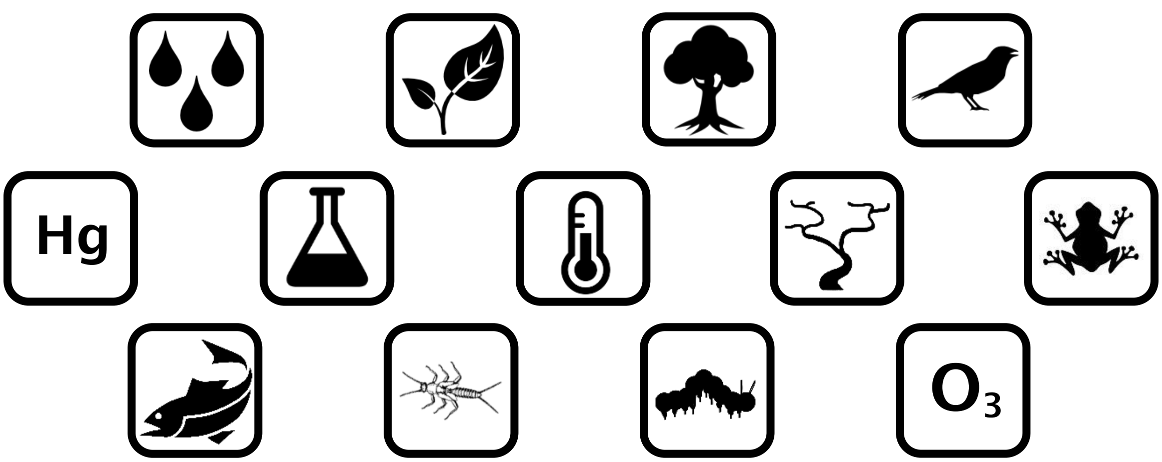
FEMC

Forest Ecosystem Monitoring Cooperative

Long-Term Monitoring Update 2018

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 - 2018

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Forest Ecosystem Monitoring Cooperative, South Burlington, VT, USA

Contributing Editors: Matthias Nevins, James Duncan, Alexandra Kosiba, John Truong, Rebecca Stern and Jennifer Pontius.

Acknowledgments

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Preferred Citation

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Introduction

The Forest Ecosystem Monitoring Cooperative (FEMC, formerly the Vermont Monitoring Cooperative), established in 1990, is 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 systems, not only supporting many organisms but also providing a wealth of ecosystem services. Since a healthy forest system is inherently dynamic in response to natural climate variability, succession, and disturbances, the only way to distinguish normal year-to-year variability from emergent forest health issues or subtle changes indicative of chronic stress is through long-term monitoring.

In its 29-year history, the FEMC network has completed nearly 250 individual research and monitoring projects. These projects were conducted by more than 215 collaborators, driven by a mission to aggregate necessary information to monitor forest health, detect chronic or emergent forest health issues, and assess their impacts on forested ecosystems. The numerous 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. The goal of this update is to provide both a summary of the latest year's (2018) data on key forest, wildlife, water, and air quality metrics, as well as an analysis of the long-term patterns and trends in the data, providing a relevant and timely source of information on the current state of the region's forested ecosystems.

The information provided in our 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 continues to grow daily. As an organization, the FEMC believes that the regular analysis and reporting of such information is critical to not only to identifying emerging forest health issues, but also to understanding 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 Vermont, with a separate report detailing trends in regional datasets.

Both reports can be found online at:
https://www.uvm.edu/femc/products/long_term_update/2018.

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 canopy condition and seedling regeneration help us monitor the status of our forest, as well as detect change. Trees with healthier, denser foliage can sequester more carbon, add more wood annually, and better resist pests and pathogen outbreaks. Measuring regeneration gives us a sense of what our forest may look like in the future. In any one year, crown health metrics may vary due to weather events and/or insect or disease outbreaks. Therefore, 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 49 long-term forest health monitoring plots across Vermont.

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 established 49 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, 7 plots were added in 2016, and one additional plot was added in 2018.

The 49 Vermont FHM plots contain 1,626 mature trees from 30 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 tree vigor. Elevated crown transparency can suggest either short or long-term decline, while crown dieback is a metric for more serious decline symptoms. Tree vigor is an assessment of the overall

Lye Brook Wilderness Area in Green Mountain National Forest.

health of the tree. Vigorous trees are healthy and resistant to stress and strain from damaging agents.

Regeneration counts provide an estimate of the relative success of germination and initial survivorship across species from year to year. Saplings (1 to <5 inches in diameter) have been measured on the 19 original FEMC plots between 1997 and 2007, and then again starting in 2014. From 2008 to 2013, the plots were measured on a 3-year rotation. Seedlings (<1 inch in diameter and greater than 12 inches tall for hardwoods or 6 inches tall for softwoods) have been measured periodically during that time as well. 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.

2018 in Summary

Crown Health

In 2018, for all selected tree species[1], mean crown dieback increased compared to 2017. For the selected species, elevated levels of crown dieback were observed for all species when compared to long-term trends (Table 1). Eastern white pine and eastern hemlock experienced the lowest levels of crown dieback in 2018 (less than 1 standard deviation from the long-term mean) (Table 1). White ash, northern red oak, and red maple experienced the highest levels of crown dieback in 2018 relative to the long-term mean. The average crown dieback, observed in 2018 for select species (12%), was greater than the 2017 average (10%) and it was greater than the long-term average (8%). 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.

The average foliar transparency of tree crowns measured in 2018 was 23%, which was greater than the 2017 average (15%) and the long-term average (20%) (Table 1). Eastern

[1] Eleven tree species were selected for crown health assessments based on their density (trees per hectare) across the FHM plot network.

white pine had the highest levels of crown transparency in 2018 (24%) which represents a 10% increase when compared to the long-term trend.

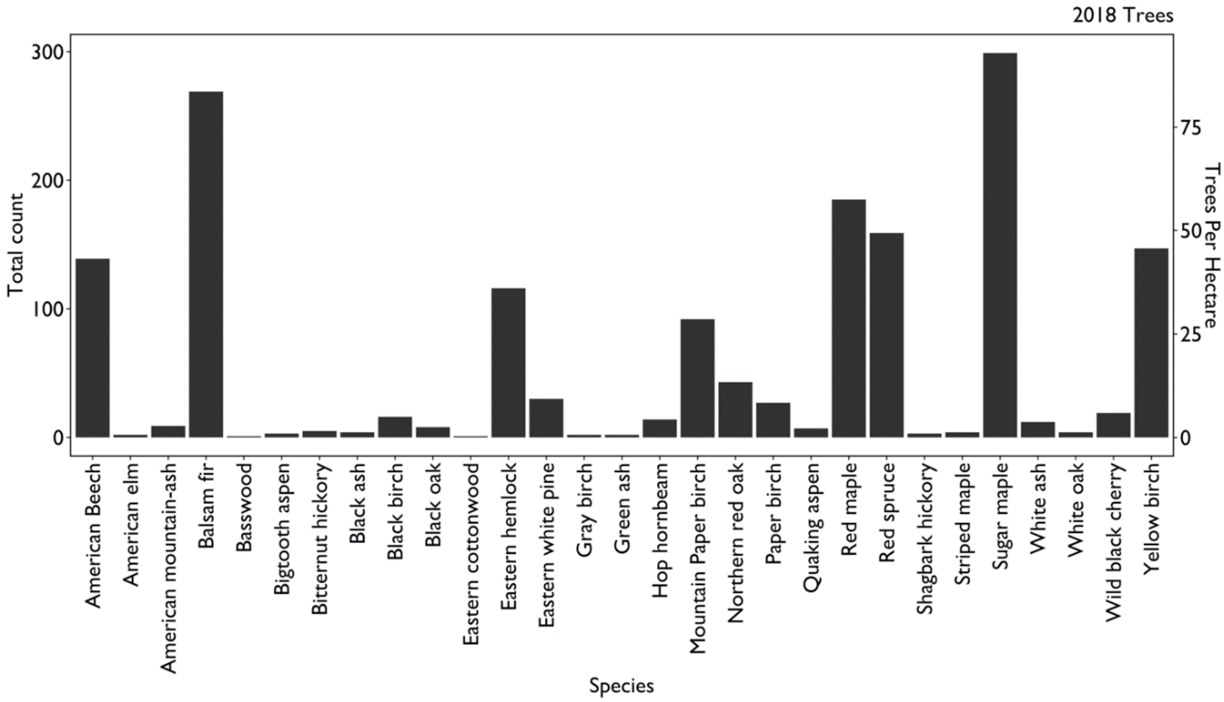
Table 1. Crown health metrics (percent twig dieback, percent foliar transparency, and tree vigor) in 2018 compared to the long-term mean (1997-2018). Both dieback and transparency are represented as species-specific means. Tree vigor is the percent of poor vigor trees (ratings 3 and 4) detected. 'Dif' column indicates the difference between 2018 and the long-term mean, with red values showing a decline in health (one standard deviation away from the long-term mean), blue shows an improvement, and no color indicates change that is within one standard deviation away from the mean. Note that tree vigor assessment ratings began in 2014.

Species	Dieback (%)			Transparency (%)			Poor Vigor (%)		
	2018 mean	Long-term mean	Dif	2018 mean	Long-term mean	Dif	2018 mean	Long-term mean	Dif
American Beech	14	10	**4**	22	22	0	16	17	-1
Balsam fir	16	12	**4**	23	19	**4**	10	12	-2
Eastern hemlock	8	5	3	20	22	-2	6	6	0
Eastern white pine	10	9	1	34	24	**10**	10	5	**5**
Northern red oak	12	5	**7**	21	17	4	21	10	**11**
Paper birch	15	10	**5**	28	23	**5**	19	19	0
Red maple	14	7	**7**	22	20	2	8	7	1
Red spruce	10	7	**3**	21	17	**4**	3	2	1
Sugar maple	9	6	**3**	19	17	2	6	6	0
White ash	16	9	**7**	24	19	**5**	17	15	2
Yellow birch	10	7	**3**	20	19	1	7	7	0

For the 2018 annual report, we have summarized trends in tree vigor, which is an assessment of a tree's overall health. We compared the proportion of trees that were identified as having poor vigor to all trees assessed in 2018 and for a four-year period when vigor data were collected (2014 to 2018). For the select species listed in Table 1, the proportion of poor vigor trees was 11% in 2018 which is slightly higher than the five-year average of 10%. Northern red oak and eastern white pine showed the greatest increase in proportion of poor vigor trees in 2018 in comparison to the four-year average for those species. While northern red oak and white pine do show a significant increase in poor vigor rating compared to the mean, tree vigor assessments were only conducted on 22 plots in 2014 which likely underrepresents these species. However, the trend over the measurement period does indicate an increasing proportion of poor vigor rating for red oak and white pine.

Overstory trees

For all living overstory trees measured in 2018, sugar maple was the predominate species across the plot network with 299 trees measured at a density of 93 trees per hectare (tph; 38 trees per acre (tpa)) (Figure 1). Balsam fir was the second most abundant overstory tree species (269 trees, 84 tph, 34 tpa), followed by red maple (185 trees, 58 tph, and 23 tpa), red spruce (159 trees, 49 tph, and 20 tpa), yellow birch (157 trees, 46 tph, and 19 tpa), American beech (139 trees, 43 tph, and 17 tpa), and Eastern hemlock (116 trees, 36 tph, and 15 tpa) (Figure 1).



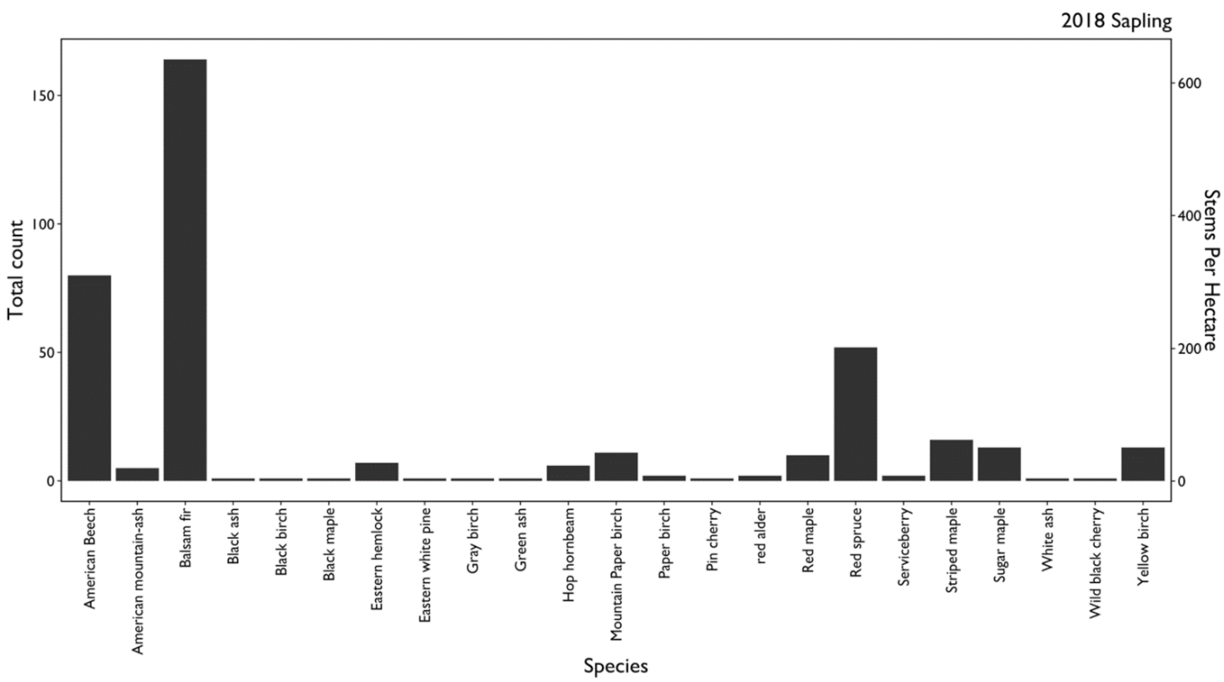


Figure 1. Species composition of all dominant and codominant trees greater than 5 inch diameter (top), saplings (bottom) tallied across the 2018 FEMC Forest Health Monitoring plots. Total stem count on left axis and stem density (as stems per hectare) on the right axis.

Regeneration

Across the plot network, the sapling layer remained relatively stable over the past year. Balsam fir decreased slightly from the previous year's measurement of 167 live stems to 164 live stems (635 tph; 257 tpa) (Figure 1). American beech remained the second most abundant species in the sapling layer with 80 live stems tallied (310 tph; 126 tpa) (Figure 1). Red spruce (52 stems, 201 tph, and 81 tpa), striped maple (16 stems, 62 tph, and 25 tpa), and yellow birch and sugar maple (both with 13 stems, 50 tph, and 20 tpa) are among the most abundant species in the sapling layer. Together, these results indicate little change in sapling composition in the past year, which is to be expected given the low rates of natural disturbance within the forest types represented and the lack of canopy disturbance resulting from forest management. The sapling layer represents those tree species that have the potential of growing into the overstory. We have not seen increased rates of sapling mortality in recent years which does suggest the potential for new trees to be recruited into the overstory if additional growing space is made available.

In 2018, we saw an increase in total seedling regeneration of the selected species relative to 2017. As some tree species experience heavier and lighter seed years, annual fluctuations are expected. 2017 was an excellent seed year for many of the common species found in Vermont forests, which may have had a positive influence on 2018 seedling counts. A good seed year also may also have coincided with favorable germination and growing conditions. Sugar maple seedling regeneration was recorded to be 11,168 stems per hectare (4,521 stems per acre), which represents a major increase from the 2017 measurement (2,362 stems per hectare; 956 stems per acre). American beech (2,067 stems per hectare; 836 stems per acre), balsam fir (3,661 stems per hectare; 1482 stems per acres), red maple (6,581 stems per hectare; 2,664 stems per acre), red spruce (595 stems per hectare; 241 stems per acre), and yellow birch (5,216 stems per hectare; 2,112 stems per acre) all experienced increased levels of seedling regeneration in 2018 (Figure 2). Seedling densities are shown as two distinct size class. Class 1 seedlings are < 12 inches tall for hardwoods and < 6 inches tall for softwoods. Class 2 are all seedlings < 1 inch in diameter and are not included in class 2.

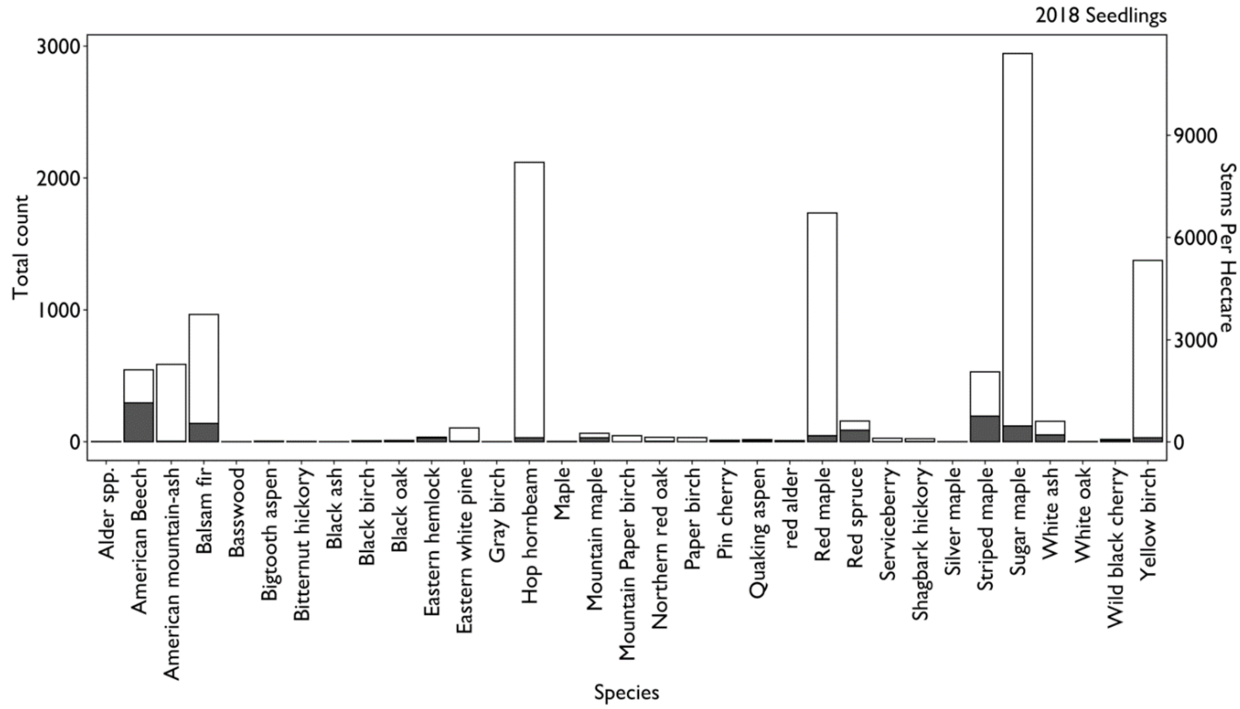


Figure 2. Species composition of all seedlings tallied across the 2018 FEMC Forest Health Monitoring plots. Seedling class 1 is depicted in white and seedling class 2 is depicted in black.

Long-Term Trends

Crown health

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 a high annual variability in the crown health metrics, particularly for certain tree species. White ash and paper birch show a trend of increasing foliage transparency over the past ten years compared to the long term average. The total number of trees assessed has increased every year due to the inclusion of additional monitoring plots which may have had an impact on observed trends in crown health metrics. Red oak has experienced a slight increase in crown transparency over the past four years while sugar maple appears to be experiencing a decreasing crown transparency trend (Figure 3). Sugar maple,however, appears to have increasing levels of crown dieback over the past five years (Figure 3). White ash, yellow birch, red maple, paper birch and red oak are all likely experiencing higher than average levels of crown dieback over the past four years (Figure 3).

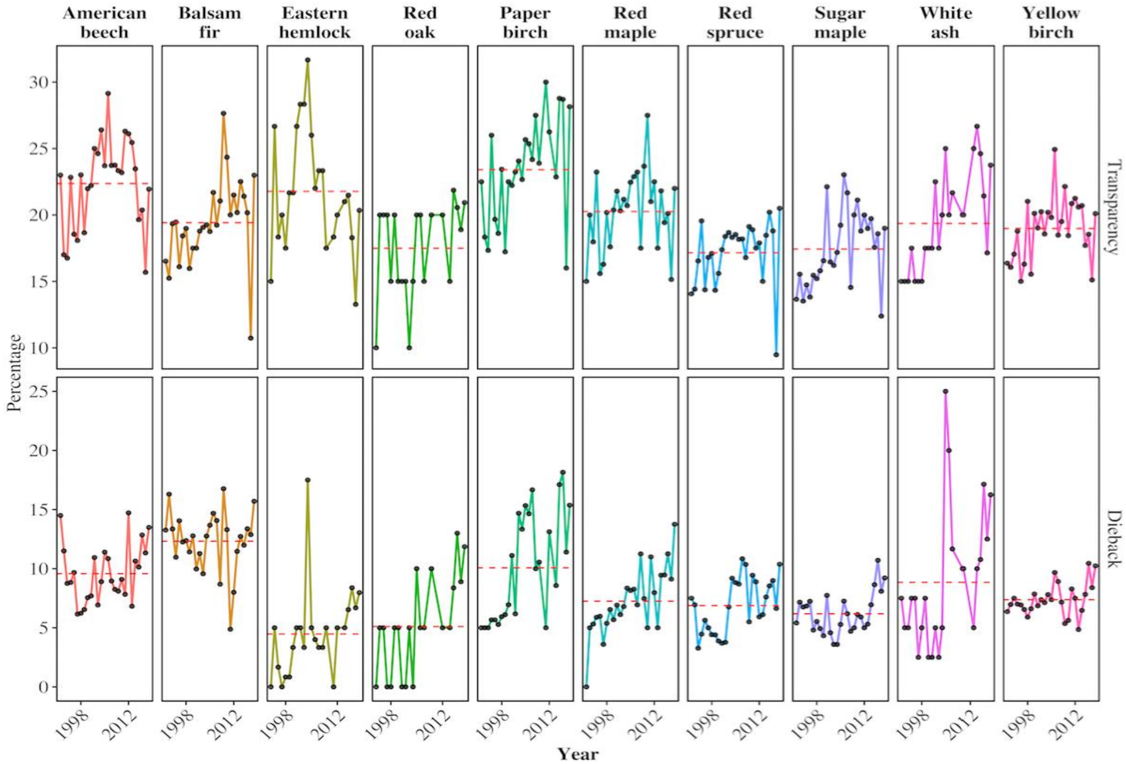


Figure 3. Tree crown health metrics: percent crown transparency (top), percent dieback (bottom) for 10 selected tree species in Vermont. Red dashed line shows the long-term mean (1993-2018) for that species and metric.

Tree vigor is a measure of a tree's overall health. During annual data collection, each tree that is measured is assigned a vigor rating from 1-5, with 5 being dead. A vigor rating of 1 (excellent health), indicates a tree that is in good health with less than 10 percent crown dieback, minimal to no branch mortality, defoliation, or crown discoloration. A tree with a vigor rating of 4 (poor health) indicates that the tree has elevated levels of branch mortality, crown dieback, and more than 50% crown defoliation and/or crown discoloration. To assess the long-term trends in average tree vigor across all plots in the FMH program, we assessed the percent of all live trees that were identified as having poor vigor (vigor rating of 3 or 4) relative to the total number of trees. The proportion of poor vigor trees in the sampling population represents another useful metric to assess changes in overall forest health over time. Vigor rating began in 2014; therefore, we present the trend from 2014 to 2018.

The proportion of poor vigor trees has remained stable for most species across all monitoring plots over the past five years, with the exception of red oak, which show signs of elevated proportions of poor vigor trees (Figure 4). The increase in white pine trees assessed as "poor vigor" in 2018 may be a result of white pine needle disease which had made large impacts over the past two years.

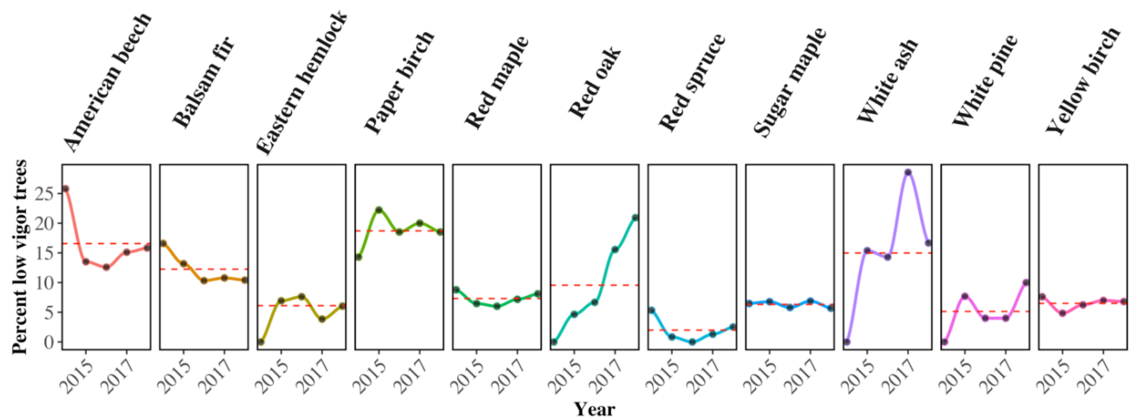


Figure 4. Percentage of trees assessed as having "poor vigor" over a 5-year period from 2014-2018. Red dashed line shows the long-term mean (2014-2018) for each species.

Tree regeneration

In 2018, overall seedling density was greater than previous years (Figure 5). It is important to note that a protocol change, implemented in 2014, expanded the definition of seedlings to capture recent germinants. Prior to 2014, seedlings were only counted when they exceeded a certain height (6" for conifers, 12" for hardwoods, as per FIA protocol). Since 2014, all seedlings with true leaves and smaller than 1" diameter were counted. Therefore, we have chosen to present the trends in tree regeneration for the five-year period from 2014 to 2018.

Seedling densities (stems per hectare) increased in 2018 when compared to the preceding four years. Sugar maple, yellow birch, and balsam fir regeneration increased substantially in 2018 (Figure 5). Other species commonly found at lower relative abundances also experienced increases in seedling regeneration in 2018. Hop hornbeam, American mountain-ash, and striped maple all showed large increases in seedling regeneration when compared to the past four years. In 2018, northern red oak seedling densities in 2018 were the second highest recorded since 2014 (129 stems per hectare) but lower in comparison to 2017 (248 stems per hectare). Eastern white pine seedling densities were the highest recorded since 2014 (398 stems per hectare).

Long-term seedling regeneration trends appear to indicate that 2018 was a favorable year for tree regeneration across many commonly found tree species in Vermont. The increase in seedling regeneration may be related to the abundance of seed observed in 2017.

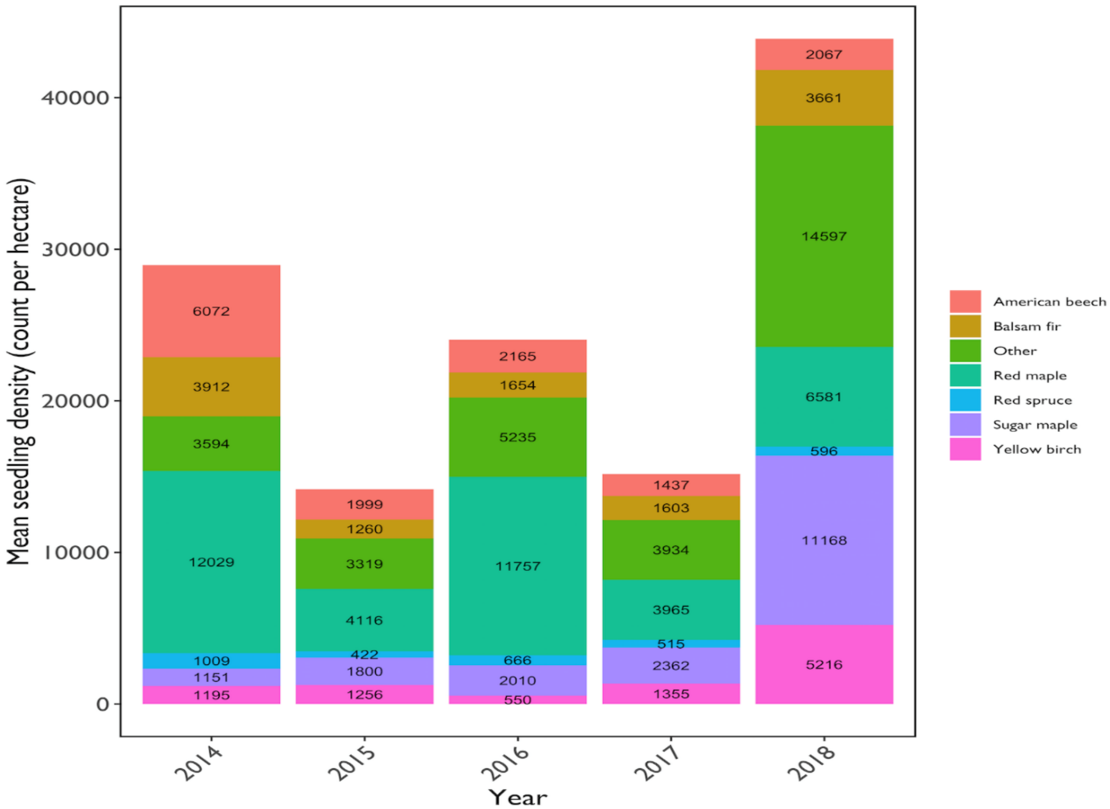


Figure 5. Mean seedling density (count per hectare) for selected species assessed on FEMC forest health monitoring plots. "Other" species include hop hornbeam, striped maple, American mountain maple, white ash, eastern hemlock, northern red oak, eastern white pine, and a host of other hard and softwood species found in low abundance in the regeneration layer.

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. Examination of metrics for other species indicates long-term trends that warrant ongoing monitoring of declining condition, particularly for paper birch, red oak, and white ash.

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.

Project Lead: Joshua Halman
Staff Editor: Matthias Nevins

Long-term trends continue to show declining tree crown health for white ash and paper birch, while others species continue to remain stable. 2018 proved to be an impressive year for tree seedling regeneration across Vermont.

Acknowledgements:

Special thanks to Josh Halman from the Vermont Forest Parks and Recreation Department for reviewing and editing the Forest Health Section of the 2018 FEMC Long-Term Monitoring Update.

Additional Resources

VT Forests, Parks and Recreation Vermont Forest Health Highlights 2018
https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2018%20VT%20Forest%20Health%20Highlights.pdf

VT Forest Insects and Disease Conditions 2018
https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2018%20Conditions%20report.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.

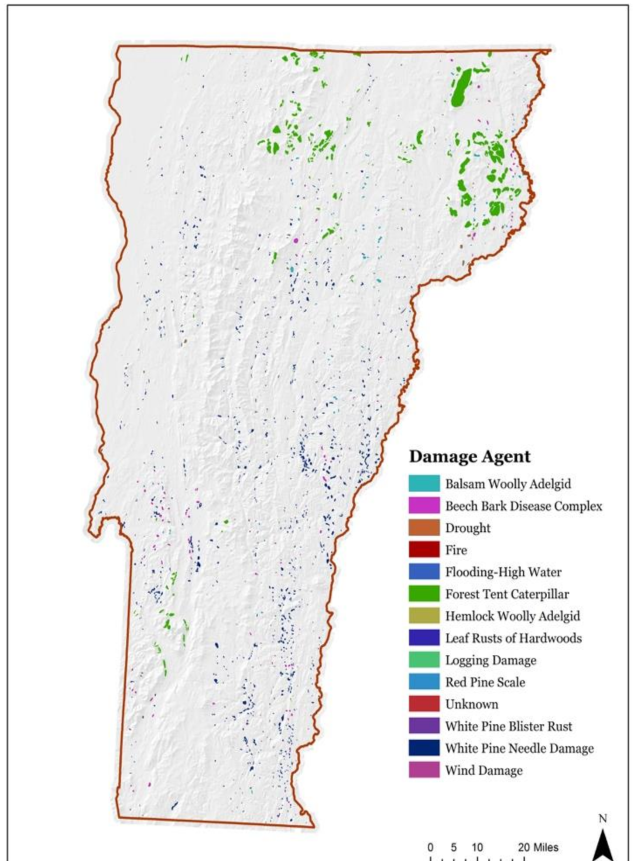


Figure 6. Locations of 2018 mapped forest disturbance from Vermont aerial detection surveys. Disturbance polygons were increased in size for visibility. Only those damage agents with the highest occurrence are shown.

The Data

The 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.

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.

2018 in Summary

In 2018, 52,172 hectares (128,866 acres) of forest disturbance were mapped in Vermont, which is approximately 2.7% of Vermont's forestland. This is an increase from 2017 when 39,898 ha were mapped, but it is less than the long-term (1995-2018) average of 96,165 ha/year.

Emerald ash borer (EAB). EAB was confirmed to be in Vermont in 2018.

2018 marked the third year of a forest tent caterpillar (*Malacosoma disstria)* outbreak, with 30,715 ha of damage mapped during the season. This is an increase over the 24,515 ha mapped in 2017 and 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 16,491 ha mapped (Figure 6). This value represents a significant increase in the white pine needle damage area mapped in 2017 (6,650 ha).

Symptoms attributed to drought were more commonin 2018 than in 2017 and the impacts were likely underrepresented due to the timing of aerial surveys (VT FPR 2018). Forest tent caterpillar (FTC) populations increased in 2018, resulting in greater defoliation impacts across the state. White pine needle damage was widespread in 2018 and resulted in a two-fold increase in impacted area mapped when compared to 2017 (VT FPR 2018).

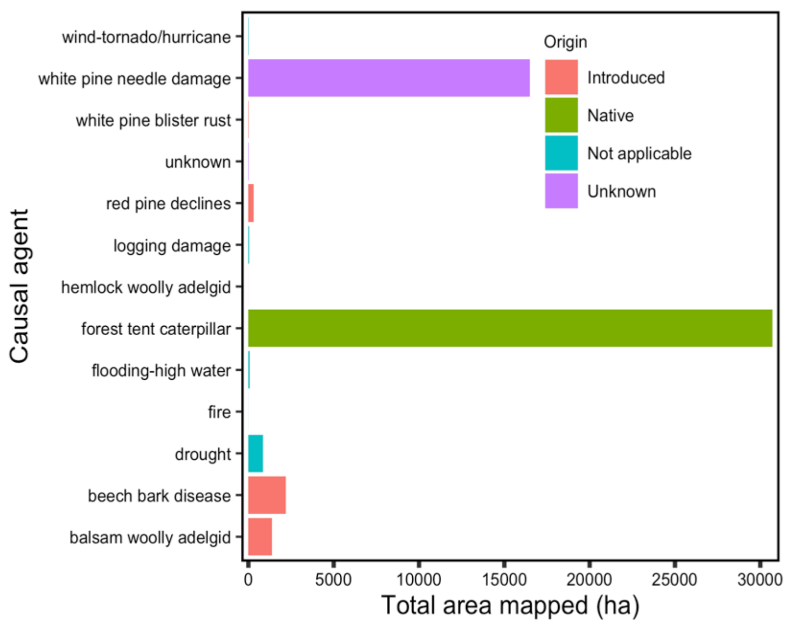


Figure 7. Area (in hectares) of mapped 2018 disturbance by causal agent according to Vermont aerial detection surveys. Color corresponds to the agent's origin.

More complete results of the 2018 Vermont IDS effort can be found in the 2018 report, *Forest Insect and Disease Conditions in Vermont* (VT FPR, 2018).

Long Term Trends

A summation of all disturbances per year (1995-2018) reveals substantial year-to-year variability (Figure 8). 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 of the 23-year period: beech bark disease and birch defoliator complex (Figure 9).

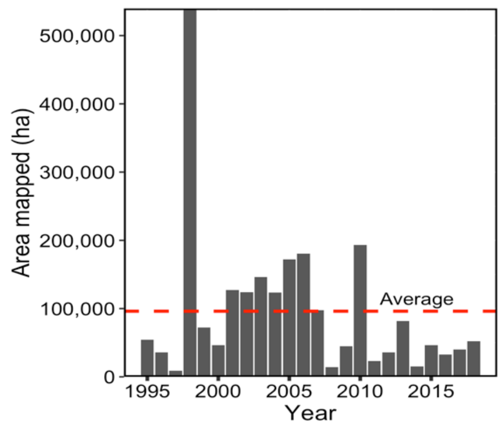


Figure 8. Annual area mapped as disturbed (grey bars; hectares) during statewide aerial detection surveys in Vermont. Red dashed line indicates the average disturbance (1995-2018).

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 9). 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), forest tent caterpillar (333,005 ha), and beech bark disease (224,188 ha).

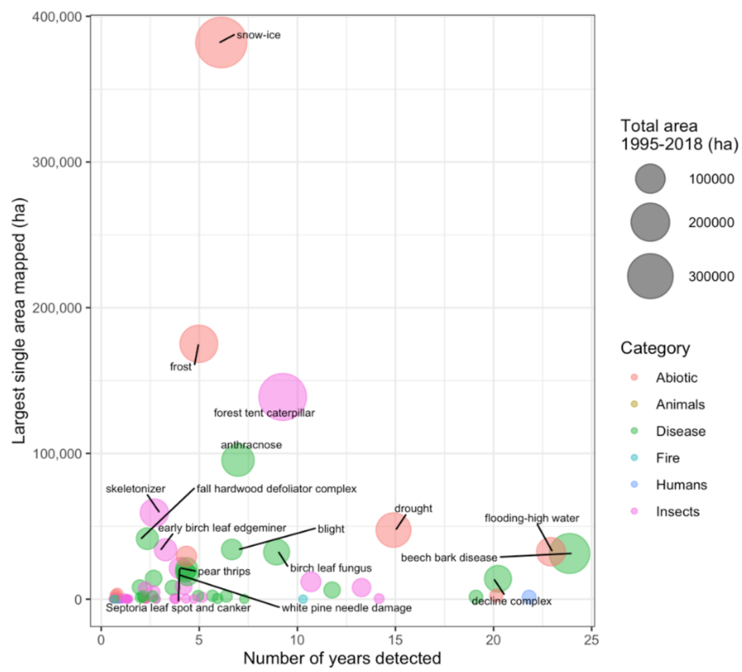


Figure 9. Mapped disturbance agents in aerial detection surveys from 1995-2018 plotted by the frequency (number of years detected) and largest single area mapped (ha; e.g., largest polygon) attributed to agent. Circle size corresponds to the total area recorded for that agent over the twenty-one-year 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 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 9). 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 9). It is only as we continue to monitor disturbances over time that we can 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. In late February of 2018, the emerald ash borer was confirmed in the town of Orange making Vermont the 32nd state known to be infested. Overall, introduced pests and pathogens have caused much more disturbance to the region's forests than those of native origin, and we can 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 2018, Vermont's forests experienced greater levels of disturbance than in 2017 but less than the average (1995-2018). The most damaging disturbance agents in 2018 were forest tent caterpillar and white pine needle damage. Prolonged drought in 2018 also had significant impacts state-wide. The emerald ash borer was confirmed to be in Vermont in 2018.

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). 2018. Forest Insect and Disease Conditions in Vermont: 2018. Report. Available online at: https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/2018%20Conditions%20report.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 datasets include visual assessments from 1991 to present of sugar maple (*Acer saccharum* Marsh.) bud break and fall senescence, from 1991 to the present, 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 continue until leaves are fully expanded. Spring phenology is assessed twice weekly on five dominant sugar maple trees at the Proctor Maple Research Center, at an elevation of 415 m (1400 feet). Trees are assigned to one of eight bud developmental stages based on an assessment of 10 random buds (Skinner and Parker, 1994) and then averaged to a plot-level mean.

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

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

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

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

Fall phenology was similarly examined by comparing the timing of two significant fall phenological events across time: (1) the day of year (DOY) with maximum fall color observed in the canopy; and (2) the day of year (DOY) on which all trees' 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.

2018 in Summary

The day-of-year of first bud break in 2018 for sugar maple (DOY 127) was two days later than the long-term average (DOY 125). Full leaf out (DOY 138) was similar to the long term average (DOY 137). The transition from bud break to full leaves was more rapid than normal, taking 12 days compared with the long-term average of 15 days. At lower elevations, maximum fall color occurred 2 days earlier than the long-term mean and full leaf drop occurred 2 days later than the long-term mean. At higher elevations, peak color was consistent with the long-term mean, and full leaf drop was 1 day earlier than the long-term mean (same as in 2017).

Long Term Trends

Spring phenology in 2018 was similar to the long-term mean and fits a long-term trend toward an earlier start of spring (Figure 10). High variability in our spring phenology data is likely the result of our low sample size (n=5) for each year. As such, it is difficult to make statistical inferences for bud burst or leaf out. Nevertheless, there does appear to be a weak but consistent trend for earlier spring phenological measures over the course of our monitoring efforts (Figure 10).

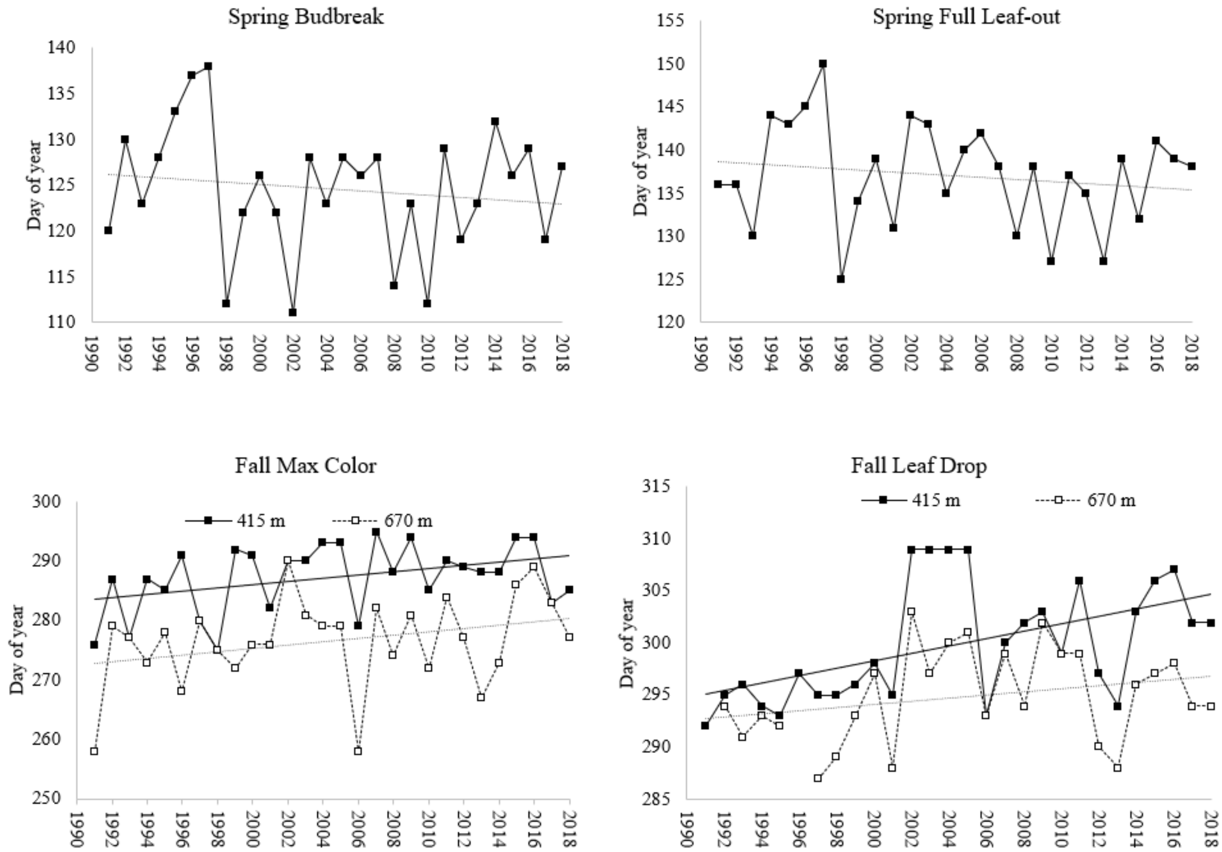


Figure 10. Long-term trends in the timing (mean day of year) of spring and fall phenological events for sugar maple from 1991 to 2018. Spring bud burst (top left) and full leaf out (top right) are assessed yearly at lower elevation (415m), with linear trend line shown. Fall maximum coloration (bottom 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 10). 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 model data suggesting that warming due to climate change may be more severe at higher elevations (Giorgi et al. 1997). Exploring microclimatic differences at each elevation is 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 dataset (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 this may impact forested ecosystems. There are possible implications for water cycling in forests, as earlier springs may escalate evapotranspiration resulting in increased periods of low stream flow during the peak growing season (Daley et al., 2007). Although a longer growing season typically increases forest productivity, carbon sequestration dynamics could be altered by water and nutrient limitations in northern hardwood forests. While expanded growing seasons may benefit some species, it may leave others more vulnerable to climate extremes that occur more often in shoulder seasons. There may also be cascading impacts through forested ecosystems, including phenological asynchrony across taxonomic groups.

The changes we observed in the timing of foliar development carry important economic repercussions for Vermont's maple syrup and tourist industries. Vermont is the largest producer of maple syrup in the United States, accounting for 41% of the country's production and earning 50 million dollars in 2011 (Sawyer et al., 2013). Warmer winters and earlier springs are now shortening and advancing the sugaring season (Skinner et al., 2010), and maple syrup producers will need to employ new management techniques for the industry to adapt to the changing climate (Frumhoff et al., 2007; Skinner et al., 2010).

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

Sugar maples continue to show a trend towards earlier spring and later fall phenological events. Earlier springs may shorten the window for maple syrup production.

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

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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

Proctor Maple Research Center Air Quality Site in Underhill. Sampling at this site started in 1984.

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

The Data

National Atmospheric Deposition Program (NADP) has been monitoring precipitation chemistry in the US since 1978 through the National Trends Network (NTN) program. The 250 national NTN sites collected 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^+).

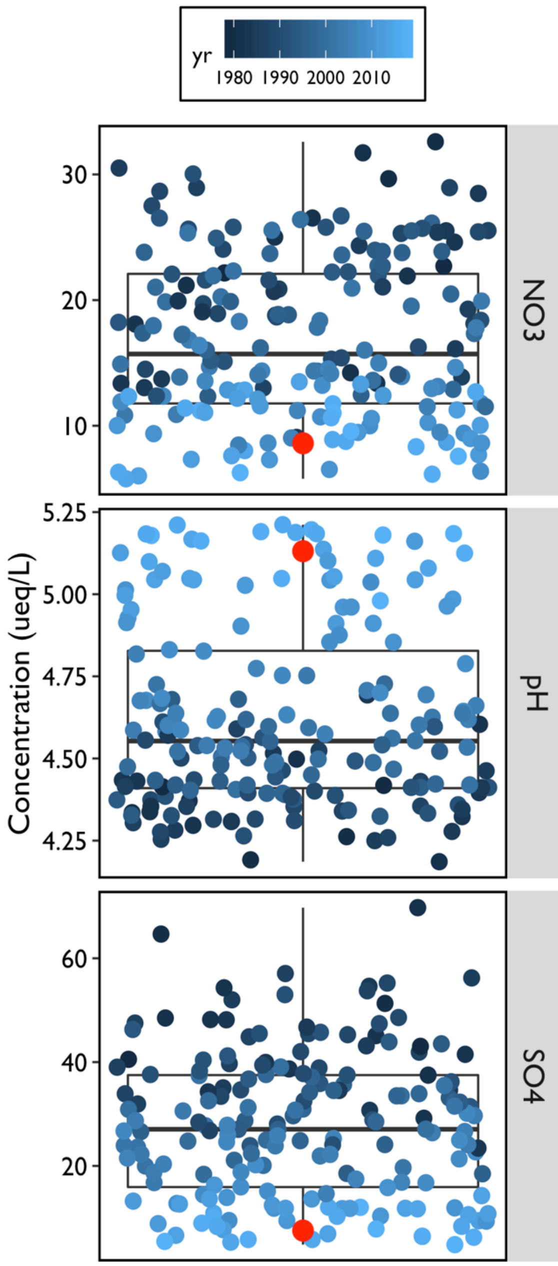

Figure 11. Mean annual deposition of nitrate (NO3), sulfate (SO4), and pH displayed with quantile box plots. The most recent year's measurements (2018) are indicated in red, and shades of blue correspond to the year, with lighter values corresponding to more recent data. Solid horizontal line indicates 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. 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.

2018 in Summary

For all three metrics of acid deposition (NO_3, SO_4, pH), 2018 continued the trend of reduced pollution concentrations over historical measurements (Figure 11).

While mean deposition of NO_3 in 2018 was not the lowest value observed in the record (Figure 11), it was the second lowest at 9.56 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 2018, we saw the lowest concentration of SO_4 in the record (5.45 μeq/L), continuing a five-year streak of record lows. This is a dramatic decline from the historical high of 48.20 µeq/L in 1982. For the fifth year in a row, deposition of SO_4 fell below that of NO_3.

The average pH was the highest on record in 2018 at 5.185, 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 acidity of precipitation. As pH is a logarithmic scale, this increase represents a roughly fivefold improvement in precipitation acidity.

In the early years of acid rain monitoring in Vermont, 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. 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 12Figure 12). 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 12Figure 12).

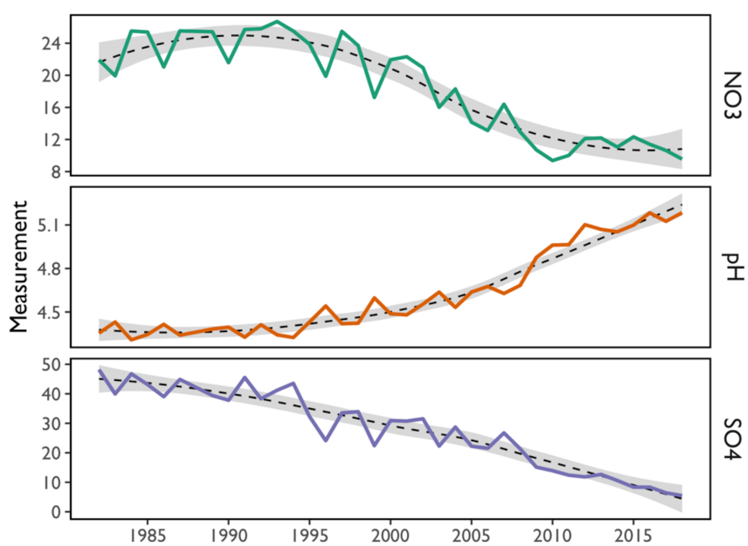

Figure 12. Long-term precipitation chemistry showing annual mean concentrations (ueq/L) of nitrate (NO3) and sulfate (SO4), and mean pH (solid colored lines). Black dotted line shows trend (LOESS function) with 95% confidence intervals (grey shading).

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 12Figure 12). 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 12Figure 12), along with resultant decreases in precipitation acidity. However, it appears that reductions in NO_3 concentrations may have plateaued, even though concentrations are down from last year's measurement. 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.

Regional Context & Implications

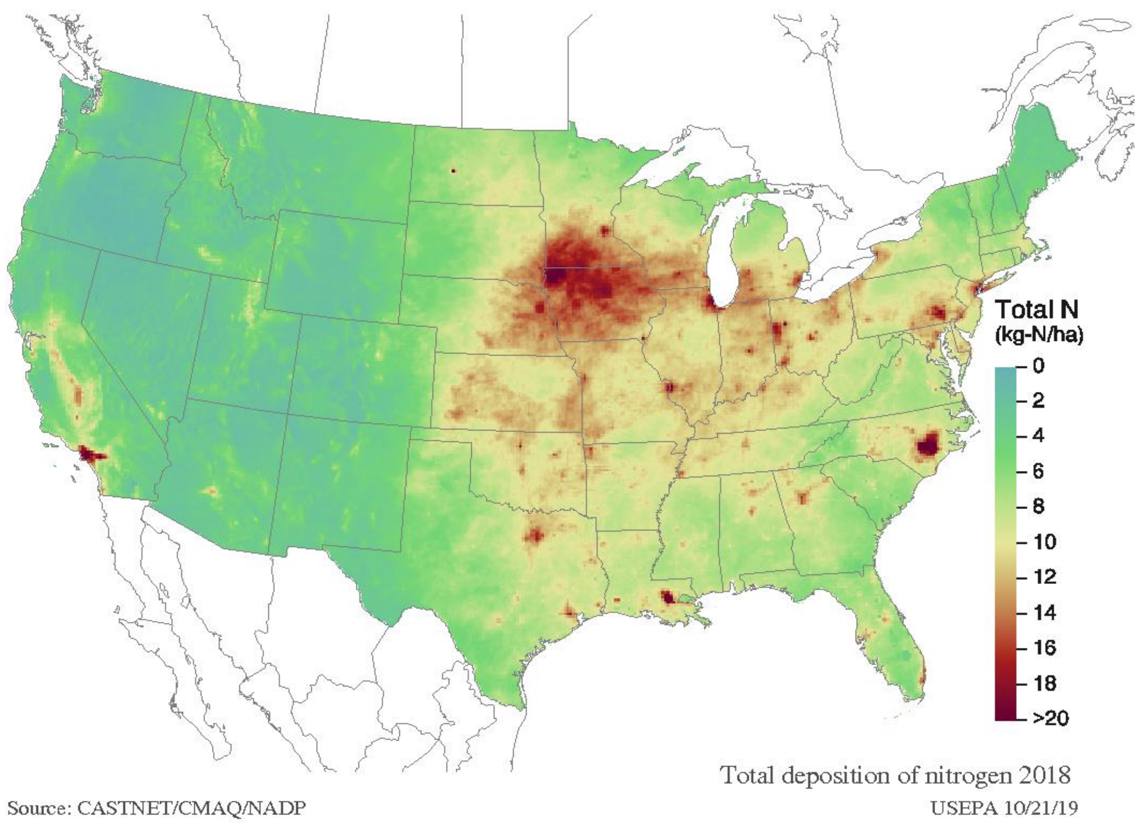

Figure 13. Spatial distribution of total nitrogen deposition (kg/ha) across the continental US in 2018. Source: US EPA.

Vermont is in relatively good shape compared to nitrogen pollution loads nationwide (Figure 13). 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 have been seen elsewhere in the region, however western and southern portions of New York continue to receive elevated deposition (Figure 13). 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 2018. The average pH of precipitation was 5.185, the highest value on record. Nitrate deposition declined in 2018 but long-term trends suggest it may have plateaued. Continued monitoring is recommended.

Additional Resources

National Atmpospheric Deposition Program. http://nadp.slh.wisc.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 Monitoring at VT99

Mercury Deposition Network automated sample collector located in Underhill, Vermont

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 of mercury deposition in the U.S. In 2004, the FEMC joined the Mercury Deposition Network (MDN, part of the National Atmospheric Deposition Program) as one of nearly 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 extensive record has provided context to many shorter-duration studies[2]. FEMC and its partners have committed to this long-term monitoring in order to document and better understand the input of mercury into Vermont's forested ecosystems and the inhabitants of those ecosystems, including birds, fish, bobcats and human beings.

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

The Data

FEMC conducts year-round sampling of precipitation for mercury analysis at the air quality-monitoring site at the Proctor Maple Research Center in Underhill, Vermont (MDN 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 Wisconsin State Laboratory of Hygiene[3] 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[4].

2018 in Summary

Mercury monitoring at FEMC's air quality site VT99 in 2018 shows slightly lower total annual mercury (Hg) deposition than the average for the 14-year record and a slightly higher total annual mercury deposition than 2017 levels (Table 2). Over the 2005-2018 period 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 2018, precipitation-weighted mean concentration was slightly lower than the average for the record. In 2018, Vermont registered lower

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 2018. 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
2018	5.6	22.5	7.5
Overall Mean	**5.7**	**46.6**	**7.8**

[3] In 2019, analytical services for the Mercury Deposition Network were moved to the Wisconsin State Hygiene Laboratory in Madison, Wisconsin.
[4] http://nadp.slh.wisc.edu/mdn/

concentration and deposition averages than most sites elsewhere in the United States (Figure 14).

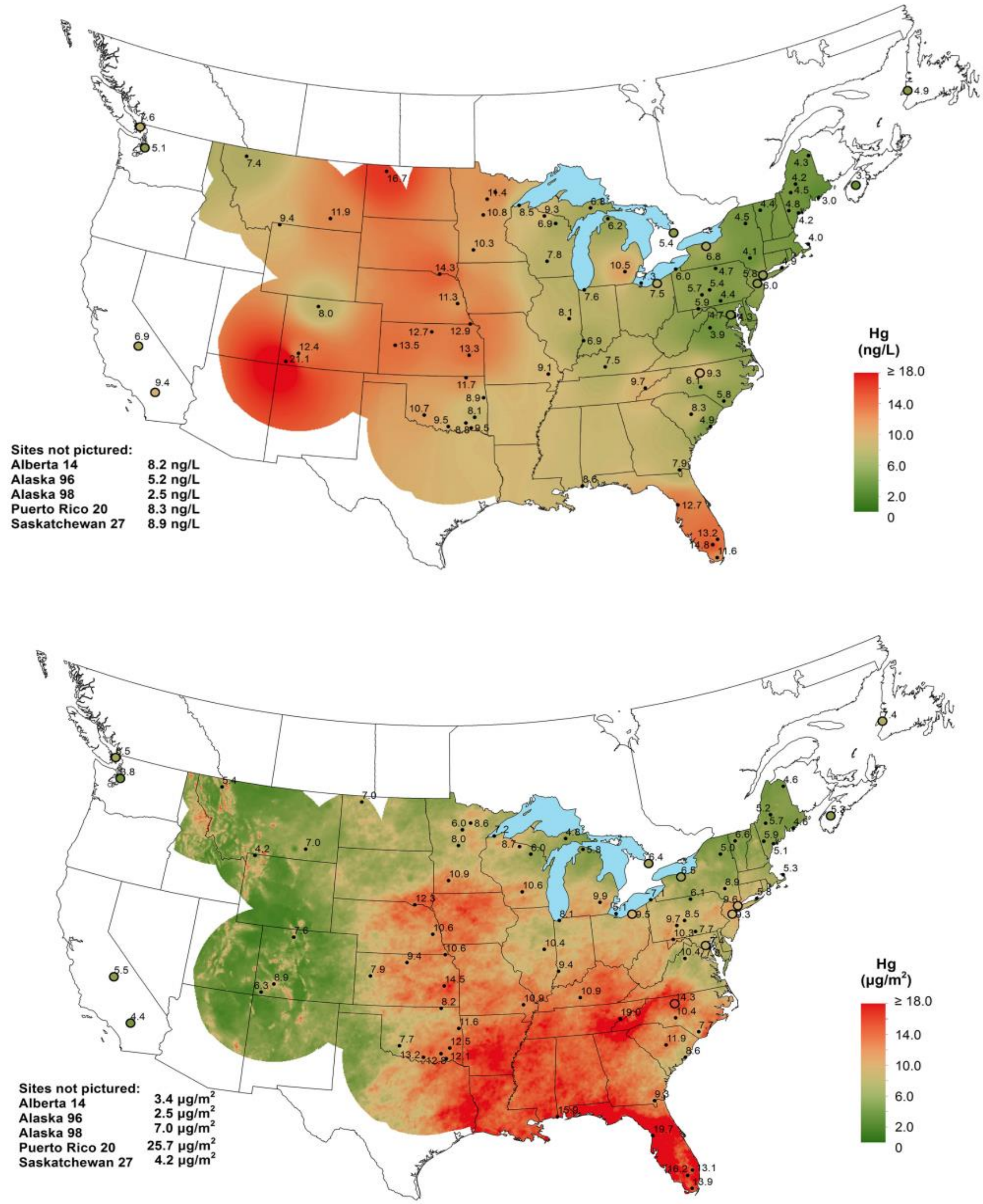

Figure 14. Estimated concentration (top) and deposition (bottom) of mercury in precipitation across the United States in 2018. Mercury concentration varies with the amount of precipitation, and is used to determine pollution sources and other atmospheric possesses. Total mercury deposition is the amount deposited from the atmosphere on the landscape, and is used to assess the consequences on the ecosystem. Source: http://nadp.slh.wisc.edu/lib/data/2018as.pdf

Long Term Trends

Total mercury deposition across the northeast appears to decrease over the 2005-2018 period (Figure 15), although interannual mercury concentration and precipitation volume remain variable.

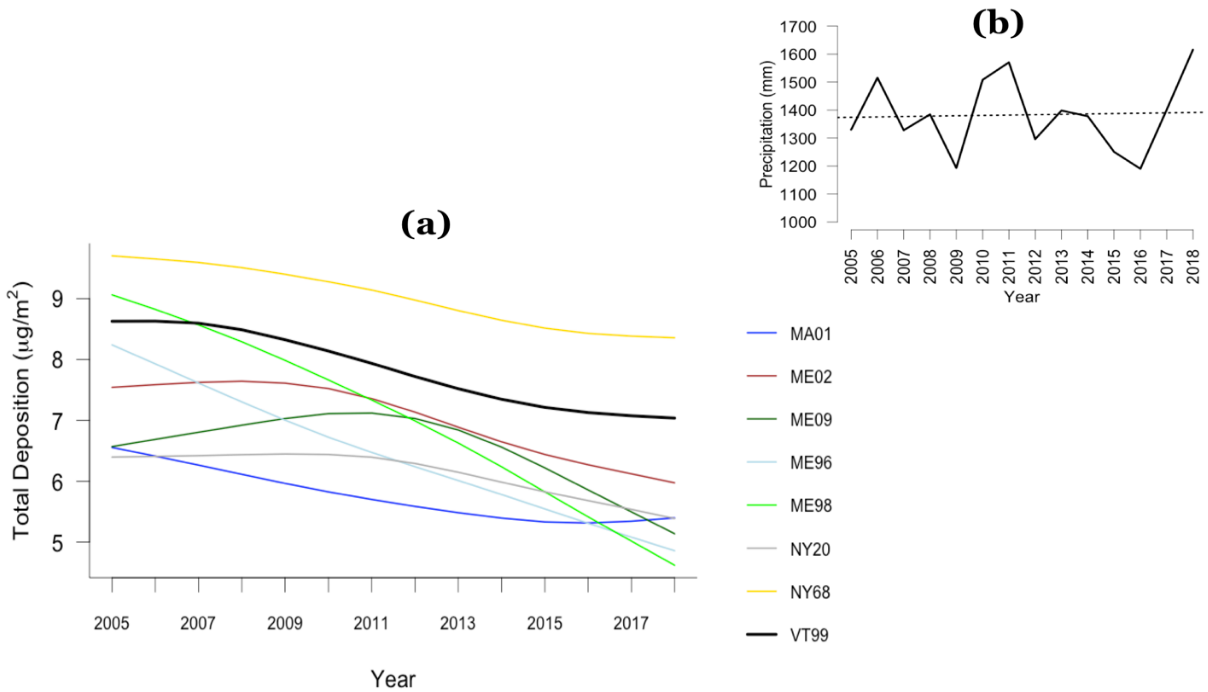

Figure 15 . (a) Total mercury (Hg) deposition (µg/m2) by year for MDN monitoring sites in the northeastern US (Massachusetts, Maine, New York, and Vermont) with comparable years of data collection, displayed as spline-smoothed lines. Inset (b) displays the precipitation (mm) record at the sites, which shows little trend over the same period.

Implications

In the long term, mercury deposition levels decreased dramatically with the implementation of the Clean Air Act Amendments of 1990 (Kamman and Engstrom 2002). However, as we have seen in Vermont, mercury deposition has not continued to decline as expected with other air pollutants.

Historically, sulfur emissions were strongly correlated with mercury emissions because they shared the same primary source -- coal-fired utility boilers -- but with the impressive reduction in sulfate deposition, as a result of improved emissions controls and shut-downs of coal-fired utility boilers, sulfate deposition is no longer well correlated to mercury deposition. In the northeast, mercury concentrations have not continued to decrease as expected. This suggests that the reduced, but ongoing level of mercury deposition in Vermont is no longer associated with regional sulfur emissions and may have other sources.

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 organisms 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 in Vermont as fish advisories continue to be 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 a complex process that is not fully understood.

As of December 2018, the Environmental Protection Agency proposed a change to the Mercury and Air Toxics Standards ("MATS"), which would change the accounting of costs for any required reductions of toxic air pollutants, like mercury, from existing and new coal and oil-fired power plants, opening the rule to new legal challenges. If MATS survives, we should see a continued downward trend in mercury deposition from regional sources in Vermont and the Northeast. It is important to continue monitoring mercury deposition to assess the environmental impacts of changing environmental regulations and pollution sources. Further reduction of mercury emissions, globally and regionally, would likely reduce exposure and bioaccumulation in humans and other species.

In 2018, Vermont experienced another year of below-average maximum concentrations of mercury in the 14-year record. However, Vermont's mercury deposition has not been decreasing as much as expected, highlighting the role of monitoring for identifying regional and global patterns in 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: https://www.healthvermont.gov/health-environment/recreational-water/mercury-fish

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

Project Lead: Bennet Leon Staff Editor: Matthias Nevins

Ozone

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

Ozone foliar damage on Milkweed

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 the 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 2019 data now available, the three-year average design value can be compared to the other sites, which average similarly to, and in-between, the concentrations monitored at Bennington and Underhill.

2018 in Summary

The most recent 2018 4th highest maximum and 3-year average ozone concentrations for Bennington, Rutland, and Underhill are summarized in the table below (Table 3). All of the monitored design values are at or below (i.e. in attainment of) the 70 ppb level of the current primary health standard. Bennington concentration levels for 2018 and the average of the past three years are both higher than the concentration levels measured at the Underhill station (Table 3). Concentrations at the Rutland station remain between the levels reported at the Bennington and Underhill sites.

Table 3. 2018 and 3-Year Average Ozone Concentrations in Northern (Underhill), Central (Rutland), and Southern (Bennington) Vermont. Values are reported in parts per billion (ppb).

	2018 4th Highest 8-hr Maximum	**2016-2018 Avg. 4th Highest 8-hr Maximum**
Underhill	65 ppb	63 ppb
Bennington	70 ppb	70 ppb
Rutland	66 ppb	65 ppb

Long-Term Trends

Long term trends in ozone in northern (Underhill), southern (Bennington), and the recent record for central (Rutland) Vermont are plotted in Figure 16. 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. Bennington has reported ozone concentrations which have been consistently higher than the Underhill site and, recently, the Rutland site as well. Current ozone concentrations (4th highest 8-hour maximum) at the Bennington site are currently at the 2015 the maximum levels, based on the US EPA national ambient air quality standards (NAAQS). Underhill remains below these levels (Figure 16). While the recorded ozone concentrations at two monitoring sites in Vermont appear to indicate a downward trend over the past 30 years, recently, the data show a leveling off of this trend as concentration levels seem to have stabilized.

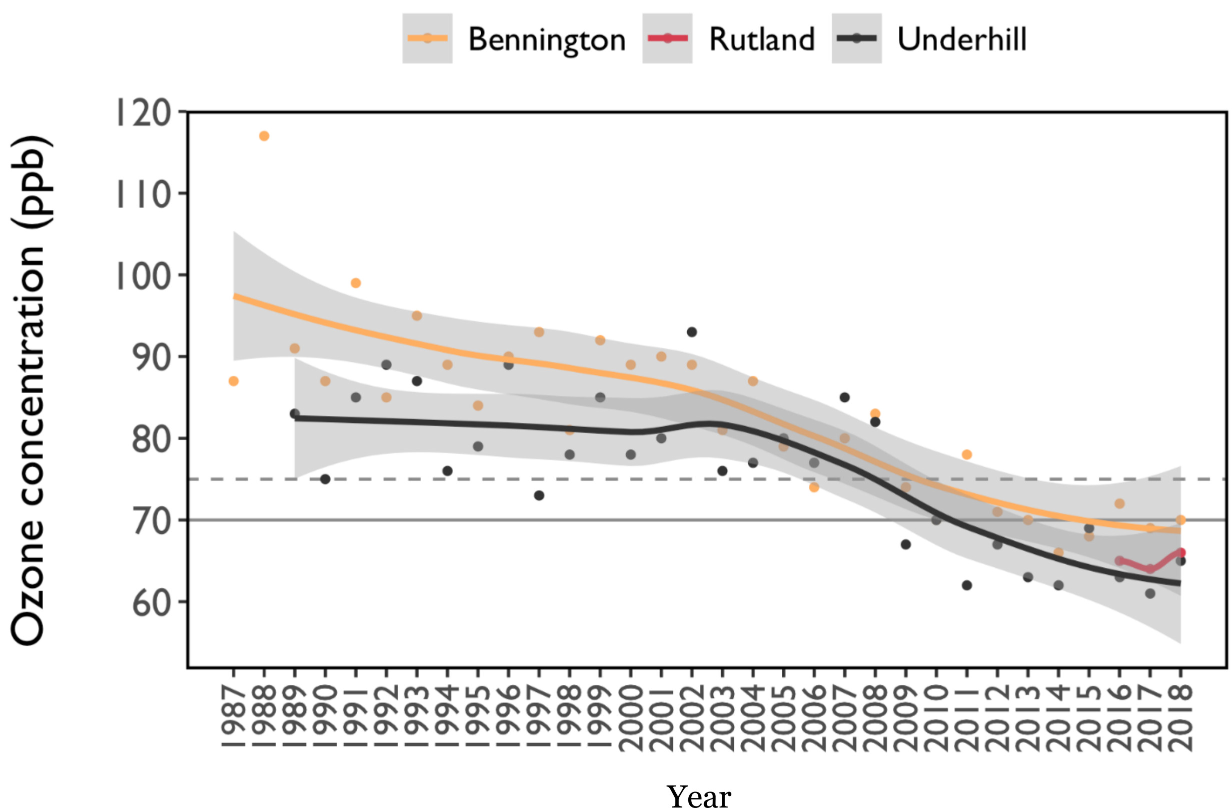

Figure 16. Vermont trends in ozone concentration. Data in the figure above are illustrated for the period 1987 to 2018. Average ozone concentration is shown for the Bennington (yellow line) and Underhill (black line) ozone monitor locations (lines smoothed with LOESS function plus 95% confidence interval in gray shading). Dashed line is 2008 ozone NAAQS levels (75ppb) and solid gray line indicates 2015 ozone NAAQS levels (70 ppb).

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 existing 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.

FEMC Project Database Links

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

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

Climate

Climate Monitoring in Vermont and the Northeast

FEMC operated meteorological station on Mount Mansfield in Vermont.

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[5] (NRCC) provides detailed information on trends in climate and weather for the Northeast. Weather and climate are related but very different phenomena: weather being the condition of the atmosphere (precipitation, temperature, etc.) over the short term, while climate refers to longer-term trends and seasonal patterns. Without long-term weather records it would be impossible to tease out short term (i.e. yearly) anomalies from more ecologically significant climate trends, which makes this information critical to scientists and planners of all kinds. To add temporal and spatial depth to our summary, we summarize trends from a 12-state region (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont and West Virginia) using records from the NRCC. This approach provides a broader picture of emerging trends across a larger region. Much of the following regional summary is adapted, with permission, from the NRCC annual summary[6] .

Vermont Summary

The annual state-wide average temperature for 2018 was less than 1°F above the average for the last 30 years, but lower than the previous two years. 2018 marked a slightly warmer than average winter for Vermont. Summer temperatures in 2018 were slightly above the 30-year average and warmer than the previous two years. Annual precipitation in Vermont for 2018 was approximately 47.28" which was slightly higher than 2017 (46.30") and 1.61" higher than the 30-year average (45.67") (Figure 17).

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

Table 4. Monthly mean temperature (°F) recorded at each weather monitoring station in Vermont during 2018.

Vermont Station	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual*
AVERILL	10.3	20.9	23.8	32.1	53.8	58.4	67.5	65.8	56.7	41.2	26.5	17.6	**39.6**
BARRE MONTPELIER KNAPP STATE AP	17.5	26.4	27.5	36.2	57.1	60.0	69.1	68.6	60.4	44.6	29.6	21.4	**43.2**
BENNINGTON MORSE STATE AP	21.4	31.8	31.7	39.7	61.2	63.2	71.9	71.8	64.6	49.0	35.6	29.5	**47.6**
BRATTLEBORO 3N	20.8	28.7	34.0	41.5	60.7	65.0	73.4	72.9	64.7	49.3	34.8	28.6	**47.9**
BURLINGTON AREA	20.1	30.6	31.0	41.1	61.8	65.9	75.9	74.9	65.8	48.8	33.6	26.5	**48.0**
BURLINGTON INTERNATIONAL AIRPORT	20.1	30.6	31.0	41.1	61.8	65.9	75.9	74.9	65.8	48.8	33.6	26.5	**48.0**
CORINTH	14.7	22.7	27.4	35.0	54.7	60.4	67.0	66.3	59.0	43.9	29.2	20.7	**41.8**
CORNWALL	16.0	26.0	29.6	38.0	59.8	63.9	73.8	72.5	63.8	46.8	32.5	25.2	**45.7**
EAST HAVEN	10.7	19.5	25.5	34.0	53.1	57.7	67.2	67.0	57.9	42.2	26.8	18.4	**40.0**
ELMORE VERMONT	17.0	25.7	28.0	35.7	56.8	60.7	70.2	69.7	61.3	43.8	29.7	19.9	**43.2**
ENOSBURG FALLS 2	14.3	24.3	26.8	37.2	55.3	60.7	71.5	71.0	62.8	45.9	29.4	21.7	**43.4**
ESSEX JUNCTION VERMONT	16.3	29.2	30.9	40.0	60.5	65.4	75.0	73.7	64.6	47.4	33.0	25.9	**46.8**
ISLAND POND	13.3	22.3	25.4	33.8	54.0	59.3	68.4	68.1	60.1	42.9	28.4	19.9	**41.3**
ISLAND POND AP	12.0	16.7	25.1	34.3	53.5	58.9	68.1	67.6	58.8	42.3	27.1	17.1	**40.1**
JOHNSON 2 N	14.2	23.4	27.0	35.0	54.5	59.0	68.5	67.9	59.5	43.0	28.3	20.6	**41.7**
LYE BROOK	15.5	26.7	23.4	35.3	54.9	57.4	66.4	66.6	63.4	33.0	27.8	23.3	**41.1**
MONTPELIER 2	17.0	26.0	30.1	38.3	58.6	63.0	72.7	70.9	60.8	46.7	32.1	23.8	**45.0**
MORRISVILLE STOWE STATE AP	19.8	24.5	26.6	36.6	55.5	59.8	69.2	69.2	56.5	45.1	30.1	19.9	**42.7**
MOUNT MANSFIELD	12.1	20.6	22.3	29.0	53.5	56.1	65.5	63.1	64.6	36.3	24.6	19.1	**38.9**
N SPRINGFIELD LAKE	19.3	27.9	32.3	40.6	59.9	64.0	74.4	73.8	60.5	47.2	33.3	26.4	**46.6**
NEWPORT	12.4	22.7	26.2	35.6	55.3	61.0	70.6	69.9	62.3	43.4	28.2	19.5	**42.3**
NORTH HARTLAND LAKE	16.6	25.1	29.6	37.9	57.8	61.8	70.8	70.0	59.1	45.4	31.2	23.9	**44.1**
NORTHFIELD	18.3	26.4	31.3	37.8	51.8	59.8	70.8	67.4	59.8	49.5	28.4	19.2	**43.4**
NULHEGAN VERMONT	14.3	24.2	28.4	35.3	55.0	59.5	68.4	68.0	59.2	42.8	29.7	24.1	**42.4**
PERU	15.3	26.2	26.6	34.4	56.7	58.9	67.5	67.0	59.8	43.4	29.0	19.6	**42.0**
PLAINFIELD	14.2	21.8	26.9	35.9	54.7	59.7	69.2	68.5	61.6	44.2	41.8	26.6	**43.8**
ROCHESTER	18.1	26.2	29.4	36.8	56.6	60.2	72.2	68.9	62.4	46.1	32.0	27.0	**44.7**
RUTLAND	16.8	26.0	28.9	38.1	57.7	61.2	71.0	69.9	63.0	46.6	33.9	23.6	**44.7**
RUTLAND STATE AP	20.7	30.4	29.8	38.3	60.2	62.4	71.6	71.1	63.6	46.6	31.9	22.1	**45.7**
SAINT JOHNSBURY	18.4	27.0	31.1	39.7	59.1	63.8	72.2	71.5	61.4	47.2	30.4	26.0	**45.7**
SAINT JOHNSBURY ASOS	17.6	25.5	29.6	38.0	57.4	61.8	70.4	69.7	65.3	45.3	33.1	21.4	**44.6**
SOUTH HERO	17.9	27.9	30.2	38.9	60.1	65.4	76.3	74.3	58.5	48.4	28.1	26.5	**46.0**
SOUTH LINCOLN	15.0	24.0	24.7	33.6	54.8	58.4	68.0	66.5	62.8	41.9	32.9	19.4	**41.8**
SPRINGFIELD HARTNESS STATE AP	19.2	27.8	31.4	38.9	59.4	63.0	71.4	71.2	59.5	46.8	34.4	28.2	**45.9**
SUTTON	12.3	21.3	26.7	33.9	54.6	60.0	68.8	68.2	64.1	42.5	34.4	23.6	**42.5**
SWEEZY VERMONT	20.8	31.7	32.1	40.0	60.7	63.0	71.3	71.1	63.2	47.2	31.0	27.5	**46.6**
UNION VILLAGE DAM	15.7	24.3	30.6	38.5	58.6	63.3	72.3	71.3	64.2	46.1	33.3	24.4	**45.2**
VERGENNES	17.5	28.3	31.2	39.4	58.8	63.8	74.5	73.8	60.0	47.8	30.8	24.4	**45.9**
WAITSFIELD 2 SE	19.6	27.9	28.9	36.7	56.5	59.9	69.5	67.8	63.7	44.4	31.5	22.2	**44.1**
WOODSTOCK	16.3	24.1	29.5	38.6	58.8	62.8	71.9	71.2	60.2	46.7	30.2	*NA*	**46.4**
WORCESTER 2 W	15.8	25.5	29.5	37.2	57.0	60.7	70.3	69.2	69.2	44.5	*NA*	*NA*	**47.9**
ALL	**16.5**	**25.6**	**28.6**	**37.0**	**57.1**	**61.3**	**70.7**	**69.8**	**61.8**	**45.0**	**31.1**	**23.1**	**44.1**

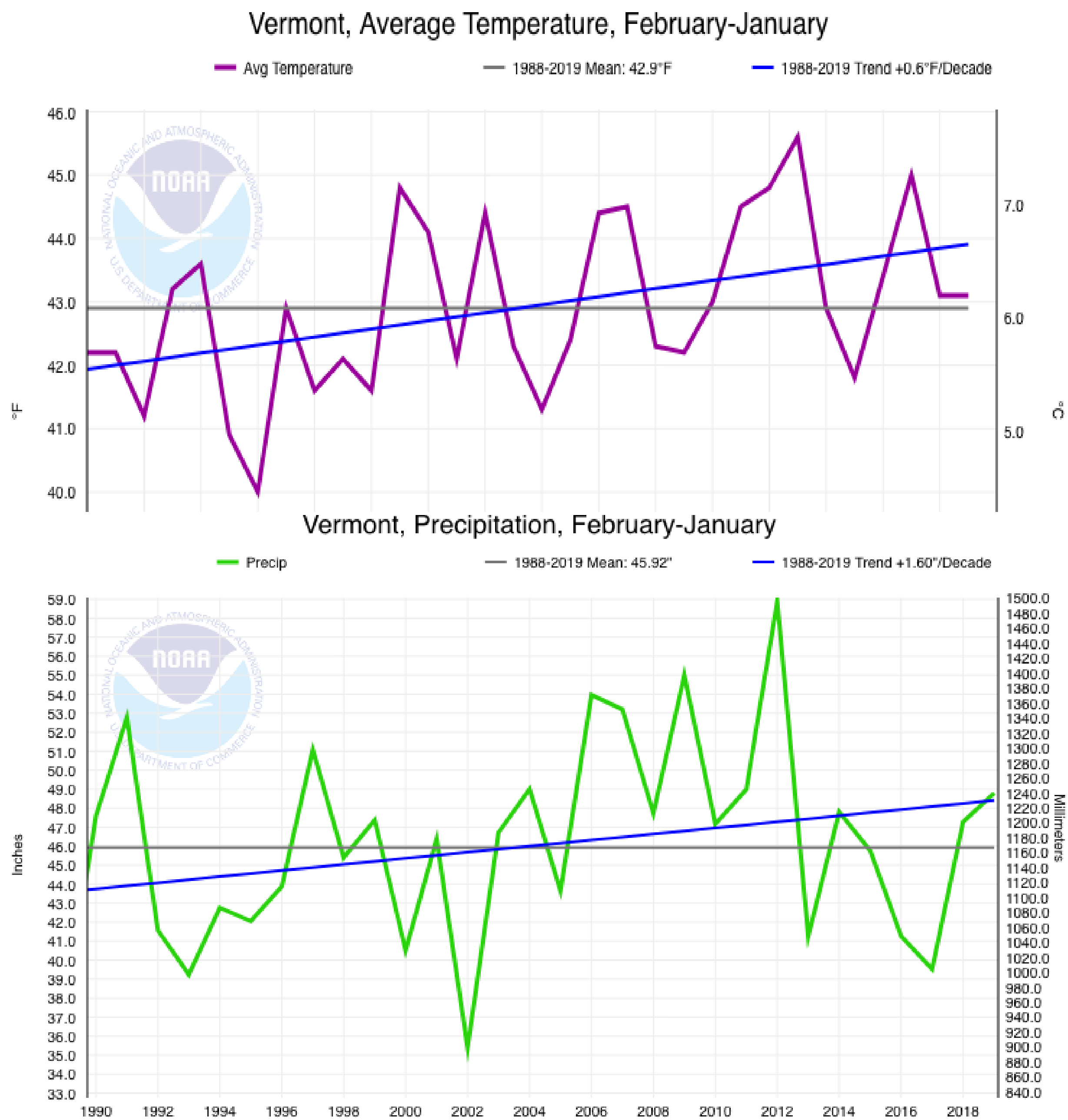


Figure 17. Annual temperature and precipitation for Vermont, with 30-year average and trend. Figure credit: NOAA National Centers for Environmental information. Climate at a Glance: U.S. Time Series, Average Temperature, Precipitation, published October 2019 (http://www.ncdc.noaa.gov/cag/)

Regional Summary

The climate pattern in the Northeast during 2018 is generally one of warmer than normal temperatures (Table 5) with annual precipitation varying from below to above average regionally. The average temperature for the twelve-state Northeast region was 48.1 °F making it the 17th warmest since recording began in 1895. All states had a warmer than average year.

Table 5: Average temperature in 2018 for the 12 states in the Northeast (°F). Table credit: NOAA, Northeast Regional Climate Center at Cornell University.

Monthly/Seasonal Climate Summary Tables

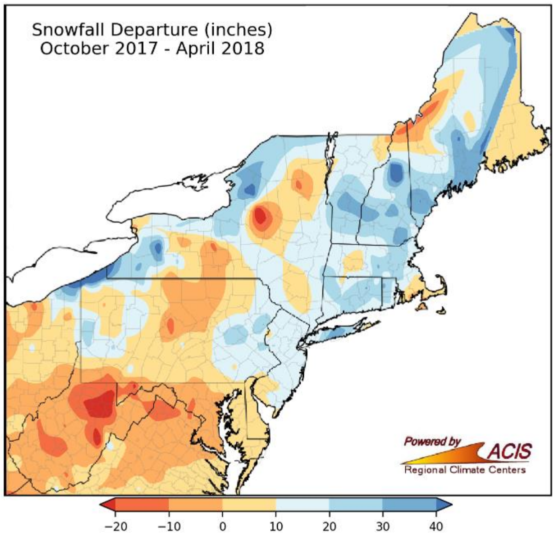
Annual (Jan-Dec) 2018 Temperature Averages (°F)

State	Average	Departure	Rank	Coolest	Warmest
Connecticut	50.7	1.4	114	44.3 in 1904	52.5 in 2012
Delaware	56.8	1.4	115	50.9 in 1904	58.5 in 2012
Maine	41.8	0.5	107	36.5 in 1904	44.6 in 2010
Maryland	55.9	1.1	114	50.6 in 1904	57.5 in 2012
Massachusetts	49.5	1.4	112	43.3 in 1904	51.3 in 2012
New Hampshire	44.5	1.0	112	38.8 in 1904	46.6 in 2012
New Jersey	54.2	1.3	114	47.8 in 1904	55.9 in 2012
New York	46.2	0.7	107	41.1 in 1917	48.8 in 2012
Pennsylvania	49.8	0.9	108	45.2 in 1917	51.8 in 2012+
Rhode Island	51.5	1.5	117	44.8 in 1904	52.9 in 2012
Vermont	43.2	0.7	108	37.6 in 1904	45.9 in 2012
West Virginia	53.3	1.2	113	48.8 in 1917	54.3 in 2012+
Northeast	48.1	0.9	108	43.1 in 1917	50.1 in 2012

Rankings are for the 124 years between 1895 and 2018. 1=coolest; 124=warmest.
Departures are calculated using the 1981-2010 normals.
+ indicates extreme also occurred in one ore more previous years.

The first three months of the year, below normal January temperatures were reported in central and southern New England States, while northern New England states experienced above normal January temperatures. February was the third warmest on record for the region in 2018 (32.1°F, 5.9 °F above normal). On the 20th-21st of February, 2018 twenty weather stations across the region recorded their highest or tied their highest temperatures to date. Spring, summer and fall temperatures varied across the region. August and September were warmer than the observed normal across the entire region.

The above average late summer and early fall temperatures of 2018 shifted in November as an unseasonably cold air mass settled over the region and resulted in some of the coldest November temperatures recorded in the region. Snowfall varied across the region in the beginning of 2018 with New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island experiencing above average snow fall (Figure 18). Snow fall was consistently above average across the region the winter of 2018-2019.



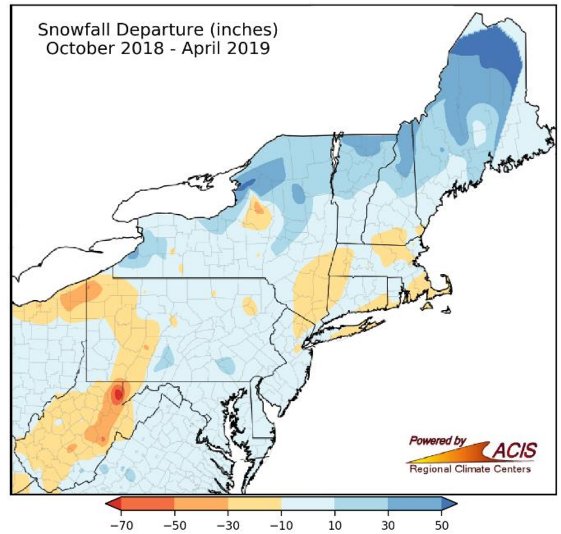


Figure 18. Regional snowfall departure from long-term normal for the winters at the beginning and end of 2018. The winter going into 2019 had more than average snow accumulation across the region, while the winter at the beginning of 2018 was variable across the region. Note the different scales in the two maps. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University.

Rainfall

In 2018 the Northeast experienced the second wettest year on record receiving 56.30 inches, representing a 20% increase from the regional average. The majority of the increased precipitation occurred in the southern states, while the northern states experienced precipitation at or slightly below average (Figure 19). Autumn in the Northeast was the wettest on record with 17.21 inches of precipitation received (45% increase from recorded mean).

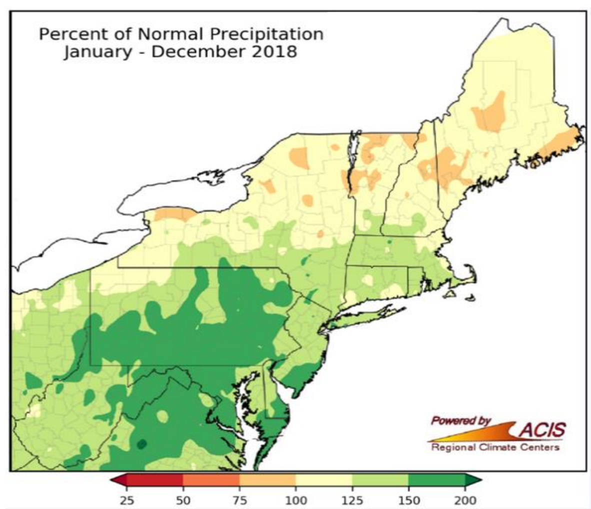


Figure 19. Across the 12 state region, the northeast saw below-average precipitation in 2018. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/monthly/monthly.html)

The above average precipitation was contrasted with drought conditions across the region. Beginning in the early spring in northern New England, drought conditions expanded and intensified as the summer progressed. In July, the U.S. Drought Monitor showed 6 percent of the Northeast in a moderate drought and 27 percent as abnormally dry. These drought conditions persisted through the fall, but the abundant rainfall during November eased drought across the region.

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. The increase in extreme temperatures witnessed in 2018 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).

Variable temperatures may eventually affect phenological adaptations, potentially increasing vulnerability to insects, diseases, and may have an adverse impact on major agricultural crops in Vermont such as apples and sugar maples (Grubinger, 2011; Rustad, 2012).

Acknowledgements

A special thank you to NOAA and Jessica Spaccio from the Northeast Regional Climate Center at Cornell University for the use of their regional data, draft review, and their generous permission to adapt their 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/

NRCC Data Online: http://climod2.nrcc.cornell.edu/

FEMC Weather Database: https://www.uvm.edu/femc/data/archive/project/themes#air+weather

NOAA National Centers for Environmental information, Climate at a Glance: Statewide Time Series, published September 2019, retrieved on October 7, 2019 from https://www.ncdc.noaa.gov/cag/global/time-series/

Trout

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

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.

Brook trout photo by Chesapeake Bay Program.

The Vermont Fish and Wildlife Department 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 2018 at two stations on the West Branch and two stations on Ranch Brook. In 2018 trout population surveys were not conducted at the 1,440' elevation station on the West Branch of the Little River. 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 done July 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, (1) yoy and yearlings and (2) older fish greater than 1 year in age (1++) distinguished by length distribution. The population estimates were standardized to represent number per mile (#/mi) for each age class and summed for the total brook trout population within each station (Table 6). Live brook trout biomass (lbs/acre) was also calculated at each station (Table 6).

Table 6. Population estimate (#/mile) and biomass (lbs/acre) of brook trout for each age class (YOY combined with yearling and older fish (1++)) at each monitoring station in 2018 and compared to the long-term mean (1991-2018). 'Diff' column indicates the difference between 2018 and the long-term mean, with red values showing a decline (one standard deviation away from the long-term mean), blue showing an increase, and no color indicates change that is within one standard deviation of the mean. Note that population estimates were not conducted at the 1440' West Branch Station in 2018.

		lbs/acre			number/mile		
Station	Age Class	2018	Long-term mean	Diff	2018	Long-term mean	Diff
Ranch Brook 960'	*YOY*	0.3	1.1	-0.8	279	954	-675
	1++	10.9	9.4	1.5	837	730.0	107
Ranch Brook 1200'	*YOY*	6.0	1.3	4.7	539	970	-431
	1++	20.2	14.3	5.9	1,509	1,132	377
West Branch Little River 1410'	*YOY*	1.3	1.2	0.1	993	830	163
	1++	14.5	16.3	-1.8	866	971	-105
West Branch Little River 1550'	*YOY*	2.3	2.1	0.2	1574	1525	49
	1++	10.2	12.7	-2.5	442	725	-283

2018 in Summary

In 2018, natural reproduction of brook trout (yoy) decreased at both Ranch Brook stations when compared to 2017 and the long-term mean (Table 6). Natural reproduction at the two West Branch stations increased relative to 2017 and the long-term mean (Table 6). Population estimates for fish older than one year declined at all stations except the 1200' Ranch Brook Station when compared to 2017 estimates. Population estimates varied across stations when compared to the mean population estimates for the entire sampling period (Table 6). The West Branch 1550' station recorded population estimates much lower than the long-term mean, which may be partly due to a change in suitable fish habitat throughout the sampling reach as a beaver pond complex above the station forced a new channel to form within the station. The 1200' Ranch Brook station had modest increases in population compared to the long-term mean (Table 6). Biomass (lbs/acre) estimates were relatively stable across all stations (Table 6). However, the 1200' elevation Ranch Brook station estimates in 2018 were much higher than the long-term mean at this location (Table 6).

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 1760 trout per mile over the 22-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.

Beaver Pond complex immediately upstream of the sampling site on the West Branch of the Little River at 1550 ft.

Annual brook trout yoy production showed clear highs and lows, often consistent across the 4 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 those 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.

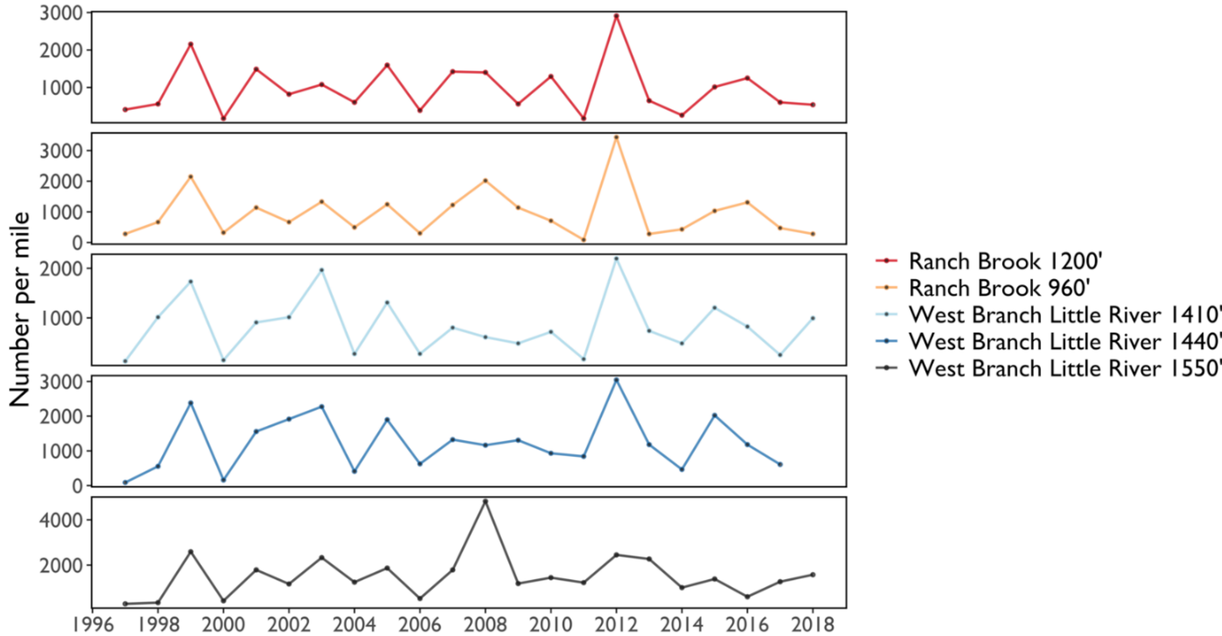


Figure 21. Vermont Department of Fish and Wildlife trout surveys: Young of year (yoy) expressed as number per mile, from 1997 through 2018.

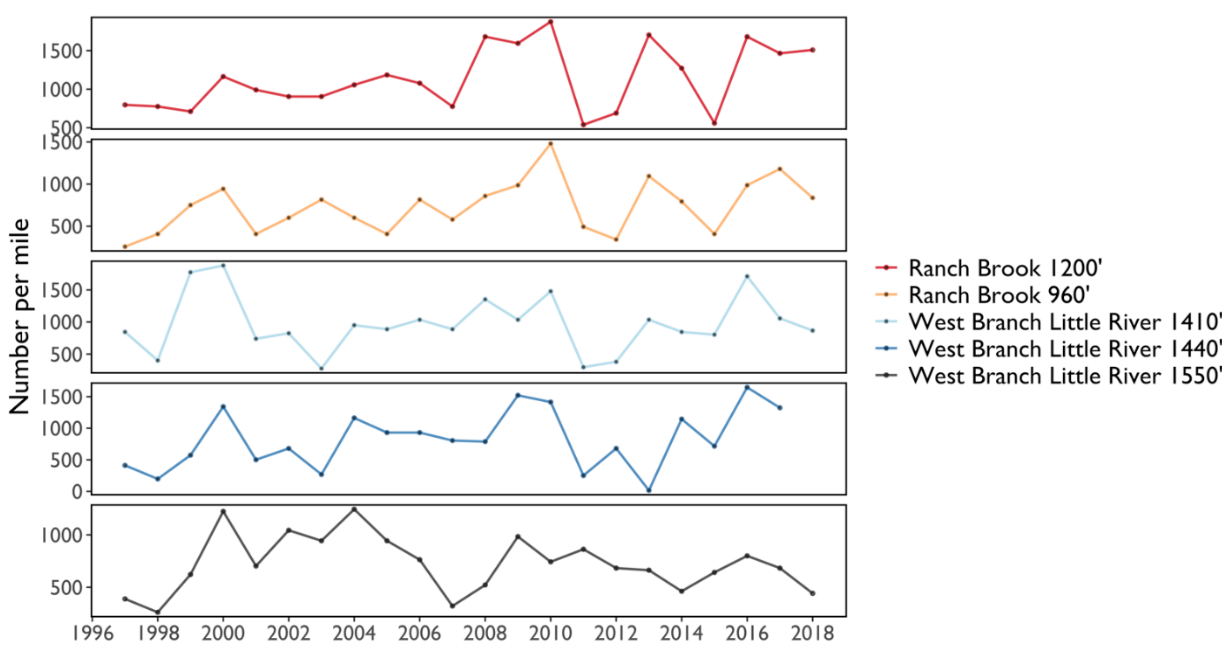
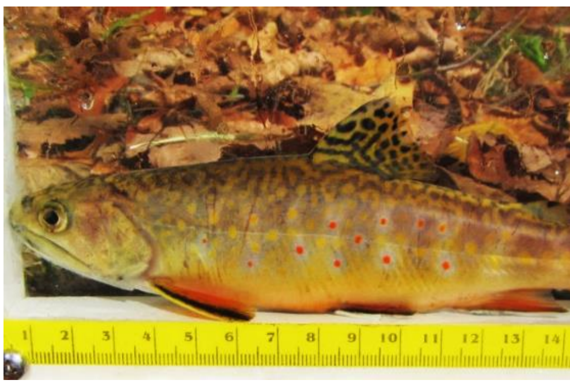


Figure 21. Vermont Department of Fish and Wildlife trout surveys: Yearlings and older fish, expressed as number per mile, from 1997 through 2018.

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 predicted climate change has induced an increase in flood frequency and stream temperatures which does not bode well for brook trout populations.

References

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

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

Bicknell's Thrush (*Catharus bicknelli*).

In 2018, 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 27th consecutive breeding season on the Mt. Mansfield ridgeline. 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.

The Data

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, is performed on the Mt. Mansfield ridgeline.

Demographic monitoring uses mist-netting and banding techniques at an established study plot on the Mt. Mansfield ridgeline between 1155-1190 m (3800-3900 ft) elevation. Every year, typically between the end of May and the beginning of August, 10–30 nylon mist nets are placed at sites that have been used annually since 1992. Each captured individual is fitted with a uniquely-numbered leg band and the appropriate data related to age, sex, breeding condition, and bird health are recorded. Other standard metrics including wing chord, tail length, weight, and tarsal length are also recorded. Additionally, a small blood sample was obtained from Bicknell's Thrushes for long-term monitoring of mercury burdens.

Breeding bird surveys were also 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 five-point count stations. Survey methods include unlimited distance point counts, based on the approach described by Blondel et al. (1981) and used in Ontario (Welsh 1995). Counts begin shortly after dawn on days where weather conditions are unlikely to reduce count numbers. Observers record all birds seen and heard during a 10-minute sampling period, divided into 2-, 3-, and 5-minute intervals.

2018 in Summary

Demographic work using netting and banding methods continued in 2018 along the Mt. Mansfield Ridgeline for the 27th consecutive season. In 2018, there were a total of 431 mist net captures, which comprised of 321 individuals of 30 species, including 275 new bandings, 48 returns from previous years, and 54 within-season recaptures.

Point count surveys at the mid-elevation, northern hardwood study sites at Underhill State Park and Lye Brook Wilderness showed similar species composition, with a total of 51 and 49 species detected over all survey years, respectively. In 2018, the number of individual birds and species richness increased at both UNSP and LBWA, although the long-term trends for both of these metrics continue to decline (Figure 22).

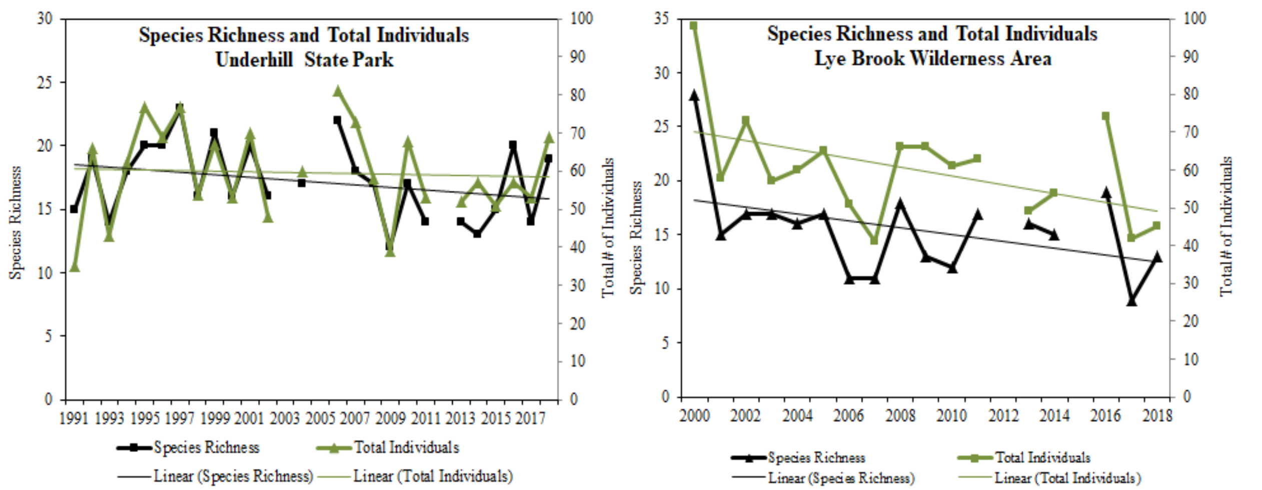


Figure 22. Annual totals and trends for species richness (black lines) and total number of individuals (green lines) detected at Underhill State Park, 1991 – 2018, and Lye Brook Wilderness Area, 2000-2018.

Long-term Trends

Mt. Mansfield Ridgeline – In 2018 there were 431 bird captures comprising 321 individuals of 30 species, including 275 new bandings, 48 returns from previous years, and 54 within-season recaptures. Blood samples were collected from 23 Bicknell's Thrushes, as part of our long-term monitoring of avian mercury burdens on Mt. Mansfield. Anthropogenic input of mercury into the environment has elevated risk to fish and wildlife, particularly in northeastern North America. Recent sampling of Bicknell's and Swainson's Thrush (2014–2017) allowed for a comparison of blood mercury burdens in these two thrush species. Combining thrush data with atmospheric wet mercury deposition data collected at the Proctor Maple Research Lab (PRML) from 1993–2016, the Vermont Center for Ecostudies published a peer-reviewed paper in *Ecotoxicology* during 2019 (Rimmer et al. 2019). Among its findings, this publication documented (1) no differences in blood mercury concentrations between the two thrush species, (2) no detectable changes in Bicknell's Thrush blood mercury burdens from 2000–2017, and (3) no relationship between atmospheric deposition at PMRL and thrush blood mercury concentrations.

Underhill State Park – Total number of individuals and species richness increased from 2017, with 69 individuals of 19 species recorded, including six Dark-eyed Juncos, the most in the count's history. Among the nine most common species, six were above the 27-year mean, and three were below. Overall, counts of Black-throated Blue Warbler and Hermit Thrush were the same as 2017, continuing the relatively flat long-term trend

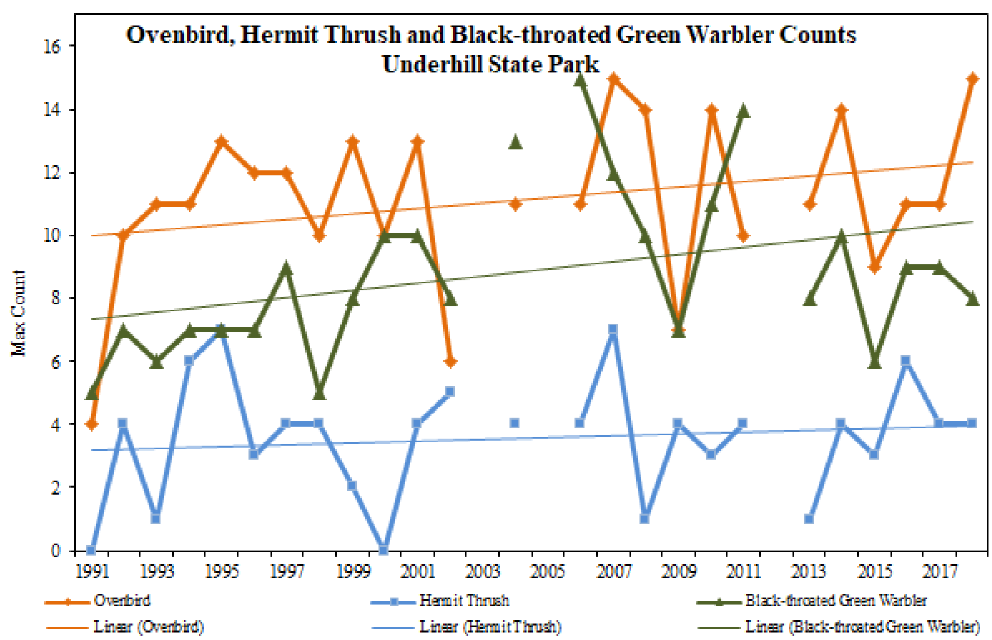


Figure 23. Twenty-six year data and trends for Ovenbird, Hermit Thrush, and Black-throated Green Warbler from annual surveys conducted at Underhill State Park, 1991-2018.

for Hermit Thrush, Vermont's State bird (Figure 23). Additionally, the number of Ovenbirds increased to 15 individuals, matching the site's highest count from 2007, while the count of Black-throated Green Warblers dropped slightly (Figure 23). These results echo the broader, 25-year trends observed for these three species in the state-wide 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 2018, although this species is declining at a rate of 3.93% annually (r^2 = 0.604) and shows the strongest decline among the nine most commonly detected species.

Lye Brook Wilderness Area – Both relative abundance and species richness rebounded slightly in 2018, after reaching near-record or record lows, respectively, in 2017 (Figure 24). Among the nine most common species, six were below the 17-year mean, with only Red-eyed Vireo, Blue Jay, and Ovenbird above the long-term average. The count of Black-throated Blue Warblers dropped for the second consecutive year in 2018, continuing the species' moderate decline (-2.18% per year, r^2= 0.225) (Figure 24). However, Red-eyed Vireo numbers remained stable, continuing a strong upward trend that increased by 5.37% annually (r^2= 0.277) (Figure 24), mirroring the significant state-wide trend exhibited by VCE's 25-year study (Faccio et al. 2017).

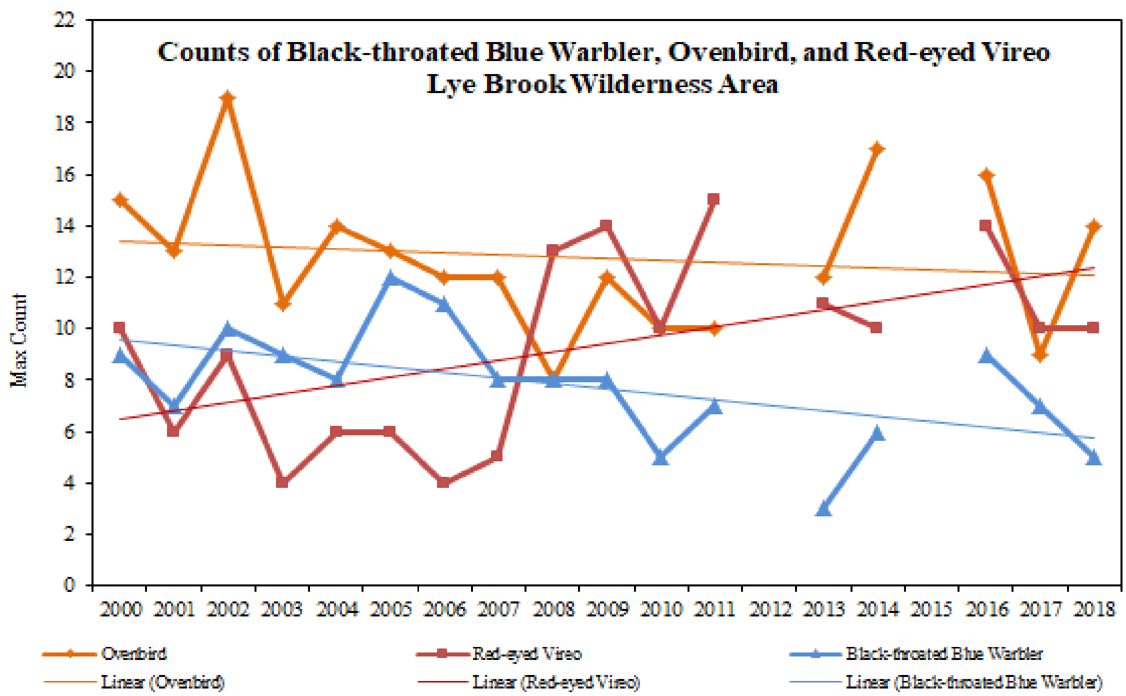


Figure 24. Twenty-six year data and trends for Black-throated Blue Warbler, Ovenbird, and Red-eyed Vireo from annual surveys conducted at Lye Brook Wilderness area, 1991-2018.

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 state-wide 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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Rimmer, C. C., J. D. Lloyd, K. P. McFarland, D. C. Evers, and O. P. Lane. 2019. Patterns of blood mercury variation in two long-distance migratory thrushes on Mount Mansfield, Vermont. *Ecotoxicology*. https://doi.org/10.1007/s10646-019-02104-3

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

Additional Resources

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

FEMC Project Database Links

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

Amphibians

Amphibian Monitoring on Mt. Mansfield

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 New England.

Wood Frog (*Lithobates sylvaticus*) is a common amphibian on Mt. Mansfield.

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 most eventually fall into a bucket buried along the fence. Lids are removed from the buckets in the afternoon when rain is forecast, and the captured amphibians are identified, counted, examined, and released the following day.

2018 in Summary

Overall, the total number of salamanders and frogs detected per trapping was considerably lower than last year, but still above the average total number detected over the entire study period. Numbers were neither the highest nor were they the lowest for any species this year.

Spring salamander (*Gyrinophilus porphyriticus*) is associated with cold, clean, streams on Mt. Mansfield.

In 2018, the usual five caudate (salamander) species were caught as adults (Table 7).They are Spotted Salamander (*Ambystoma maculatum*), Northern Dusky Salamander (*Desmognathus fuscus*), Northern Two-lined Salamander (*Eurycea bislineata*), Eastern Newt (*Notophthalmus viridescens*), and Eastern Red-backed Salamander (*Plethodon cinereus*). We did not catch any adult Spring Salamanders (*Gyrinophilus porphyriticus*) in 2018; this is a species that we have only caught 11 of in our 23 trapping seasons. The young of four of these species (Spotted Salamander, Eastern Newt, Northern Two-lined, and Eastern Red-backed Salamander) were also caught.

Adults of five of our normally trapped anurans (frogs) were caught in 2018. The species that were trapped are American Toad (*Anaxyrus americanus*), Spring Peeper (*Pseudacris crucifer*), Green Frog (*Lithobates clamitans*), Pickerel Frog (*Lithobates palustris*), and Wood Frog (*Lithobates sylvaticus*). No Gray Tree frog (*Hyla versicolor*) were captured. Juvenile Wood Frogs were abundant (41). There were a few young Green Frogs (22), only one young Spring Peeper, and no young Pickerel Frogs or American Toads (Table 7).

Figure 25. Spotted Salamander (*Ambystoma maculatum*) with an adventitious tail. Captured in 2018.

The number of abnormalities continues to be low, with only one abnormality detected in 2018 out of 450 animals captured. On Oct 12, 2018 a Spotted Salamander was found with an adventitous tail (Figure 25).

Table 7. Monitoring results from drift fences on Mt. Mansfield in 2018.

Common name	*Scientific name*	#of all ages	#of young of the year	% young of the year
Caudates (Salamanders)				
Spotted salamander	*Ambystoma maculatum*	35	7	20%
N. Dusky Salamander	*Desmognathus fuscus*	10	0	0%
N. Two-lined Salamander	*Eurycea bislineata*	8	3	38%
Spring Salamander	*Gyrinophilus porphyriticus*	0	NA	NA
Eastern Newt	*Notophthalmus viridescens*	26	6	23%
E. Red-backed Salamander	*Plethodon cinereus*	127	1	1%
	Group totals	**206**	**17**	**8%**
Anurans (Frogs)				
American Toad	*Anaxyrus americanus*	26	0	0%
Green Frog	*Lithobates clamitans*	34	22	65%
Pickerel Frog	*Lithobates palustris*	1	0	0%
Wood Frog	*Lithobates sylvaticus*	150	41	27%
Spring Peeper	*Pseudacris crucifer*	15	1	7%
	Group totals	**226**	**64**	**28%**
Amphibian totals		***432***	***81***	***19%***

Long Term Trends

The total number of suitable nights to open the drift fence was low in 2018. This resulted in lower total numbers of animals captured relative to 2017.

Northern Two-lined Salamander (*Eurycea bislineata*) is associated with streams on Mt. Mansfield.

Populations of Spring Peeper had declined through 2010 (Figure 26). While this species rebounded in 2016 and 2017, 2018 capture numbers were down slightly but still suggest a recovery. Eastern Red-backed Salamander population indices show a continued and dramatic increase over the length of the study while Eastern Newt has declined slightly. Spotted Salamander populations remain fairly stable with a very slight recent increase (Figure 27).

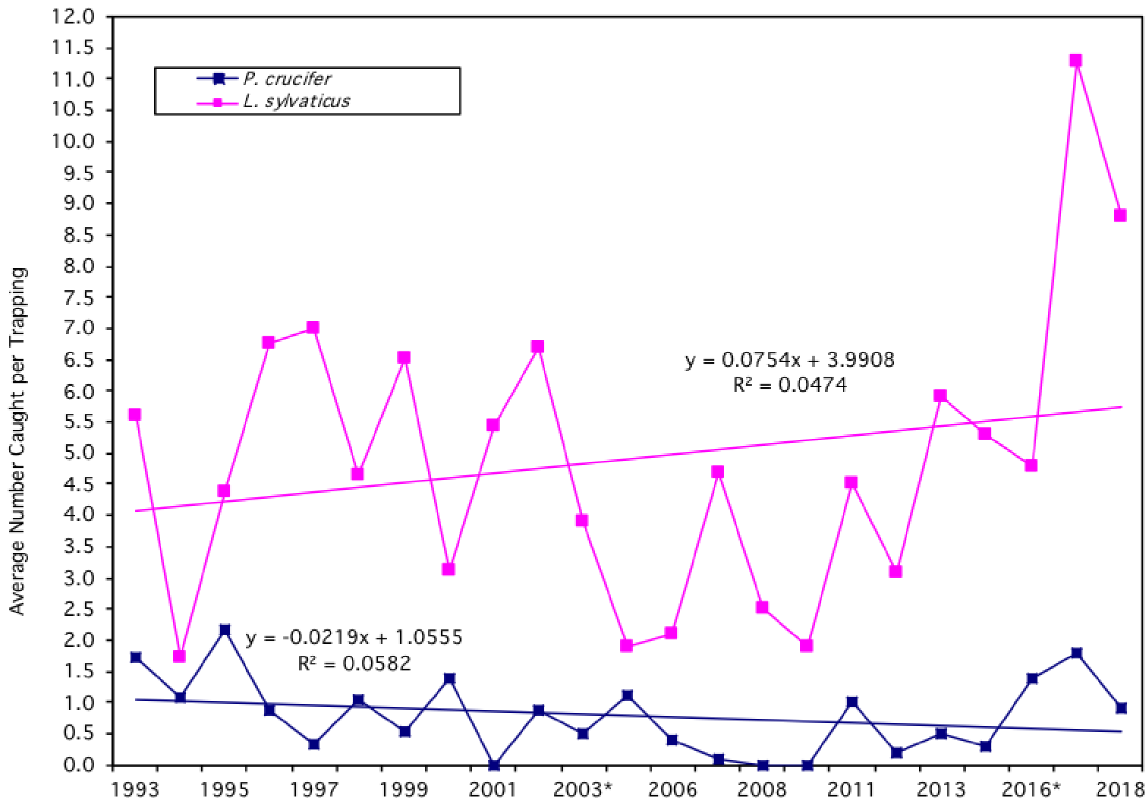


Figure 26. Wood Frog (*Lithobates sylvaticus*) and Spring Peeper (*Pseudacris crucifer*) population indices from 1993-2018 from Mt. Mansfield, Underhill, Vermont.

Populations of American Toad, and Wood Frog have increased over the study period. Green Frog populations remain stable, with the exception of 2002 when there was a large increase in the young of the year.

Beginning with the 1995 report, we began documenting the number of young of the year (YOY). In 2018, young of the year made up 19% of those caught (Table 7).Over the course of the entire study (1995 – 2018) the average percentage of young of the year of total catch was 27.1%. Since the study's inception, the young of the year have varied from 11% (2014) to 74% (2002).

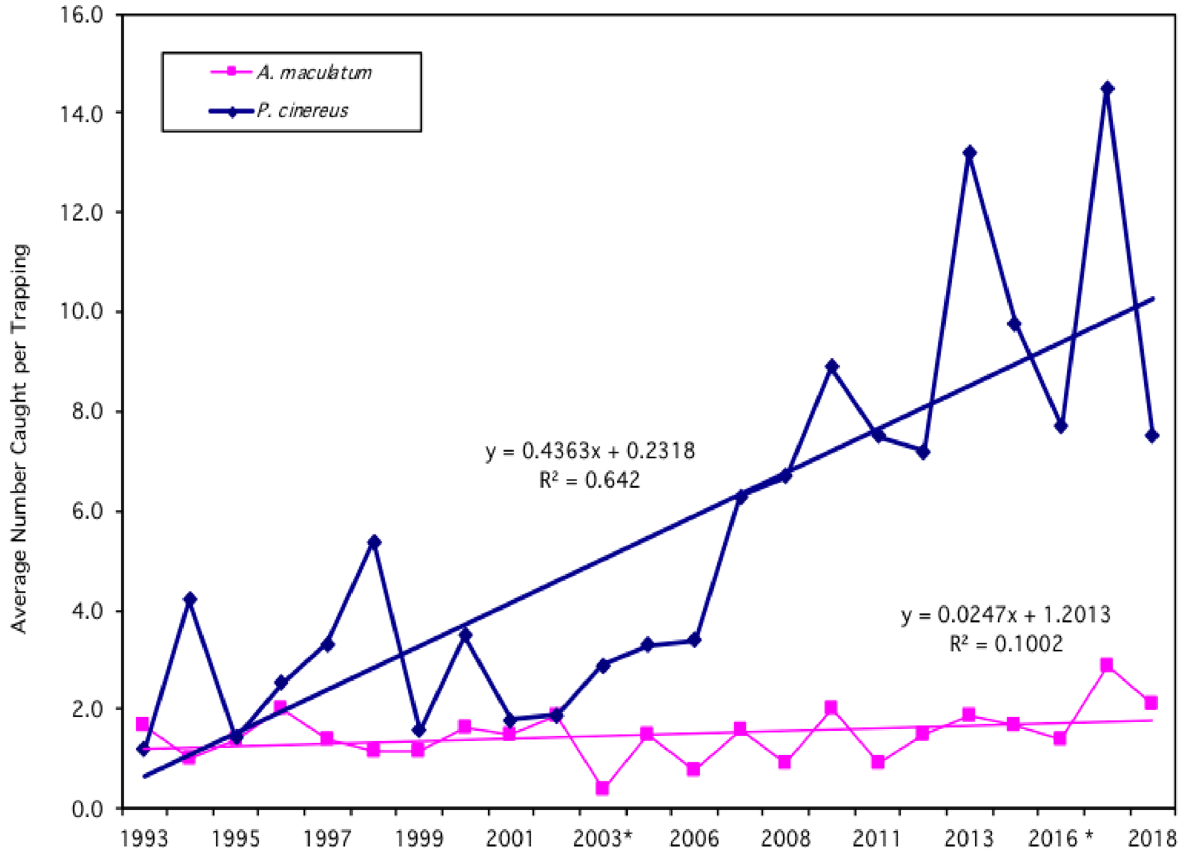


Figure 27. Spotted Salamander (*Ambystoma maculatum)* and Eastern Red-backed Salamander (*Plethodon cinereus*) population indices from 1993-2018 from Mt. Mansfield, Underhill, Vermont.

Implications

The data collected through amphibian monitoring on Mt. Mansfield and statewide through The Vermont Reptile and Amphibian Atlas have been used to provide conservation information to private individuals, companies, organizations, and governmental units. These data serve as the basis for status and conservation advice to the Vermont Endangered Species Program; management recommendations for biologists from the Green Mountain and Finger Lakes National Forest, private foresters, private landowners, and the Vermont Department of Transportation. Many species benefit from management and conservation measures for these species. The continuing decline of several species of reptiles and amphibians in Vermont and the apparent extirpation of the Boreal Chorus Frog (*Pseudacris maculata*) remain a cause for concern.

The long-term decline in Spring Peeper numbers on Mt. Mansfield bottomed out in 2010 and populations appear to be recovering. Eastern Red-backed Salamanders continue a dramatic increase in numbers on the western slopes of Mt. Mansfield.

Additional Resources

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

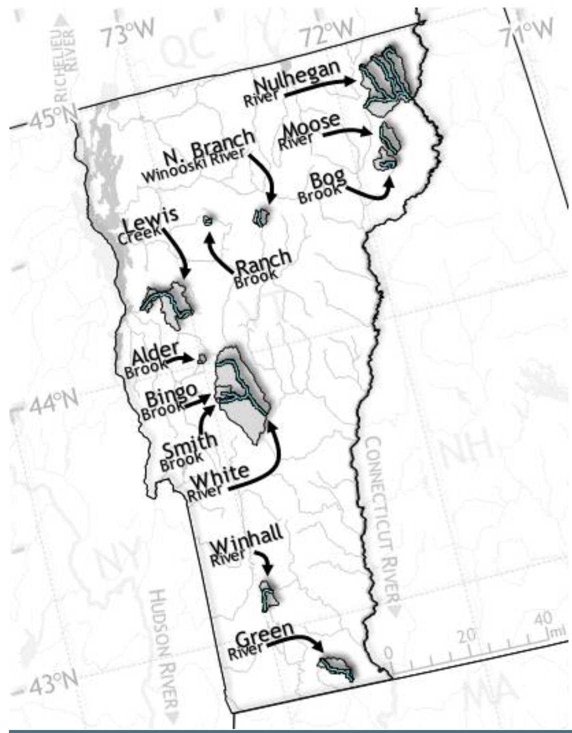
FEMC Project Database Link

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 (VTDEC) conducts long term monitoring at twelve "sentinel" streams in Vermont. These reference streams are widely variable in terms of size (4.6-510 km^2), elevation (34-589 m) and geographical separation. Most are in watersheds that have substantial protected lands, such as Green Mountain National Forest or Vermont Wildlife Management Areas, and all but one has a watershed with greater than 90% combined forest and wetland (based on 2016 land use/land cover data, Table 8). Six 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).



Location of VTDEC sentinel streams (Table 8).

By focusing on streams with negligible prospects for development or land use change, VTDEC hopes to be able to isolate long term impacts related to climate change. Many of these streams have monitoring data going back to the 1990's, and all are currently being monitored on an annual basis for water chemistry, physical habitat, water temperature, and macroinvertebrate community condition. Many of these sites are also being monitored for stream discharge, air temperature, and fish community composition. Through this work, VTDEC seeks 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 streams is Ranch Brook in Stowe, VT. With a drainage area of 10 km^2 and an elevation of 381 m, it is one of the smallest and most pristine sentinel streams. Ranch Brook has annual macroinvertebrate community data, and a continually operated stream gage that has been collecting data since 2000, and has served as a focal point for early analyses on the VTDEC sentinel network.

Table 8. Geographical information and 2018 land use/land cover data for sentinel streams

Stream	Macro-invertebrate Stream Type*	Town	Drainage Area (km^2)	Elevation (m)	% Open Water/ Wetland	% Forest	Hydrologic Gaging Record	Temperature Monitoring Record**
Ranch Brook[+]	**SHG**	**Stowe**	**9.9**	**381**	**0.0**	**98.9**	**USGS (2000)**	**A (2018), W (2015)**
Smith Brook	SHG	Rochester	4.6	589	0.0	100.0		A (2018), W (2008)
Bingo Brook[+]	SHG	Rochester	23.5	343	0.1	98.8	VDEC (2015)	A (2018), W (2008)
North Branch Winooski River[+]	MHG	Worcester	28.8	293	5.1	93.2	VDEC (2018)	A (2018), W (2013)
Winhall River[+]	MHG	Winhall	46.6	455	13.1	86.4		A (2018), W (2008)
Moose River[+]	MHG	Victory	58.5	398	1.2	97.3	VDEC (2014)	W (2013)
Green River[+]	MHG	Guilford	65.9	192	2.6	88.5	USGS (1990)	W (2012)
White River	MHG	Stockbridge	510	219	1.1	92.9		W (2011)
Lewis Creek	WWMG	Ferrisburgh	208	34	8.3	62.6	USGS (1990)	A (2018), W (2009)
Nulhegan River	WWMG	Bloomfield	352	273	10.8	87.8		W (2009)
Alder Brook	HLG	Ripton	7.2	408	3.9	94.0		A (2018), W (2016)
Bog Brook	SLG	Victory	48.0	344	7.3	90.5		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

VTDEC biologists collect macroinvertebrate community samples from stream reaches during an annual index period that runs from September 1st through mid-October. Utilizing this relatively short period of time allows for insects and other invertebrates to be captured at comparable sizes and life stages each year. Samples are sorted and identified in the laboratory, and biologists use population data, as well as several 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. VTDEC 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). Ratings of *Very Good* to *Excellent* represent communities at or near the expected natural condition. In addition to assessment ratings, this report focuses 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. Previous analyses at sentinel sites show 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).

Climate change is predicted to cause increased average air temperatures and an increase in the frequency of heavy precipitation events (Henson 2019, Easterling et al. 2017). In turn, it is expected that this will lead to warmer stream temperatures and more variability in discharge, including drought conditions and increased extreme flow events. In addition to annual information on macroinvertebrate community health, a primary focus at sentinel streams has been the collection of temperature and hydrological data. Several sentinel sites have been co-located with USGS gauging stations, and VTDEC has installed stream gages on several others. VTDEC biologists have also begun to use time-lapse cameras to help 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, in addition to riparian air temperature at ten locations.

2018 in Summary

Figure 28 shows the 2018 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); VTDEC 2017) in Vermont streams are also displayed. Results from Ranch Brook include samples taken at both the beginning and end of the 2018 fall index period.

Representative larvae of the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies).

Assessment ratings and metric values at sentinel sites are generally well above the minimum VTDEC thresholds for a robust and healthy community, and their similarity to statewide averages shows the overall high quality of streams throughout Vermont. However, higher assessment ratings of *Very Good* or better are generally indicative of communities at or near reference condition, and macroinvertebrates at four sentinel sites failed to meet this benchmark in 2018. Of these, the communities at the Green River and Moose River did not meet the richness values needed for higher assessment levels, and the Moose River and Winhall River had slightly elevated Biotic Index scores.

It appears that there may have been an overall decline of some metrics in 2018, compared to the previous year, most notably Biotic Index (9 of 12 sites). It has been speculated that this may have been due to very low flows as a result of summer drought-like conditions in many areas of Vermont. Stream flow data from Ranch Brook demonstrates this pattern (Figure 29). In the three months leading up to the index period, there were very few high flow events, and base flows were less than what was seen in recent years. Very low flows can lead to degraded water quality and habitat conditions, which in turn can decrease both insect densities and the proportion of sensitive taxa (Boulton & Lake 2008). While Ranch Brook has only recently begun being monitored for water temperature, data from other streams (like the Nulhegan River; Figure 30) show generally higher temperatures in the summer of 2018 when compared to other recent years.

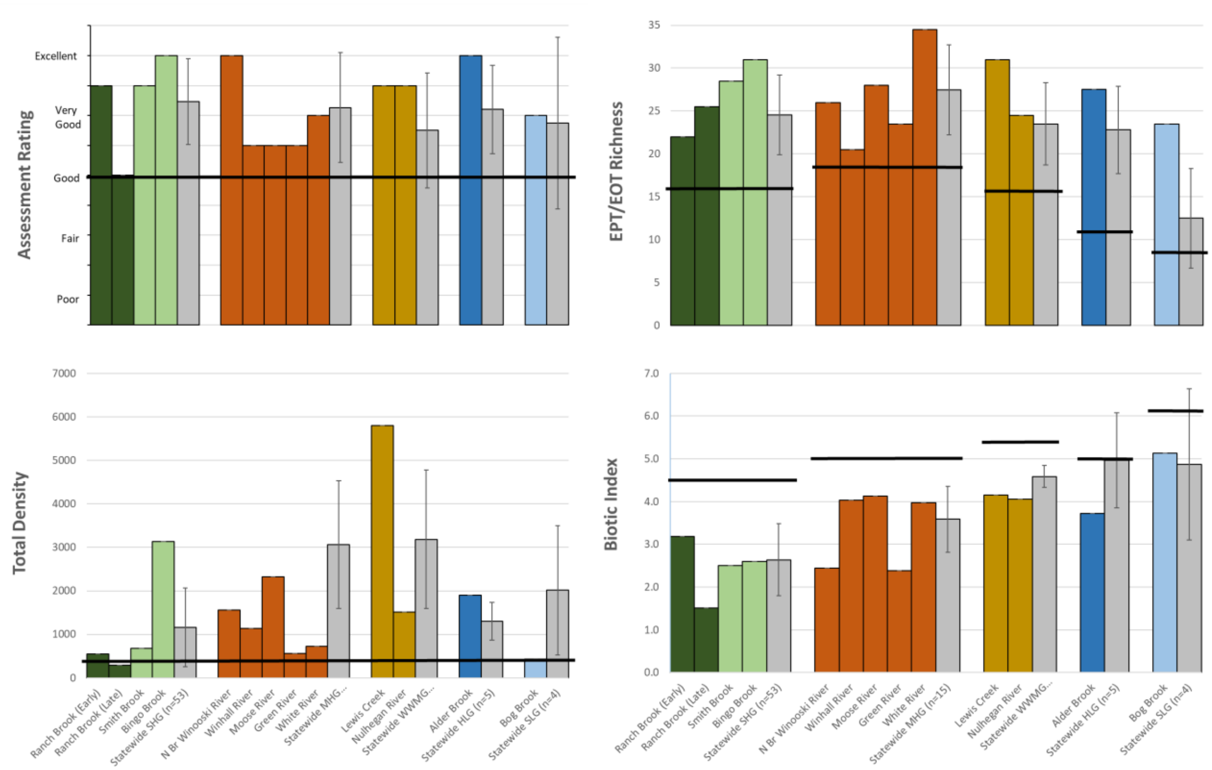


Figure 28. 2018 assessment ratings and scores for three key biological metrics used to assess community health. Sentinel sites are grouped by stream type, and compared to streams from throughout the state. Horizontal black bars represent DEC's minimum acceptable thresholds.

Ranch Brook, which has served as the primary case study for sentinel stream monitoring, received assessment ratings of *Very Good/Excellent* and *Good* for its two community samples in 2018. The decrease in assessment rating was a result of a change in macroinvertebrate density over that time period. Density was found to be moderate when sampled at the beginning of September (522 organisms/m^2), which is common for small, low productivity streams, but was just below the minimum threshold of 300 per square meter when sampled in mid-October. It is believed that this may have been the result of a series of high flow events (following the previously mentioned low flows) in the two weeks leading up to the October sampling event, causing some of the organisms to be scoured from the substrate (Figure 29). EPT richness in the Ranch Brook samples (22 and 26, respectively) was still significantly higher than the minimum criteria (16) for small high gradient streams, suggesting that the loss of organisms did not significantly affect diversity.

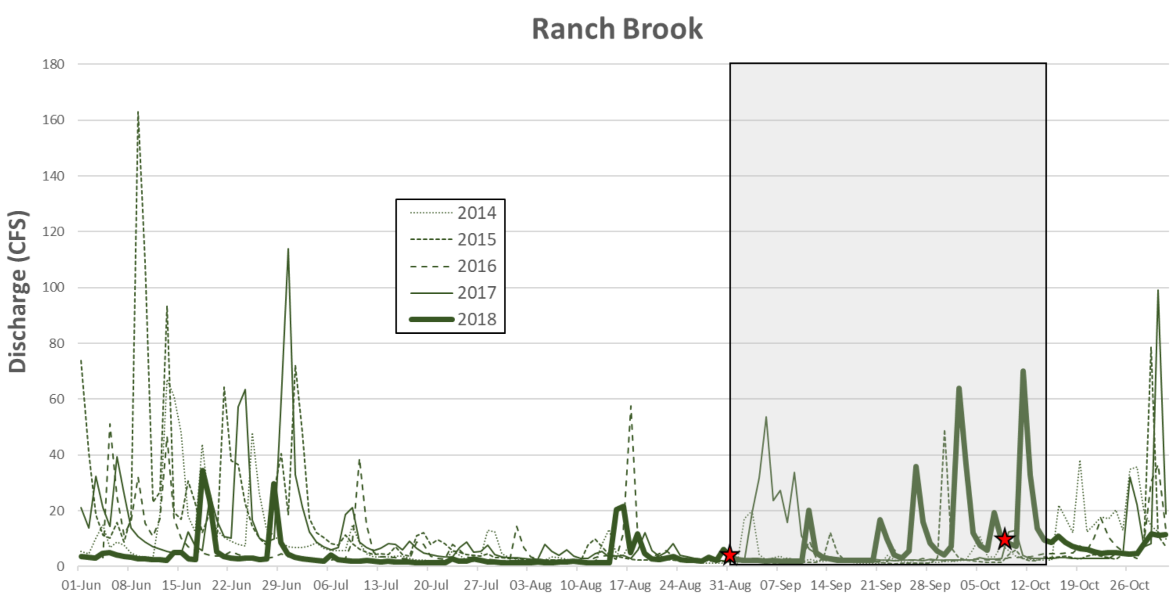


Figure 29. Discharge profiles for Ranch Brook from June 1st – October 31st over the last five years. The shaded area represents the VDEC fall index period for macroinvertebrate data collection (September 1st through October 15th). The red stars show the 2018 sampling dates.

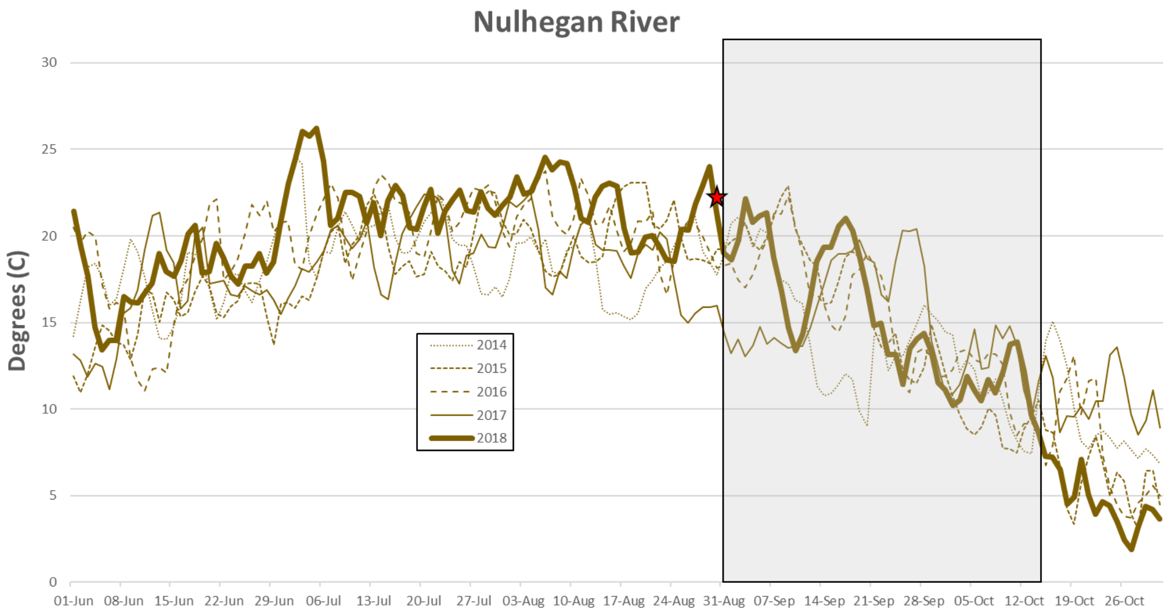


Figure 30. Stream temperature profiles for the Nulhegan River from June 1st – October 31st over the last five years. The shaded area represents the VDEC fall index period for macroinvertebrate data collection (September 1st through October 15th). The red star shows the 2018 sampling date.

Long Term Trends

Photograph of Bridge 19 in Rochester, VT after Tropical Storm Irene. (VT Department of Transportation, 2011)

While several sentinel sites were added by VTDEC 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 31). Through this dataset, VTDEC hopes to be able to observe any emergent trends that may be related to climate change or other large-scale environmental 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. 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.

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, Biotic Index, and distribution of feeding groups. This trend has appears to have stabilized with less extreme flow events over subsequent years, though October 2018 densities at Ranch were again lower than expected, likely due to corresponding precipitation and high flows.

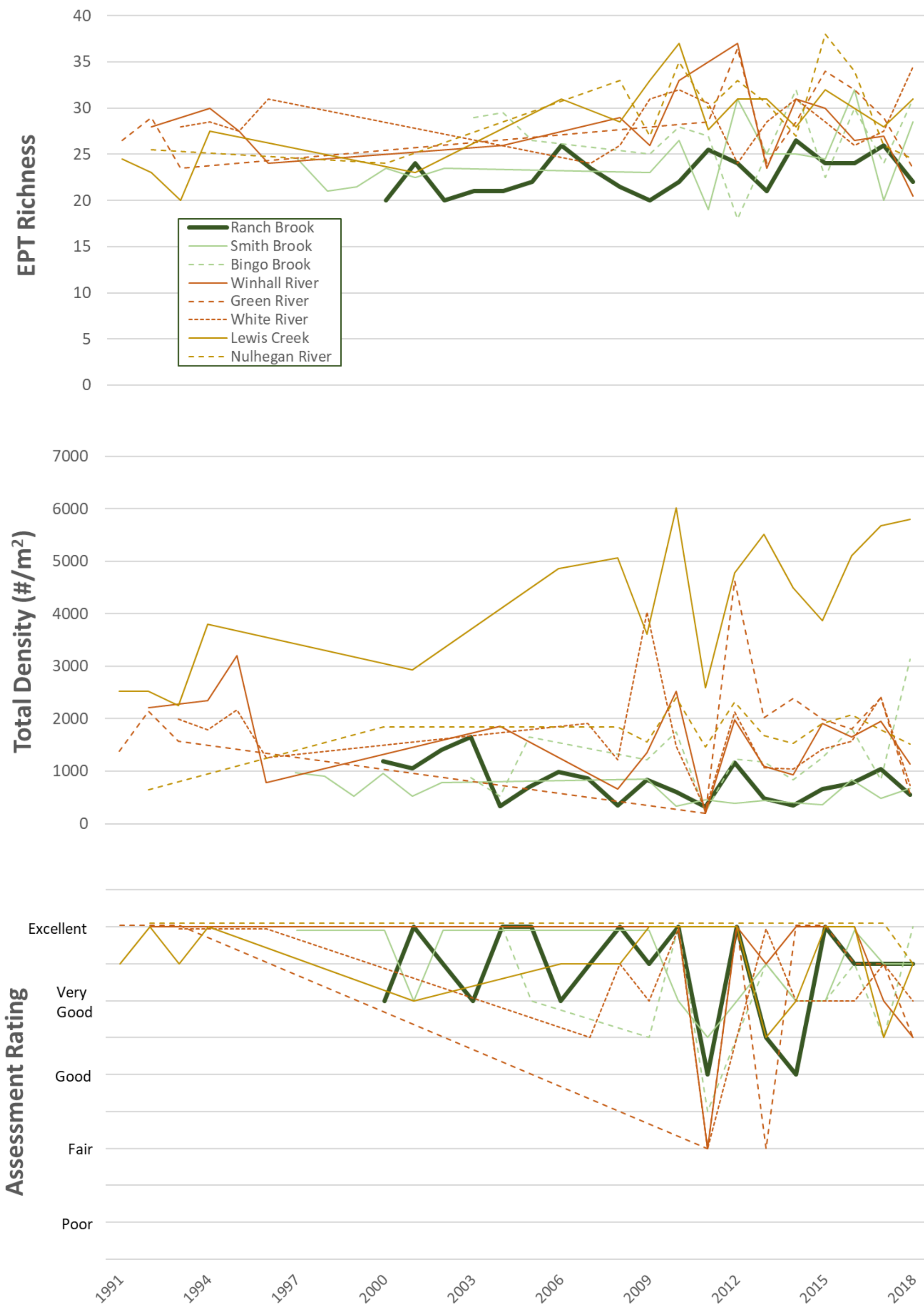


Figure 31. Long-term trends in macroinvertebrate density, richness and overall assessment rating for the eight sentinel sites with data going back to before 2012.

Implications

It will take a much longer period of record to fully understand how long-term changes in temperature and hydrology are influencing biological communities at sentinel sites. Only Ranch Brook has a continuously paired hydrological and biological record longer than 10 years. Most sites have a water temperature record of 6 years or less. 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 alter 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 VTDEC's ability to differentiate impacts caused by climate change versus more localized stressors.

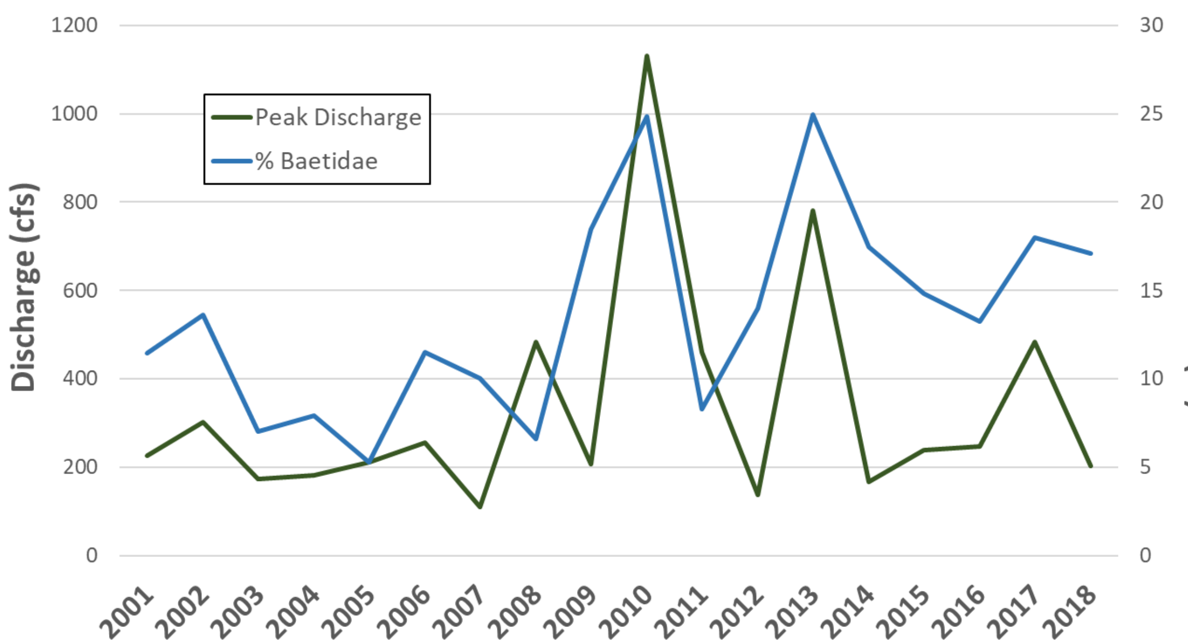


Figure 32. A comparison of the peak discharge in the 90 days prior to macroinvertebrate sampling each year, and the proportion of the community comprised of the mayfly family Baetidae, an early colonizer of disturbed substrate.

Despite the limitations of the dataset, 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 correlated to the relative abundance of the mayfly family Baetidae (Figure 32). Mayflies of this family are known to be early colonizers of disturbed substrates. In contrast, very low flow conditions may increase stream temperatures and alter macroinvertebrate communities in other ways. Many species that depend on colder water may begin to be lost from these communities as average stream temperatures rise, leading to an assemblage of more tolerant taxa. Understanding the population dynamics and life history traits of species that vary with these climatic variables will be essential, and VTDEC seeks to further explore these questions.

It appears that very low flows at many streams in 2018 may have led to increased stream temperature, and altered macroinvertebrate 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

The Little River in Stowe, VT.

Since September 2000, the U.S. Geological Survey (USGS) has been continuously operating stream gauges at Ranch Brook and West Branch near Stowe, Vermont (Wemple *et al.,* 2007). The gauging 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 gauging is for Water Year (WY) 2018 (October 1, 2017 through September 30, 2018). The report interprets the WY18 streamflows in the context of the full 18-year record. Historic and near real-time streamflow data are available on the USGS website (links have been provided in the additional resources section following this report).

In WY18, the gauges were jointly funded through a cooperative agreement between the USGS, the Vermont Department of Environmental Conservation and the Forest Ecosystem Monitoring Cooperative (FEMC). The gauges 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 gauges 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 gauges as a base for student projects and hands-on learning, and to attract additional funding for value-added research.

The Data

Stream gauges 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^{+}), anions (Cl^{-}, NO_3^{-}, SO_4^{2-}), Si, suspended sediment, snowpack and snowmelt, and extreme climate events. These gauging 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 33). 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 units as 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.

Water Year 2018 in Summary

Relative to the 18-year record, WY18 had slightly below average runoff. WY18 featured low runoff in fall and winter, followed by average to slightly below average runoff in spring (Figure 33).

Compared to WY17, in which the cumulative runoff was above average for the most of the year, WY18 remained below average levels throughout the year (Figure 34). Cumulative runoff at both sites peaked in May, reaching average levels. The rest of the water year remained below the average cumulative runoff levels for the 18-year study. The cumulative runoff patterns at the two sites in WY18 were similar to long-term patterns (Figure 34), 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 the melting of machine-made snow. (Note that water used for snowmaking at the Stowe Mountain Resort is extracted from West Branch upstream of the gauge, 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 34).

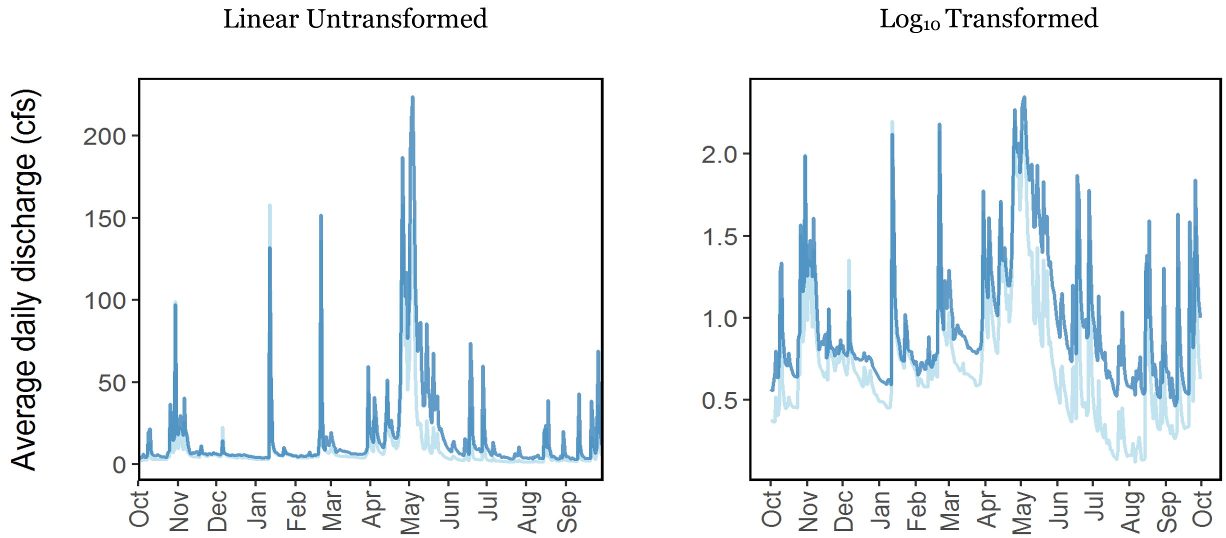

Figure 33. Streamflow at Ranch Brook (light blue) and West Branch (dark blue) gages for Water Year 2018 (Oct 1 2017 through Sept 30 2018) in linear untransformed (left) and log_{10} transformed (right) scales. The log scale better highlights the higher sustained base flow levels at West Branch (dark blue).

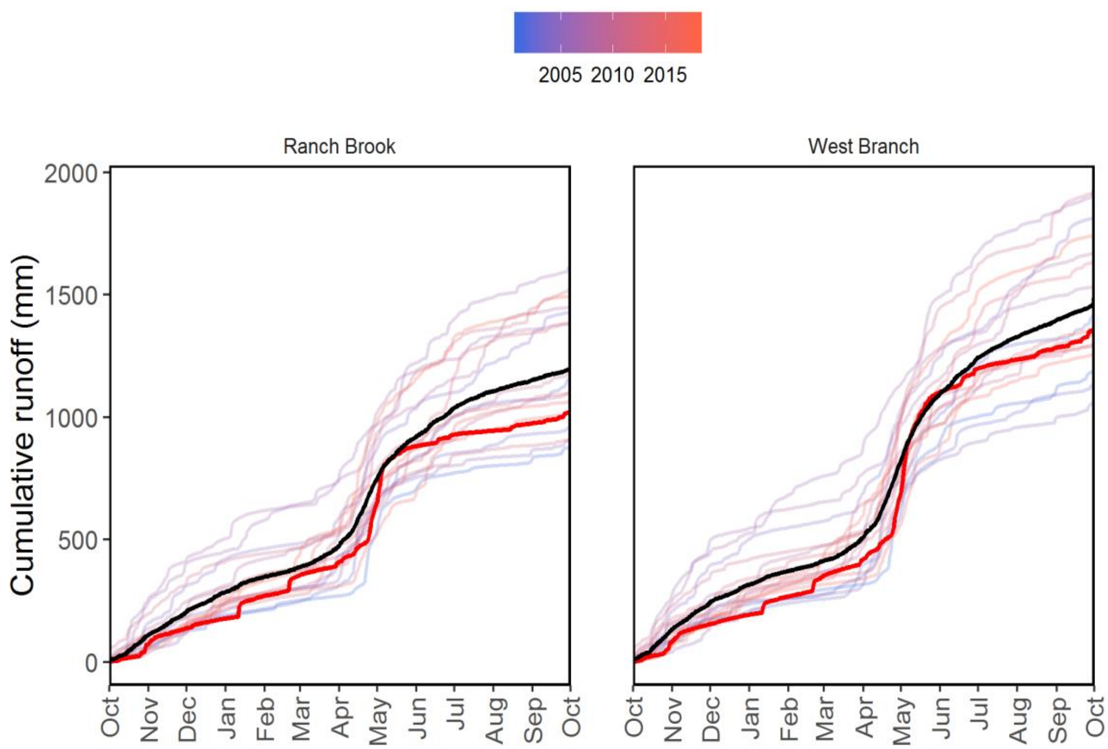

Figure 34. Cumulative runoff at Ranch Brook and West Branch based on the averages across the 18-year record (black line) and for Water Year 2018 only (red line). Faded lines show cumulative runoff for individual years (color denotes the year).

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 33 and Figure 34). Over the long-term, the average difference has been a 23% greater runoff at West Branch. The Water Year 2018 differential was 33% above the long-term average (Figure 35). Greater runoff at West Branch is what we would expect from the creation of open land and development, however, the high magnitude of the differential suggests that some part of the difference may be natural. In previous reports, we noted the extreme variability of large summer storms; these may preferentially impact West Branch. FEMC cooperators are currently investigating the role of local meteorology on the flow regimes.

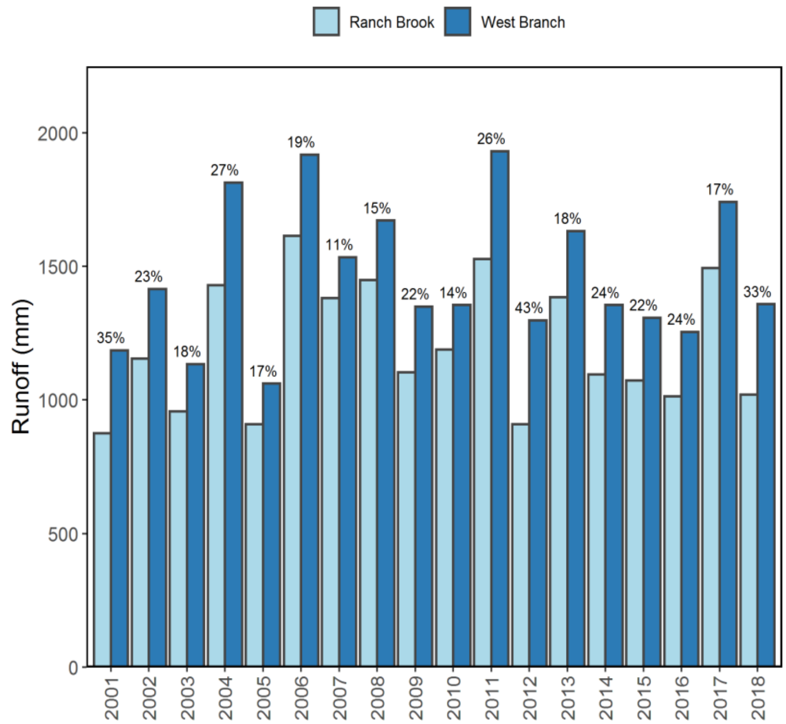

Figure 35. Annual runoff (mm) at Ranch Brook (light blue) and West Branch (dark blue) for the duration of study though the present report year (2001-2018). Percentage of greater runoff at WB relative to RB is given over each pair of bars.

In a first step to assess the hydrologic impact of the resort expansion, we constructed flow duration curves for two three-year periods of approximately equal precipitation, from before and after the construction period (Figure 36). 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.

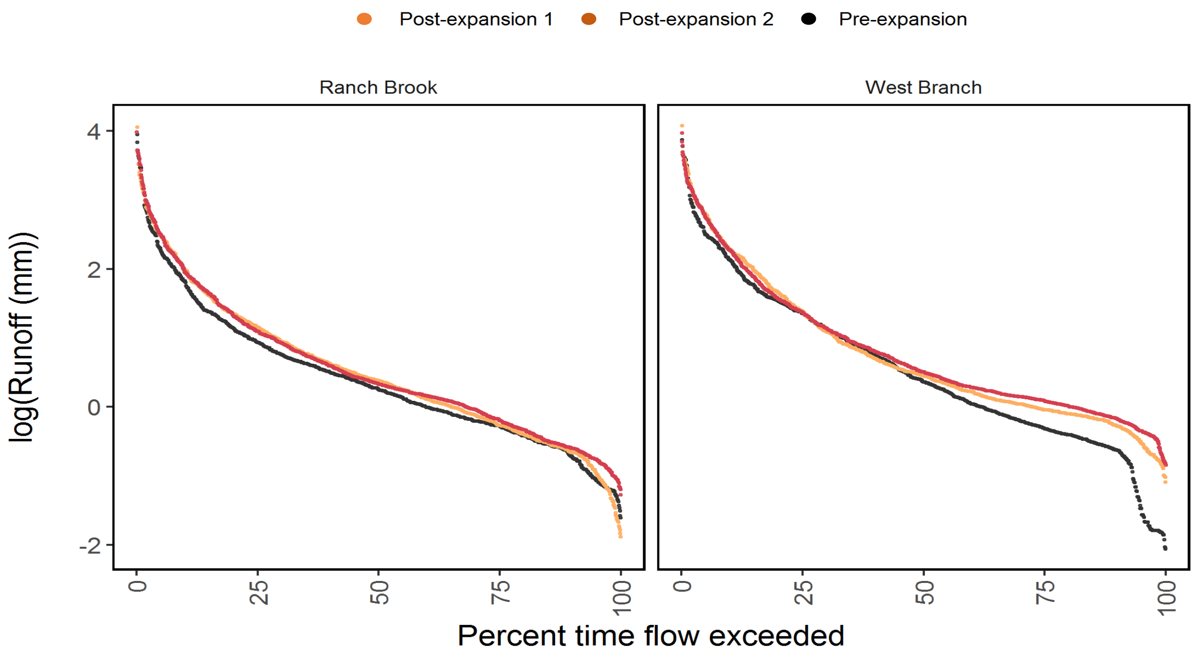

Figure 36. Flow duration curves for three three-year periods before and after the resort expansion, at Ranch Brook (left) and West Branch (right). Pre-expansion (WY01-03; black points), post-expansion 1 (WY12-14; orange points), post-expansion 2 (WY15-18; red points).

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. As ski resorts continue to develop year-round recreation and tourism infrastructure, runoff patterns, volume, velocity, and chemical make-up may change as a result. Additionally, climate change will likely disproportionally affect higher elevation ecosystems with warming temperatures and fewer, more intense precipitation events which are increasingly in the form of rain rather than snow.

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 a 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 downstream of highly developed sites.

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

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Additional Resources

Burlington National Weather Service data accessible at: https://w2.weather.gov/climate/index.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

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 many aspects 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.

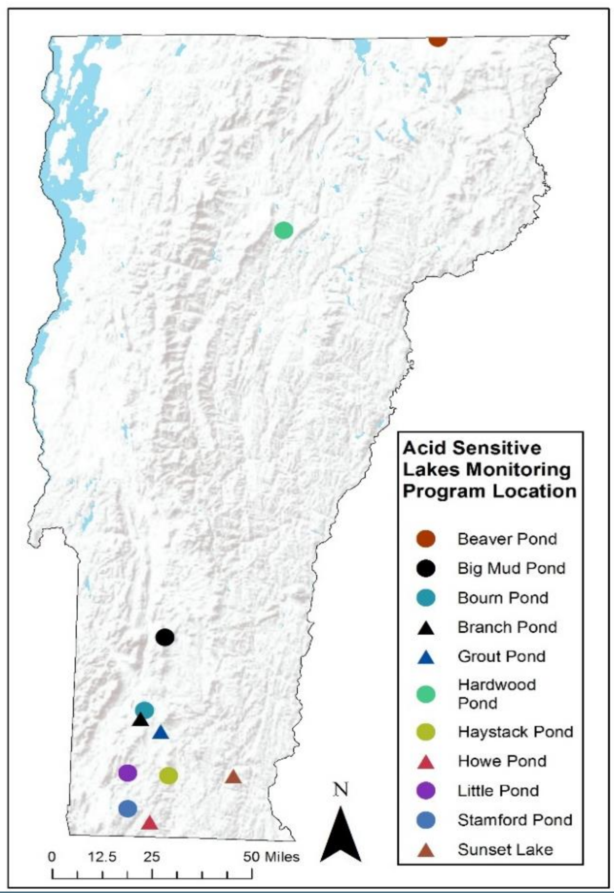

Figure 37. Locations of lakes/ponds in the Acid Lakes Monitoring Program in Vermont.

2018 in Summary

In 2018, we saw a range of values for water quality measurements in the 11 lakes and ponds in the Acid Lakes Monitoring Program (Figure 37) which reflects the variability in the different water bodies and in the parameters measured.

Average pH was 5.90 in 2018, which is slightly lower than the average value in 2017 (5.92). Reductions in aluminum are a good indicator of improving water quality, but mean dissolved aluminum across all sites has been increasing for the past three years, with 93.5 ug/L being recorded in 2016, 122.1 ug/L in 2017, and 134.42 ug/L in 2018. It should be noted that, like in 2017, dissolved aluminum concentrations were highly variable, with mean values recorded at the 11 Acid Lakes ranging from a high of 373.5 µg/L at Big Mud Pond to a low of 14.1 µg/L at Sunset Lake. This variation is likely due to a number of factors, including deposition received, water depth, bedrock, and surrounding conditions.

Similarly, average alkalinity did not improve for the third year, decreasing from 2.17 mg/L in 2017 to 1.94mg/L in 2018. Average conductivity declined slightly decline from 2017 (14.0

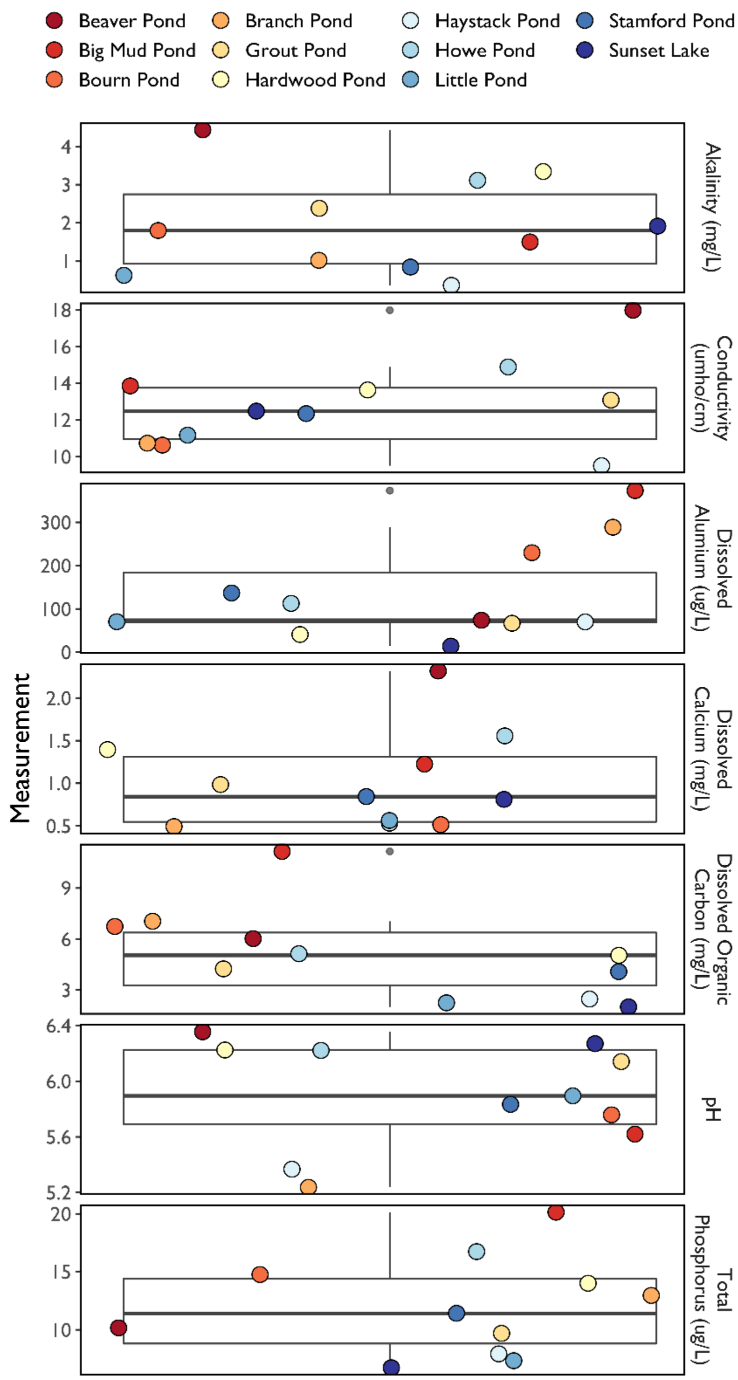

Figure 38. 2018 water quality measurements. Boxplot around points shows the mean (bold horizontal line) and extreme values (above or below vertical lines on top/bottom of box). Colors correspond to the 11 Acid Lakes in the monitoring program.

µmho/cm) to 2018 (12.96µmho/cm). Dissolved calcium also decreased slightly from an average of 1.05 mg/L in 2017 to 1.02 mg/L in 2018.

Average phosphorus concentration was 12.0µg/L, which is slightly lower than it was in 2017 (14.0 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 2018, the mean value (5.1 mg/L) which represents no change from 2017 (5.1 mg/L).

Long-Term Trends

The data from the 11 Acid Lakes demonstrate that acid accumulation and cation leaching has declined over the long-term record (1980-2018). Increases in 2018 compared to 2017 in alkalinity and pH are both indicative of an increasing trend observed over the measurement period (Figure 40). Concurrently, conductivity (a measure of the electrolyte concentration), dissolved aluminum, and dissolved calcium are still showing a decreasing trend despite increases in 2018.

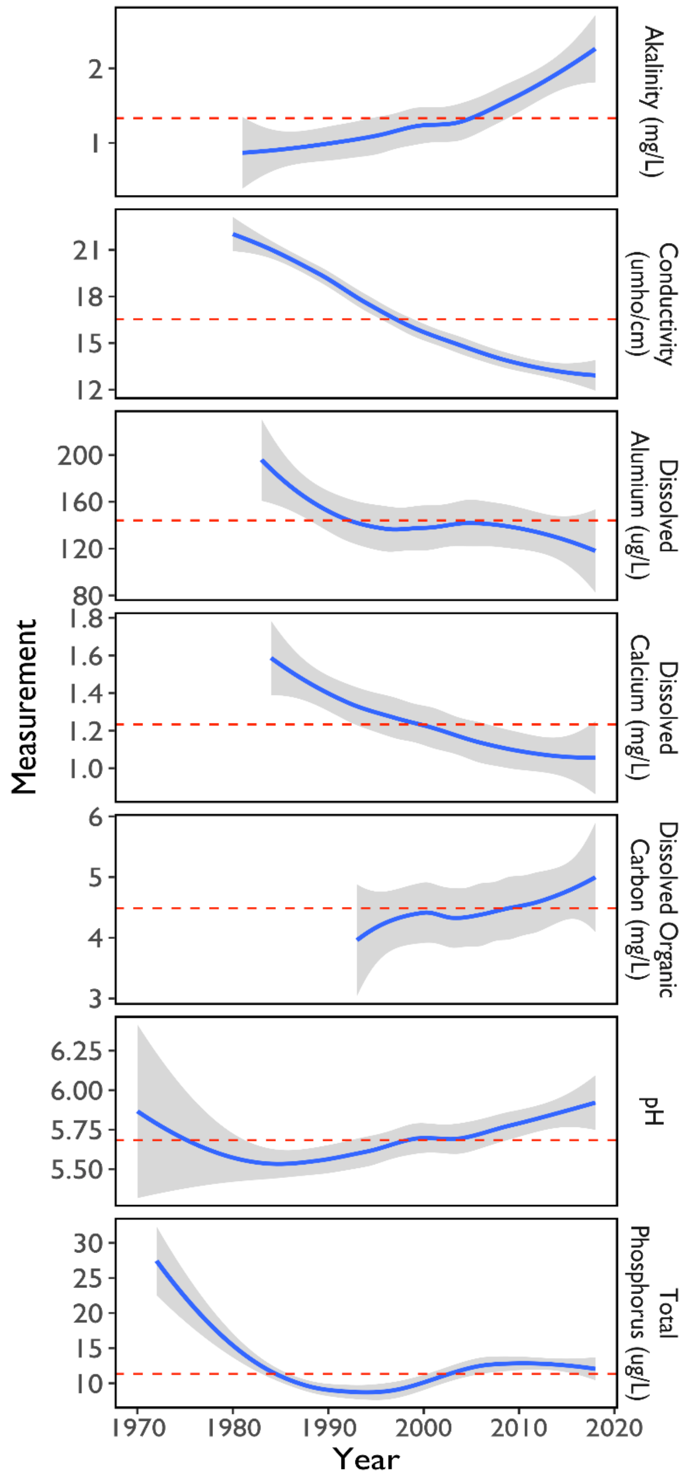

Figure 39. Average water quality measurements for 11 lakes/ponds in the VT Acid Lake Monitoring Program (blue line, smoothed with LOESS function), plus 95% confidence interval (grey shading). Red dashed line indicates the long-term average per measurement type.

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 40).

Phosphorus limits primary production in most lakes and excessive concentrations can lead to algal blooms, as observed in Lake Champlain. Historical patterns in total phosphorus show considerable variability but concentrations have decreased from a peak in 2008 (Figure 40). 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 lakes have been seeing an increase in phosphorus, or a "greening" effect (Stoddard et al. 2016). 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.

Because 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. Furthermore, 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, such as phosphorus loading in our large water bodies, are becoming more problematic.

Overall, the long-term data (1980-2018) 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.

Acknowledgements:

Special thanks to Heather Pembrook and Bruce Forsberg from the Vermont Department of Environmental Conservation for reviewing and editing the Water Quality Section of the 2018 FEMC Long-Term Monitoring Update.

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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 Health Monitoring* Section**

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Aerial Detection Surveys Section

Emerald ash borer. Retrieved from https://vtinvasives.org/land/emerald-ash-borer-vermont

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***Forest Phenology* Section**

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Sugar Maple. 2009. Photo by Meghan Hess from flickr (https://www.flickr.com/photos/scrambldmeggs/4015138277) and licensed under

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Acid Deposition Section

Proctor Maple Research Center Air Quality Site. 2019. Photo by John Truong, FEMC.

Maple Rain 3. 2016. Photo by MTSOfan accessed from flickr (https://www.flickr.com/photos/mtsofan/26113505833) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/).

Mercury Deposition Section

N-Con Collector. 2017. Photo by John Truong, FEMC.

Brook trout in Pendleton County, W.Va. 2014. Photo by Steve Droter, Chesapeake Bay Program.

Ozone Section

Ozone foliar injury on milkweed in Carl Sandburg Home National Historic Site. Photo from National Park Service.

Vermont landscape, winter, Craftsbury, 2018. Photo by Peter Rintels accessed from flickr (https://www.flickr.com/photos/off-the-road/39973527383)) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/).

Climate Section

A very cold wood frog, North Lincoln Street, Keene. Photo by Ashuelot Valley Environmental Observatory from flickr (https://www.flickr.com/photos/aveo/8552519499/) and licensed under Creative Commons BY 3.0 license (http://creativecommons.org/licenses/by/3.0/).

Trout Section

Brook trout in Pendleton County, W. Va. 2012. Photo by Chesapeake Bay Program accessed from Flickr (https://www.flickr.com/photos/chesbayprogram/8053999930) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

Beaver Pond complex. 2018. Photo from VT Fish and Wildlife.

Brook trout. Photo from VT Fish and Wildlife.

Forest Birds Section

Bicknell's Thrush. 2014. Photo by Aaron Maizlish accessed from Flickr (https://www.flickr.com/photos/amaizlish/14554573694) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

Canada Warbler. 2018. Photo by Tom Murray accessed from Flickr (https://www.flickr.com/photos/tmurray74/42419422341) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

Amphibians Section

Wood Frog. 2016. Photo by Ryan Hodnett accessed from flickr (https://www.flickr.com/photos/ryanhodnett/31989087132) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/).

Spring Salamander (Gyrinophilus porphyriticus). 2012. Photo by Dave Huth accessed from flickr (https://www.flickr.com/photos/davemedia/6831470286) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/).

Spotted salamander with adventitious tail, Proctor Maple Research Center. 2018. Photo by Karl Reimer.

E. bislineata. 2015. Erika Polner, Vermont Herp Atlas.

Sentinel Stream Section

Representative larvae of the insect orders Ehemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). Photo from VT Dept of Environmental Conservation.

Bridge Post Irene. Photo by VT Department of Transportation accessed from flickr (https://www.flickr.com/photos/vtrans/10593308935/) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/)

Green River, Guilford, Vt. Photo courtesy of Jim Deshler.

Watershed Hydrology Section

Little River, Stowe 3. Photo by Mike Freedman accessed from flickr (https://www.flickr.com/photos/mikelegend/8227777546/) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/)

Moss Glen Falls. 2009. Photo by Matthew Paulson accessed from flickr (https://www.flickr.com/photos/matthewpaulson/4331075529) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

Water Quality Section

DSC_2167 - Male Wood Duck, Westminster VT. 2019. Photo by Putneypics accessed from flickr (https://www.flickr.com/photos/38983646@N06/46755698494/) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc/2.0/).

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