the trend from the year before. Reductions in aluminum are a good indicator of improving water quality, but mean dissolved aluminum across all sites increased from 93.5 ug/L in 2016 to 122.1 ug/L in 2017 after a decrease the year prior (data not shown). Note that in 2017 there was high variability in mean dissolved aluminum measured in the 11 acid lakes, ranging from a high of 357.8 µg/L at Big Mud Pond to a low of 15.3 µg/L at Sunset Lake. This variation is likely due to a number of factors, including location, deposition received, water depth, bedrock, and surrounding conditions.

Similarly, alkalinity did not improve, decreasing from 2.29 mg/L in 2016 to 2.17 mg/L in 2017. Conductivity increased slightly from 2016 (14.0 µmho/cm in 2017; 13.7 µmho/cm in 2016). Dissolved calcium decreased from 1.13 mg/L in 2016 to 1.05 mg/L in 2017.

Phosphorus concentration was 14.0 µg/L, slightly higher than it was in 2016 (12.1 µg/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 2017, the mean value (5.14 mg/L) increased from 2016 (4.35 mg/L).

Long-Term Trends

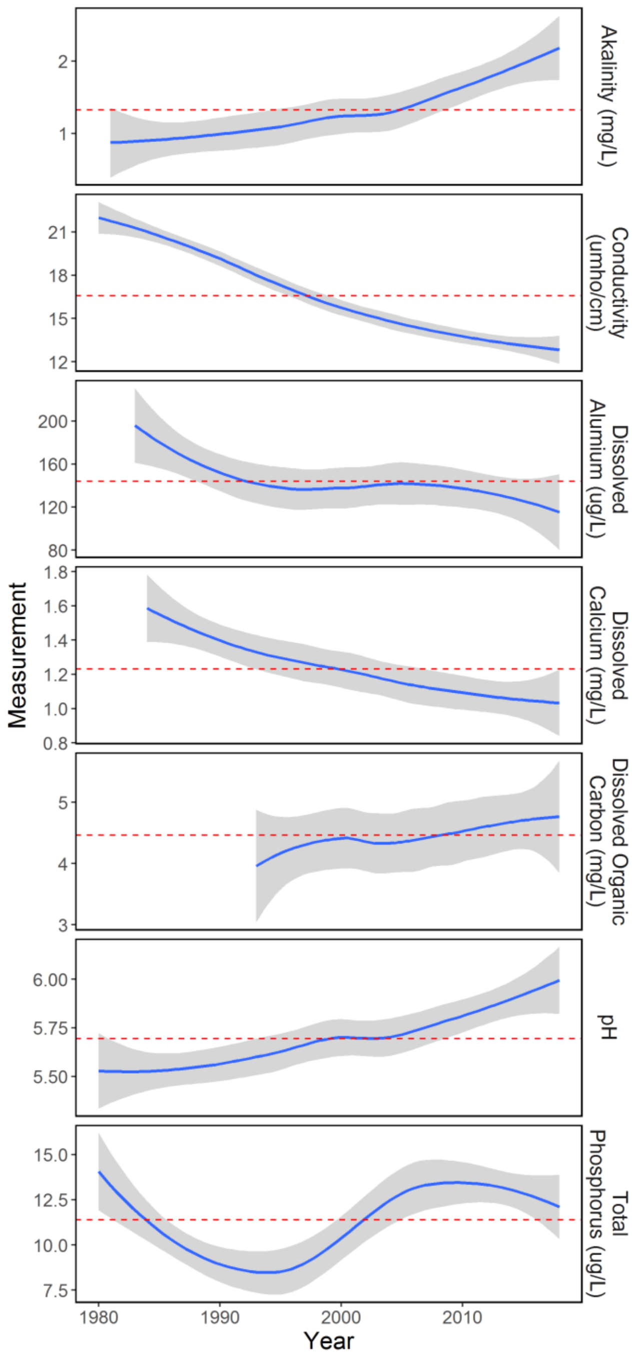


Figure 36. Average water quality measurements for 11 lakes/ponds in the VT Acid Lake Monitoring Program (blue line, smoothed with LOESS function), plus 95% confidence interval (grey shading). Red dashed line indicates the long-term average per measurement type.

The data from the 11 acid lakes demonstrate that acid accumulation and cation leaching has declined over the long-term record (1980-2016). Despite reductions in 2017, alkalinity and pH are both increasing over time (Figure 36). Concurrently, conductivity (a measure of the electrolyte concentration), dissolved aluminum, and dissolved calcium are still showing a decreasing trend despite increases in 2017.

Dissolved organic carbon (DOC) has been increasing since it was first measured in the early 1990s, although there is more variability among the 11 acid lakes for DOC compared to other measured variables, as indicated by the size of the confidence intervals around the average (Figure 36).

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. Historical patterns in total phosphorus show considerable variability, but concentrations have decreased from a peak in 2008 (Figure 36). Overall, the phosphorous values measured in the acid lakes are below the threshold for negative impacts.

Globally, northern hemisphere, lakes have been undergoing a “browning” effect due to increases in DOC. At the same time, the most pristine oligotrophic (e.g., relatively low in plant nutrients) lakes have been seeing an increase in phosphorus, or a "greening" effect. Overall, Vermont's acid lakes are following this same trend.

Regional Context & Implications

Similar trends in pH and dissolved cations are evident across the region. These long-term data are evidence that ecosystem recovery has begun 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.

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 parameter 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 recovery of our lakes and ponds compared to values in the 1980s supports the effectiveness of 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.

Acknowledgements:

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Overall, the long-term data (1980-2017), provide support that vulnerable lakes and ponds in Vermont are chemically recovering from decades of acid rain. Moving forward, phosphorus may become more problematic as acidic inputs decline and DOC increases.

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Additional Resources

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

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

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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Forest Phenology Section

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Notch Road in Stowe, VT. 2017. Photo by John Truong.

Acid Deposition Section

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Mercury Deposition Section

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Eastern Brook Trout Held by Fly Fisherman Close-up 01. 2014. Photo by Chesapeake Bay Program accessed from Flickr (https://www.flickr.com/photos/chesbayprogram/13960876260/) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

Brook trout at Ranch Brook, Stowe VT. Photo by Rich Kirn, Vermont Agency of Natural Resources.

***Forest Birds* Section**

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

Volunteer with black throated blue warbler. 2017. Photo by John Truong, FEMC.

***Amphibians* Section**

Wood frog. 2017. Photo by Caroline Drayton, FEMC.

Spring salamander. Photo by Chris Slesar. The Vermont Herp Atlas.

Bislineata dorsum, Orwell. 2017. Jim Andrews, Vermont Herp Atlas.

Spring peeper (Pseudacris crucifer) – pale coloration. 2014. Photo by Dave Huth accessed from flickr (https://www.flickr.com/photos/davemedia/14517288559/) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

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Moss Glenn Falls. 2017. Photo by John Truong, FEMC

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