Vermont Monitoring Cooperative

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

Long-Term Monitoring Update 2013

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Vermont Monitoring Cooperative, South Burlington, VT, USA

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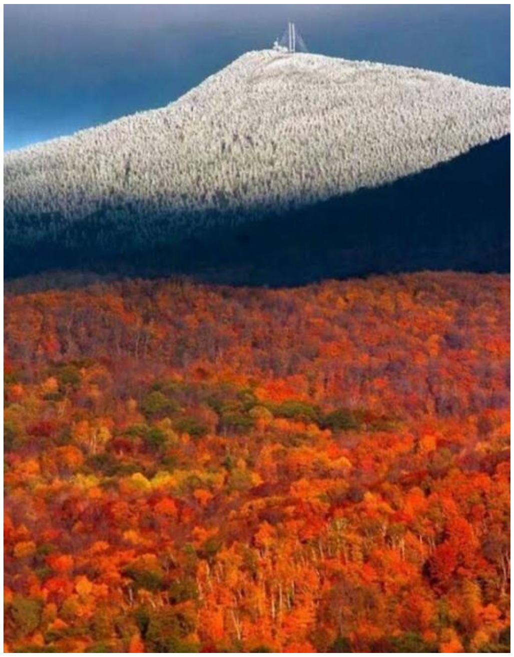
Introduction

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

Driven by its mission to amass the information necessary to monitor and detect such changes and their impacts on forested ecosystems, the efforts of the VMC network over the past 23 years have resulted in 170 individual research and monitoring projects across the state of Vermont conducted by over 180 collaborators, investigating a range of forest, soil, water, wildlife, pollutant and climate relationships. While this includes many individual investigations relevant to understanding and sustaining healthy forest ecosystems, this report offers a sampling of the extraordinary amount of information that currently contributes to the VMC's long-term archive of ecological data. Our goal is to include both a current year's summary of key forest, wildlife, water, and air quality metrics, along with an analysis of the long-term patterns and trends in the data in order to provide a relevant and timely source of information on the current state of the region's forested ecosystems.

The information in this report is intended to be a snapshot of the larger body of research that has been amassed over time, and which is growing daily. We have tried to include a subset of this work that is representative of the overall health and function of the forested ecosystem. This allows us to quantify forest health in 2013 in the context of long-term monitoring datasets. As an organization, VMC believes that the regular analysis and reporting of such information is critical to identify emerging forest health issues, as well as understand the drivers and impacts of ecosystem change.

Forest Phenology



Monitoring subtle changes in phenology can serve as an indicator of larger changes that can cascade through the forested ecosystem.

Field Assessments of Sugar Maple Phenology

The timing of seasonal plant events, including springtime leaf expansion and fall senescence, has important implications for ecosystem processes. Long-term field assessments of tree phenology allows us to understand how changes in climate are impacting forested ecosystem with the accuracy necessary to identify subtle changes that may have widespread consequences throughout the forest ecosystem. Current VMC data sets include visual assessments from 1991 to present of sugar maple bud break to fall senescence at three elevations on the western slopes of Mount Mansfield in the Green Mountains of Vermont.

The Data

Figure 1. PI Sandy Wilmot assesses phenological stages at the Proctor Maple Research Center.

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

Metrics of fall phenology included visual ratings of percent color and leaf drop, recorded weekly beginning in September on the same trees at the Proctor Maple Research Center and on trees at an elevation of 670 m (2200 feet). Percent color was assessed as the proportion of the existing leaves exhibiting a color other than green. Percent leaf drop was estimated as the proportion of potential leaves missing. While these are subjective ocular estimates, at important stages, such as full color or full leaf drop, the estimates are most reliable. After field data are collected, color estimates were recalculated as the proportion of initial foliage with color:

Actual % Color= (field%color X .01)-((field%color X .01) X (%leaf drop X .01))

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

Temporal trends in spring phenology were assessed by examining the dates of two significant phenological events across 22 years of data: (1) first day of bud break (phenological stage 4); and (2) first day 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 with maximum fall color observed in the canopy; and (2) the day of year on which all tree's leaves had either colored or fallen from the canopy. Yearly anomalies for all phenological events were calculated by comparing each year's data to the mean value for the entire measurement period. Linear regression was performed to assess the change in timing of each seasonal developmental event across the 22 year period.

2013 in Summary

The date of first budbreak in 2013 for sugar maple was consistent with the long-term average. However, green-up was more rapid than usual, resulting in a significantly earlier date of full leaf-out compared to the long term average, the second earliest on record. Maximum fall color was also consistent with the long term average for the lower elevation site at Proctor, but was earlier than normal at the higher elevation site. Leaf drop was earlier for both sites.

Long Term Trends

While 2013 was consistent with the long-term mean, a trend toward an earlier start of spring was observed in the long term dataset as evidenced by both earlier bud break and earlier full leaf expansion dates. The changes in fall development similarly showed trends which would lengthen the growing season by delaying fall senescence. The timing of maximum fall color had the strongest and most statistically significant response of all the phenological variables considered in this study, with an almost 9 day delay over the 22 year record at the lower elevation site.

First day of bud break was found to have advanced by an average of 7.4 days over the 22 year measurement period ($p = 0.1470$). First day of full leaf expansion similarly advanced over the measurement period by an average of 6.0 days ($p = 0.1890$).

Considering fall phenology, there was a slight, though not statistically significant ($p = 0.4057$) trend toward later leaf drop at low elevation, with delays on average of 3.3 days at low elevation. The delay in day of maximum fall colors at low elevations was the strongest trend, with significantly later peak foliage over time ($p = 0.0299$), culminating an average delay of 8.8 days across the data record. Trees at upper elevation, on the other hand, did not show a trend of changing fall phenology for either of the fall metrics.

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

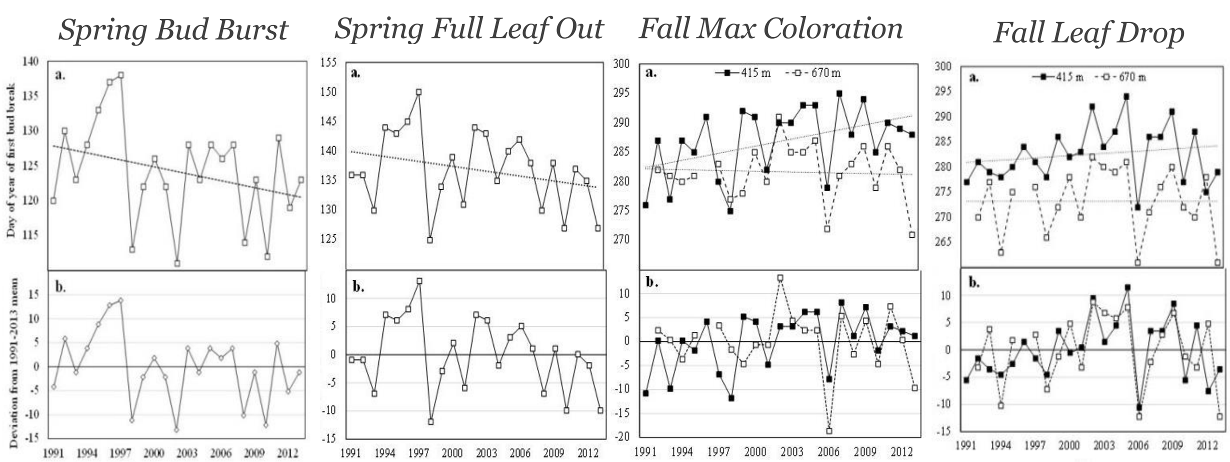


*Figure 2. **(a)** Long-term trends and **(b)** yearly anomalies from the 1991-2013 mean day of year for spring bud burst and full leaf out, and fall maximum coloration and leaf drop. Negative values indicate earlier development compared to the mean of the dataset.*

Implications

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

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

These results carry implications for water cycling in forests, as earlier springs may escalate evapotranspiration resulting in increased periods of low stream flow during the peak growing season (Daley et al. 2007). While phenology of vegetation is responding to the lengthening of the growing season resulting in a longer productive period, carbon sequestration dynamics in these systems could vary in response to projected changes in climate if trees become water limited. While growing seasons may initially create a carbon sink in Northeast hardwood forests, productivity of the region's forests will likely be water and nutrient limited over the long term.

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

Changes in the timing of sugar maple phenology will require adaptive strategies for many industries in Vermont.

Forest Phenology

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Additional Resources

VMC Project Database Links

Bud phenology http://www.uvm.edu/vmc/research/summary.php?id=13

Fall color and leaf drop http://www.uvm.edu/vmc/research/summary.php?id=62

Forest Health

Stress and disturbance are natural components of the dynamic forest ecosystem, but the severity and frequncy of such events may alter competative regimes.

Long-Term Forest Health Monitoring Network

Forest monitoring plots, such as those measured at the VMC sites, provide long term data on forest health trends and responses to disturbances. Forest response to stress events indicates their adaptive capacity in ever changing environmental conditions. Monitoring the nature and severity of stress responses is essential to understanding how best to manage forest resources into the future.

The Data

In 1990, a systematic forest health detection program started in New England and grew to become the national Forest Health Monitoring program, aimed at detecting emerging regionally significant forest health problems. We have adopted key ecosystem measurement methods from this program in our permanent forest health monitoring plots, including a full inventory of tree species, canopy characteristics, stress symptoms and damage agents. The VMC plot network provides a unique opportunity to co-locate these forest health measurements with those of atmospheric, weather, wildlife, water, and soils conditions at the Mt. Mansfield and Lye Brook Intensive Research sites. This allows us to examine relationships among environmental changes, forest health, and ecological dynamics. In addition, the VMC monitoring plots are located in forests most sensitive to anthropogenic stressors such as climate change and acid deposition, providing early indications of potential problems that will affect a wider area of Vermont's forests.

While the full long-term monitoring network includes 19 plots measured annually since 1992, in 2013 eight of these plots located on Mount Mansfield were re-measured. This included detailed assessments of almost 500 mature trees representing 12 different species.

Forest Health

2013 in Summary

Forest Health: There are many metrics used to assess the condition of tree canopies. The VMC data follows FIA's Forest Health Monitoring (P3) methods for crown health assessments including symptoms of early decline such as foliage transparancy, as well as more chronic decline metrics such as crown dieback and density. Our assessment of 2013 showed that percent dieback was considerably lower than average for all of the most common tree species (Table 1). This indicates that recent (1-2 year) stress events may be less severe than in the past. Also of note is the increased transparancy of white ash and paper birch. Declines in condition in paper birch are expected as the stand ages, but transparancy for white ash in 2013 was near the highest ever recorded on VMC plots. While there is concern that the invasive emerald ash borer may spread into Vermont, there was no evidence of infestation on VMC plots. Since ash yellows disease is not known to extend this far north, it is likely that increased transparancy and decreased density of white ash is a result of water fluctuations.

Table 1. Mean stress metrics for 2013 in comparison to the long-term mean highlight where the most common species deviate from typical condition (dif) where red represents significantly declining condition and green represents improving condition.

	%Dieback			%Transparency			%Crown Density			DBH (in)		
Species	2013 Mean	Long-term Mean	dif	2013 Mean	Long-term Mean	dif	2013 Mean	Long-term Mean	dif	2013 Mean	Long-term Mean	dif
Abies balsamea (Balsam fir)	11	12	-1	20	19	1	46	47	0	18	18	-1
Acer rubrum (Red maple)	5	7	-2	22	20	2	55	50	5	30	26	4
Acer saccharum (Sugar maple)	5	6	0	18	18	1	50	52	-2	22	23	0
Betula alleghaniensis (Yellow birch)	5	7	-2	21	19	1	55	52	3	33	30	3
Betula papyrifera (Paper birch)	8	11	-3	26	22	5	39	46	-6	19	19	0
Fagus grandifolia (American Beech)	7	9	-2	25	23	2	45	44	1	28	24	5
Fraxinus americana (White ash)	5	8	-3	25	19	6	48	52	-3	30	29	1
Picea rubens (Red spruce)	6	6	0	15	17	-2	56	53	3	24	20	3

Regeneration: Red maple regeneration dominated most plots, followed by American beech, and balsam fir (Figure 3). A contingency analysis to assess recruitment into the sapling age class showed significantly more balsam fir saplings than expected (Cell $Chi^2 = 8.97$), the highest count over the 22 year record. Similary, there were significantly fewer paper birch (Cell $Chi^2 = 4.79$), yellow birch (Cell $Chi^2 = 3.90$) and sugar maple (Cell $Chi^2 = 3.10$) saplings than expected.

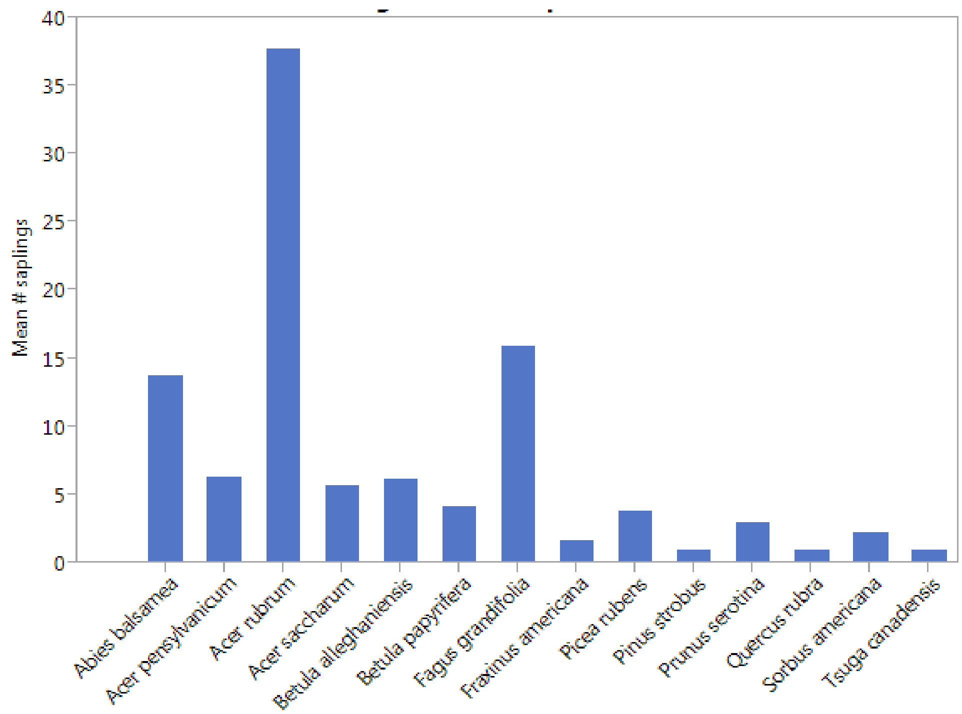


Figure 3. Mean number of saplings per plot at the VMC forest health monitoring plots in 2013 provide a picture of regeneration success and the composition of the future forest.

Long Term Trends

While 2013 was a relatively healthy year for most species, an examination of the full temporal data set allows us to look past the year to year variability, and consider species recovery rates and identify more chronic stress conditions. Figure 4 fits a simple spline to the mean transparency and dieback for each species in each year (with 2013 in red). While there is clearly a large amount of year to year variability, the nearly uniform peak in transparency and dieback in 2005 and subsequent recovery highlights the forest's natural stability. Percent dieback shows no significant long-term trends, but there is an alarming upward trend in percent transparency. Relative to measurements taken in the early 1990's, current mean transparency is nearly double for all species. The trend is particularly uniform for white ash and paper birch. While this could be the natural results of successional processes, the VMC will continue to monitor these species to determine if changing environmental conditions are altering competitive relationships among forest cohorts.

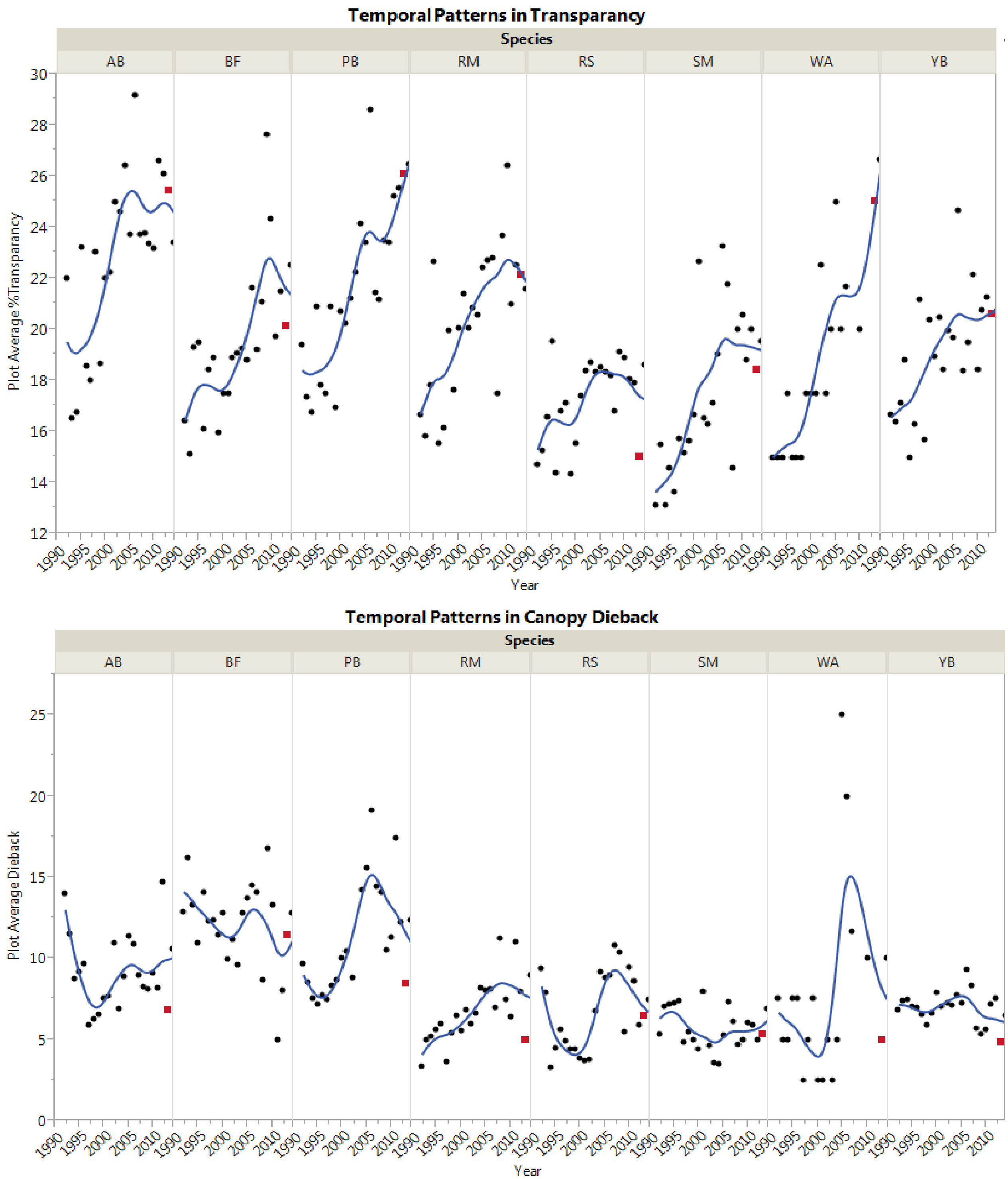


Figure 4. A simple spline fit to yearly average transparency (top) and dieback (bottom) demonstrate the decline/recovery process so common in temperate forests, but also indicate increasing trends in canopy transparency for all species. 2013 is highlighted in red for comparison.

Implications

VMC forest health monitoring has been instrumental in determining how trees respond to and recover from stress events. With increased pressures from human activities, projections are for increased severity and frequency of both climate based stress events (drought, frost injury, wind, etc.) and invasive pests and pathogens, maintenance of these long-term metrics is essential to understand how forests have already responded to these changes, and how they will continue to change. Forested ecosystems provide immeasurable benefits to society; from their aesthetic beauty and recreational opportunities to biomass energy and carbon sequestration. While the composition of forests may change, this ongoing work will inform management decisions to maximize the productivity and health of the forested landscape into the future.

While 2013 was a relatively good year for forest health conditions in recent terms, stress symptoms are far more common than they were when VMC measurements began in the early 1990's.

Additional Resources

VMC Project Database Link

Forest health monitoring http://www.uvm.edu/vmc/research/summary.php?id=17

Acid Deposition

Winter injury to red spruce stems was most severe in areas where acid deposition depletes Ca from the foliage.

National Atmospheric Deposition Program/National Trends Network

Atmospheric deposition monitoring provides an important foundation for environmental research as atmospheric inputs can accumulate on the landscape over time, and have cascading impacts on ecosystems, such as the dieback of Red Spruce growing on high elevations that was observed in the 1970s and 80s. Long-term atmospheric deposition monitoring has been a cornerstone of VMC monitoring and research, providing key information on the sources of pollution, trends in deposition rates and impacts on forested ecosystems. Today, this information is necessary to understand how air quality policies have ameliorated acid deposition across the region, and to inform future policy and management decisions to sustain the health of the region's forested ecosystems.

The Data

Atmospheric deposition monitoring has been conducted by the Vermont Monitoring Cooperative for over thirty years at the Proctor Maple Research Center and Lye Brook Wilderness Area in southern Vermont (monitoring station located in Bennington). These stations are part of either national (National Atmospheric Deposition Network (NADP, since 1984), and Atmospheric Integration Research Monitoring Network (AIRMoN) or statewide (Vermont Acid Precipitation Monitoring Program (VAPMP) networks, which enable spatial and temporal patterns of acidic deposition to be understood.

Here we examine the NADP/NTN dataset collected at the Proctor Maple Research Center on the western slopes of Mount Mansfield, Vermont. This record contains a 30 year record of pH, NO3 and SO4 measurements for weekly composite precipitation samples. This network consists of over 200 sites in the continental U.S. plus sites in Canada, as well as sites more distant as those in Argentina, Samoa and Hawaii. This robust spatial distribution of sites and reputation for high-quality data make the

NADP/NTN a good dataset to utilize to understand the trends in acid deposition in Vermont and how they compare to other regions.

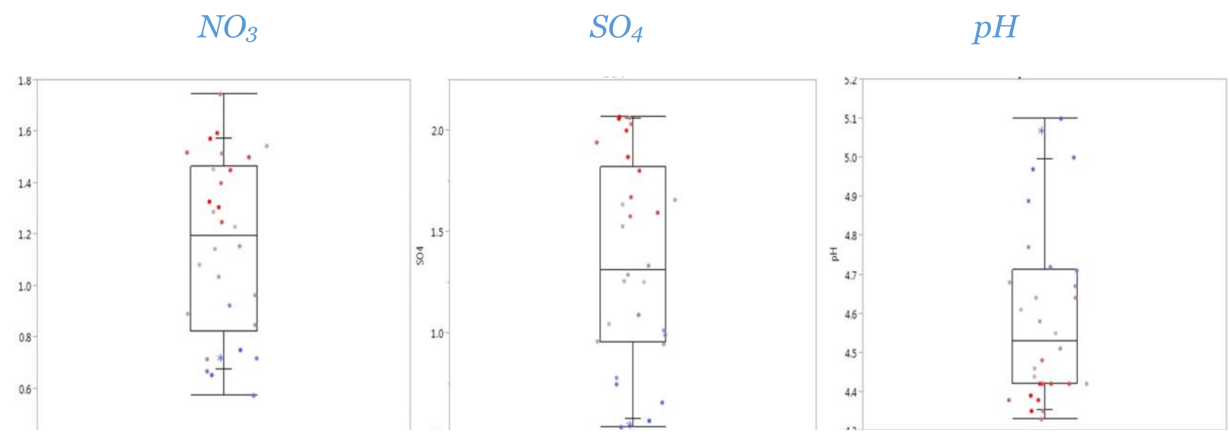


Figure 5. Quantile box plots show that while 2013 (blue asterisk) was not an outlier year, it was consistently in the highest quality quartile for NO_3 (left) and SO_4 concentrations (center), and pH (right). Each dot represents a yearly mean value, with earlier dates in red and most recent dates in blue.

2013 in Summary

For all three metrics (pH, SO4 and NO3), 2013 was one of the best years on record in terms of environmental quality, falling in the top quartile for pH and the lowest quartile for SO4. When monitoring began in 1984, the pH of rain and snow samples was close to 4.0 ("unpolluted" rain has a pH of 5.6). At the end of 2013, the pH of samples collected at Underhill were reaching a pH of 5.0. The logarithmic pH scale underscores the magnitude of this improvement.

2013 also marked the first year that NO3 deposition exceeded that of SO4. In the early years of acid rain monitoring in Vermont, sulfates accounted for about 2/3 and nitrates 1/3 of the acidity in our precipitation. Over time, upwind emissions of both sulfur oxides (SO_X) and nitrogen oxides (NO_X) have declined. However, the reductions in SO_X have been proportionately greater than reductions in NO_X. Nitrogen deposition is expected to become a more important factor in the future, especially since emissions and deposition of reduced nitrogen (NH_X) have not yet declined.

	NO3	SO4	pH
2013	0.72	0.55	5.07
Average	1.15	1.35	4.59
Standard Deviation	0.34	0.51	0.23
Minimum	0.57	0.54	4.33
Maximum	1.75	2.07	5.10

Figure 6. Mean 2013 values compared to long term norms (mg/L for NO_3 and SO_4).

Long-term Trends

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

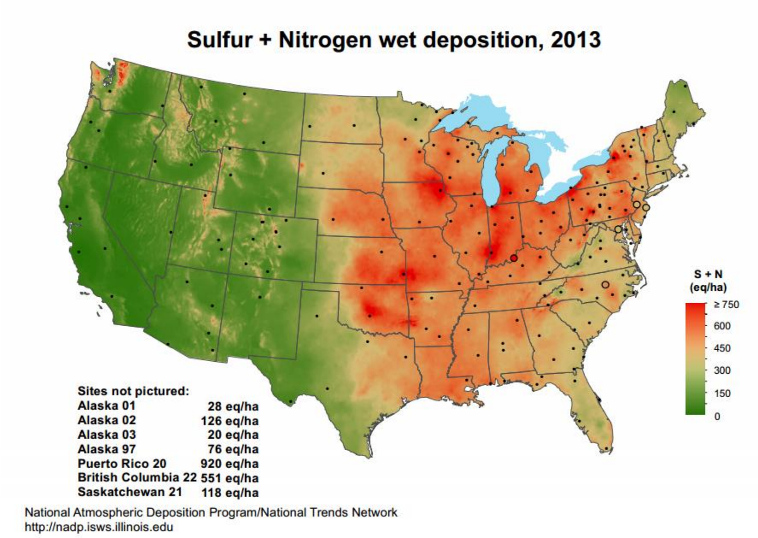


Figure 7. Modeled wet deposition of sulfur and nitrogen oxides across the continental US based on collector sampling at NADP sites.

Interesting seasonal and spatial patterns exist, highlighting the importance of weather patterns on the overall deposition load across the region. Both the Lye Brook and Underhill stations are located in the "tailpipe" of the United States. The prevailing winds bring pollution from the heavily industrial Midwest and also from more densely located electric utility boilers in more populated parts of the country. The pattern of winds is such that more acid forming chemical compounds are disproportionately deposited in the eastern half of the United States. As this 2013 map of total acid wet deposition demonstrates, in spite of the CAA, deposition remains disproportionately high for our region. This justifies continued monitoring across this highly sensitive forested region.

Long-term Trends in Acid Deposition Metrics – Underhill, VT

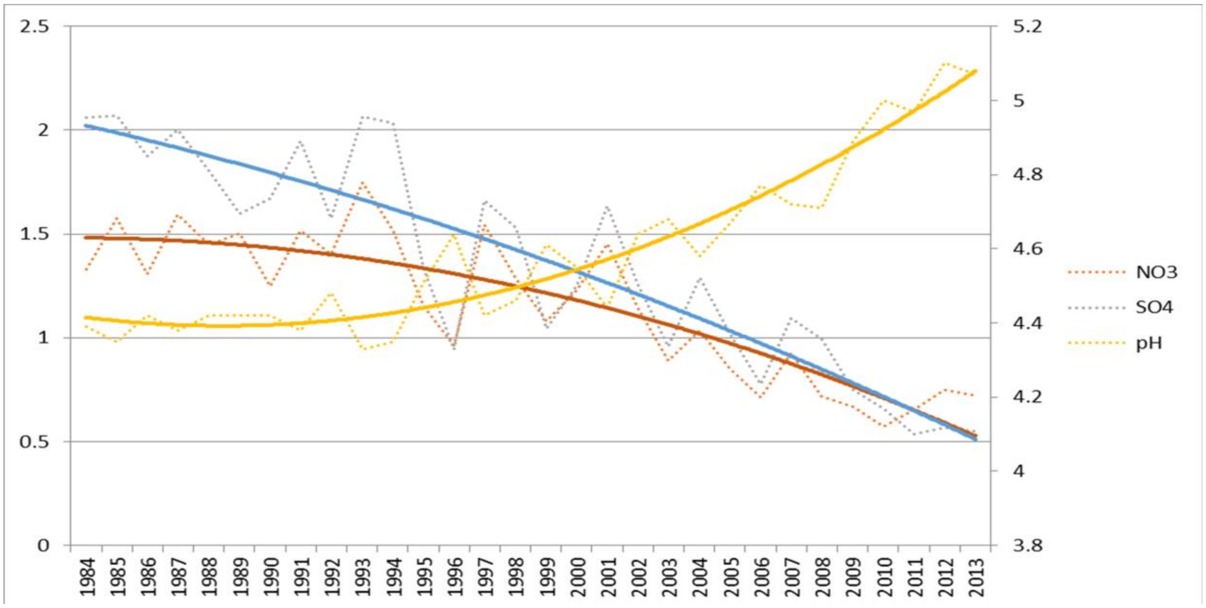


Figure 8. Long-term trends based on yearly mean concentrations (mg/L) highlight the success of the amendments to the 1990 Clean Air Act. Reductions are particularly significant for sulfate, bringing them below nitrate concentrations for the first time in 2013.

While insufficient time has passed to infer a change in this trend, it is noteworthy that both NO3 and SO4 concentrations have remained relatively stable over the last 4 years, breaking from the long term decreasing trend. EPA finalized the Cross-State Air Pollution Rule in 2011, with a goal of further reducing power plant NOX and SOX emissions. However a number of court actions have delayed its implementation until 2015. It is too soon to see results of this latest tweak but continued monitoring will determine if this EPA action meets these goals.

Implications

Acid deposition serves as the model of translating science to policy. It was measurements collected through VMC-supported networks that established a link between acid deposition and forest health, laying the foundation for amendments to the clean air act. The continuation of this monitoring program allows us to continue to serve witness to improving conditions, and study the resiliency of forested ecosystems as they respond to improvements. For example, because many terrestrial ecosystems are nitrogen limited, it is possible that the amelioration of acid content from the sulfate reduction may be sufficient to allow a minor fertilization effect by nitrate in regions where critical loads of soils have not been exceeded. Linking this data to forest health measurements will shed light on this possible shifting relationship between acid deposition and forest health. This program also serves as a bellwether, ensuring that these reductions in acid deposition are maintained into the future.

While there have been significant reductions in acid deposition over the past decade, impacts to the forested landscape are long-lived with potentially shifting implications for ecosystem structure and function.

Additional Resources

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

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

VMC Project Database Links

National Atmospheric Deposition Program/National Trends Network (NADP/NTN) http://www.uvm.edu/vmc/research/summary.php?id=19

Forest Birds

Banded Bicknell's Thrush on Mt. Mansfield. Photo courtesy of VCE.

Breeding Bird Surveys

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

The Data

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

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

2013 in Summary

All four permanent sites sampled during the breeding bird survey experienced low counts of relative abundance, species richness, or both in 2013. For the second time in four years, both montane study sites on Mount Mansfield documented record or near record lows for relative abundance and species richness. Although the number of individual birds detected at Underhill State Park in 2013 was slightly below average, species richness was among the lowest ever recorded. In contrast, the number of individual birds detected at Lye Brook was the second lowest in the counts history, while species richness was average.

Overall, a combined total of 55 avian species have been detected during breeding bird surveys at three study sites on Mt. Mansfield from 1991-2013. Species richness was similar at both montane forest sites, with a total of 31 species detected at both the Mansfield ridgeline and Ranch Brook. Surveys at Ranch Brook continue to average a greater number of individuals and species per year than the higher elevation and more exposed Mansfield ridgeline site. Surveys at the mid-elevation, northern hardwood study sites at Underhill State Park and Lye Brook Wilderness showed similar species composition, with a total of 46 species detected at both study sites.

Long Term Trends

Mt. Mansfield ridgeline: In 2013, the number of species detected (n=8) was the lowest ever recorded in the count's 23 year history, while numerical abundance (n=46) was the second lowest following 2011's tally of just 36 individual birds. Of the eight most commonly recorded species, only Winter Wren was above the 23-year average (6.48), and counts of just two species (Winter Wren and Bicknell's Thrush) increased from 2012 (Figure 9). For the first time in the survey no American Robins were detected on the ridgeline.

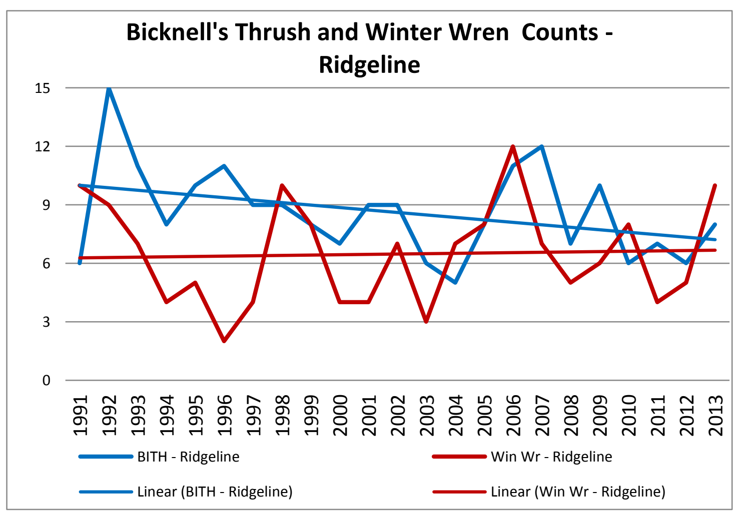


Figure 9. Twenty-three year data and trends for Bicknell's Thrush and Winter Wren from annual count surveys conducted at the Mt. Mansfield Ridgeline site.

Ranch Brook:
Abundance (n=36) was the lowest recorded in the site's 8-year history, while species richness equaled 2011's record low of 11 species. Although no new species were detected, a single Blue-headed Vireo was recorded, just the second for the survey, and a single Hermit Thrush was found for the second year in a row and the fourth for the site. Of the eight most abundant species, only Winter Wren was above the long-term mean for Ranch Brook (Figure 10). No Bicknell's Thrush were detected during the 2013 counts, but 2011 and 2012 counts were level. However, the long-term trend for Bicknell's Thrush at Ranch Brook is downward at the annual rate of 2.47%.

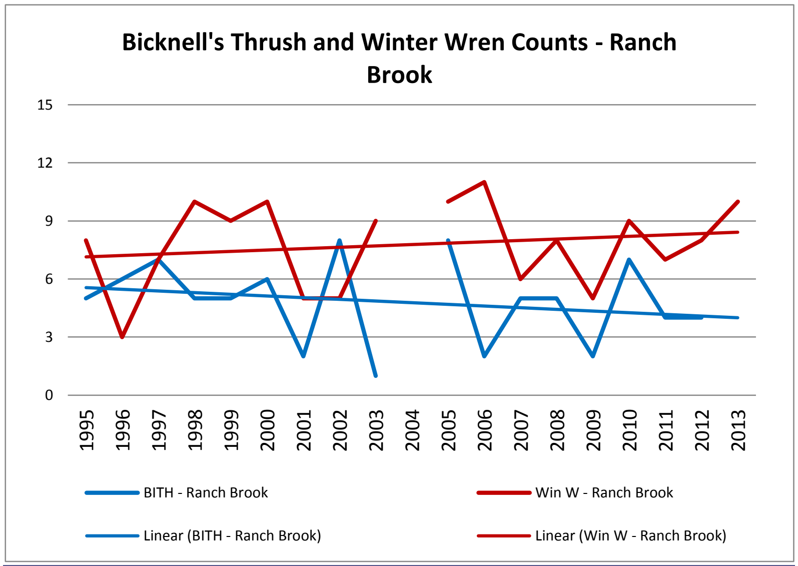


Figure 10 Eighteen year data and trends for Bicknell's Thrush and Winter Wren from annual count surveys conducted at the Mt. Mansfield Ranch Brook site.

Underhill State Park:
Total number of individuals and species richness remained well below average for the site, with just 52 individuals of 14 species recorded. Among the 8 most common species, three were above the 20-year mean, and five were below. Overall, Ovenbird numbers appear to be increasing and 2013 numbers were close to the 20 year mean (Figure 11). The long-term trend for Hermit Thrush, the VT State bird, remained nearly level, although average overall numbers are relatively low and the 2013 count numbers were down from 2012. Statewide, numbers of this bird declined on average 6.3% annually between 1989 and 2006. As with the Mt. Mansfield montane

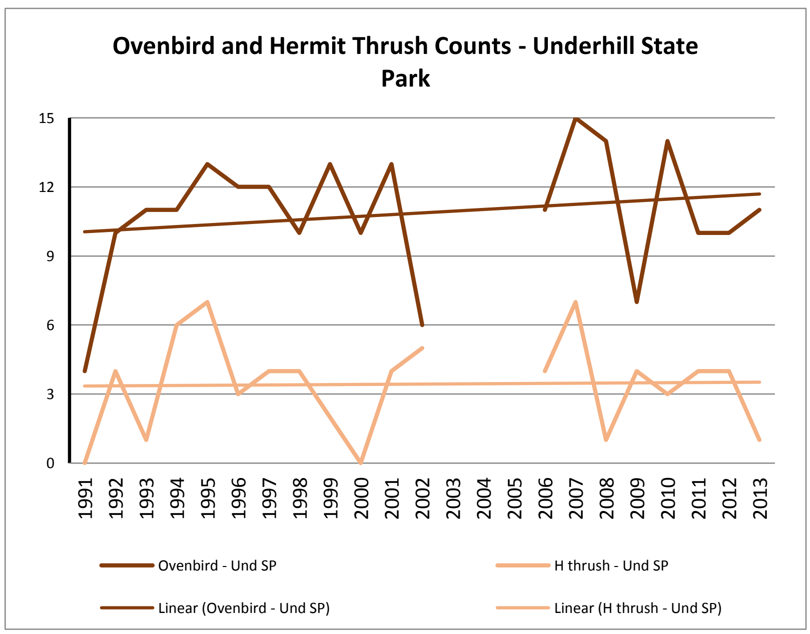


Figure 11. Twenty year data and trends for Ovenbird and Hermit Thrush from annual count surveys conducted at the Underhill State Park.

sites, Winter Wrens were abundant at Underhill State Park in 2013, equaling the record high counts of six from 1992 and 1998.

Lye Brook Wilderness Area

Abundance (n=49) dropped to the second lowest in the site's history, while species richness (n=16) equaled the 13-year mean, including three new species for the survey (Broad-winged Hawk, Nashville Warbler, and Black-and-White Warbler). Among the eight most common species, six were below the 13-year average. Of these eight species, three exhibited increasing population trends, one of which was statistically significant (Red-eyed Vireo) (Figure 12), while five declined (two significantly; Black-throated Blue Warbler and Ovenbird). Although Ovenbird numbers increased to just below the 13-year mean, the species continued a declining trend at an annual rate of 2.67% ($r2 = 0.371$; $P = 0.027$), while numbers of Black-throated Blue Warbler dropped to a record low of just three individuals, resulting in a significant decline of 3.31% per year ($r2 = 0.355$; $P = 0.032$). Although Red-eyed Vireo numbers dropped from the previous survey in 2011, their relative abundance remained above the 13-year mean (8.69) and continued an increasing trend at 10.19% per year ($r2 = 0.295$; $P = 0.055$).

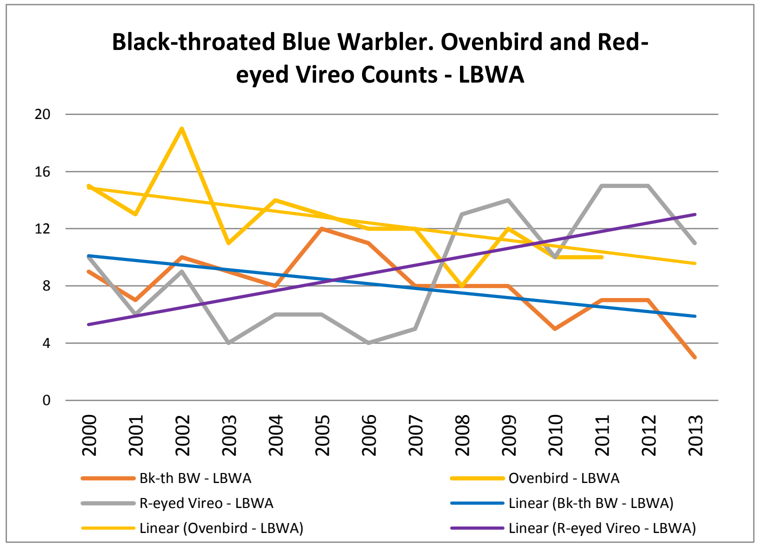


Figure 12. Thirteen year data and trends for Black-throated Blue Warbler, Ovenbird and Red-eyed Vireo from annual count surveys conducted at LBWA.

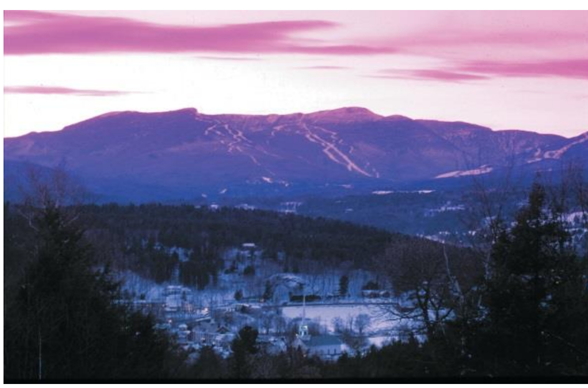
Implications

Long-term trends in count survey numbers, over the past 23 years at Mt Mansfield, strongly suggest that on average numbers of many bird species (e.g. Bicknell's Thrush, Blackpolled Warbler, Dark-eyed Junco, White-throated Sparrow) have been declining at high elevation sites since 1991. However, it should be noted that site-specific trend estimates presented must be interpreted carefully as these data are from a limited geographic sample. Year to year changes in survey counts may simply reflect natural fluctuations in abundance, differences in detection rates, variability of singing rates due to nesting stage, and/or a variety of dynamic factors, such as predator or prey abundance, overwinter survival, and local habitat change.

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

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

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



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

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Additional Resources

VMC Project Database Links

Forest Bird Surveys http://www.uvm.edu/vmc/research/summary.php?id=11

Hg

Mercury Deposition

Aerochemetrics (ACM) collector for capture and analysis of mercury contained in precipitation.

Mercury Deposition Network Monitoring at VT99

Mercury, a naturally occurring element in the environment but a persistent pollutant, can accumulate in organisms as it moves up the food chain, leading to neurological damage in humans (Mahaffery 2005) and lowered reproductive success, motor skill impairment and hormonal changes in animals (Driscoll et al. 2007, Evers et al. 2004). Human activities such as coal burning and waste incineration elevate levels of atmospheric mercury, which is later transferred to forests and waterbodies through both dry and precipitation-based deposition. In 2004, the VMC joined the Mercury Deposition Network (MDN, part of the National Atmospheric Deposition Program) as station VT99. VMC aids in monitoring the quantity of mercury reaching Vermont's forests and lakes in precipitation and contributes to a national monitoring network of more than 120 sites across the United States and Canada. VMC and its partners have committed to this long-term monitoring in order to document and better understand the input of mercury into Vermont's forested ecosystems.

The Data

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

2013 in Summary

Mercury monitoring at VMC's air quality site (VT99) in 2013 presents a mixed picture. Both the mean Hg concentration and the maximum recorded Hg concentration for a given precipitation event fell in the middle of the range documented over the past nine years. Total Hg deposition also fell in the middle of the range of reported values for this site. While it is positive that levels witnessed in 2008 have not been repeated, this still presents levels of ecological concern, with no evident downward trend (see trend analysis below).

Table 2. Mean yearly Hg concentration (ng/L), maximum Hg concentration (ng/L) and total Hg deposition (ng/m^2) reported at the VT99 site. The color scale represents the lowest (green) and highest (red) years for a given metric.

Year	Precipitation-weighted Mean Hg Concentration	Precipitation-weighted Max Hg Concentration	Total Hg Deposition
2005	2.8	23.9	3,430
2006	5.5	33.9	7,160
2007	7.1	97.2	8,012
2008	10.2	131.6	9,099
2009	2.2	20.7	6,943
2010	5.6	33.7	5,871
2011	6.7	48.0	10,990
2012	7.4	88.7	5,858
2013	6.9	63.9	6,947
Precipitation-weighted overall mean	***6.0***	***60.2***	***7,146***

Comparison to the MDN network: Examining the total Hg deposition across the region (depicted in Figure 13 and Table 2), the VT99 site has reported some of the highest and lowest total deposition across the time series. This highlights the variable nature of Hg deposition and the need for continued monitoring. Perhaps more concerning is reduction in the number of reporting sites as time has progressed. Because of funding shortfalls, four of the seven MDN sites across our region are no longer collecting data. This places additional emphasis on the remaining three sites to measure the trends in Hg deposition for our region. Also of concern is the lack of reductions in Hg deposition across the region. For a larger perspective, compared to the ***national*** network of MDN sites, the VT99 monitoring station has fallen

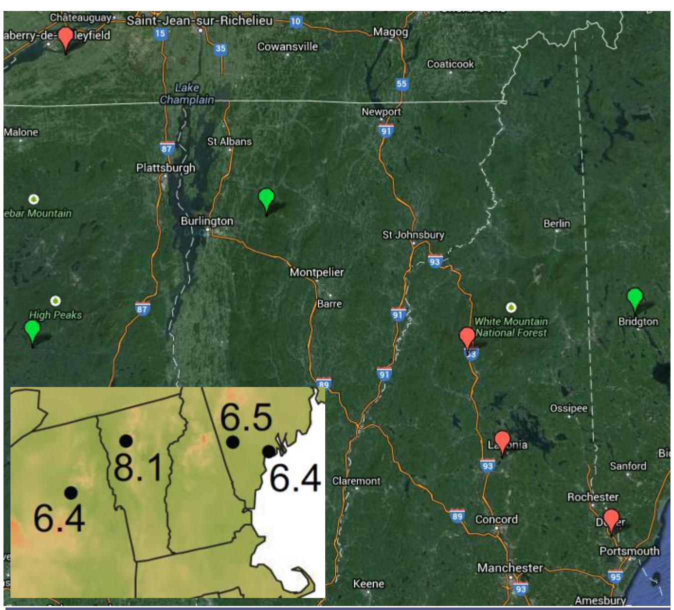

Figure 13. Of the 7 Hg monitoring sites across the region from the Adirondacks to western Maine, only 3 remain in operation today (closed sites in red). Inset: Regional deposition totals for 2013 (NADP 2013).

from the high end of measured values (2008, with higher total Hg deposition than 87% of other MDN sites) and away from low end of measured values (2005, with higher total Hg deposition than only 16% of other MDN sites). Over all the years of measurements, the Vt99 site falls in the middle of reported Hg deposition values across the Mercury Deposition Network.

Table 3. Total Hg deposition by year for the 7 regional MDN monitoring sites. The color scale represents the lowest (green) and highest (red) mean values for a given year. Percentiles provide a comparison to the larger national MDN network. This represents the proportion of MDN sites reporting total Hg deposition values below VT99.

Total Hg Deposition by MDN Site

MDN Site	2005	2006	2007	2008	2009	2010	2011	2012	2013
ME02	5144	7792	8036	4883	8540	5796	10263	6146	8016
NH00									
NH02	7599	335							
NH05									
NY20	6108	7493	6359	3646	6525	6267	7277	7375	6633
PQ04	4459	9039	6491	3813					
VT99	**3429**	**7160**	**8012**	**9099**	**6943**	**5871**	**10990**	**5858**	**6947**
VT99 percentile *(full MDN network)*	**16%**	**33%**	**48%**	**87%**	**38%**	**37%**	**67%**	**44%**	**24%**

Long Term Trends

The most recent summary on Hg emissions indicates that since 1990, emissions are down in North America, although flat between 2000 and 2005 (Figure 14). Examination of the full data record at VT99 suggests such a leveling off, though variability remains quite high. Since Hg deposition and concentration measurements began at VT99 in 2004, there has been no significant trend, either increasing or decreasing (Figure 15). While the severity of spikes in both Hg concentration and total Hg

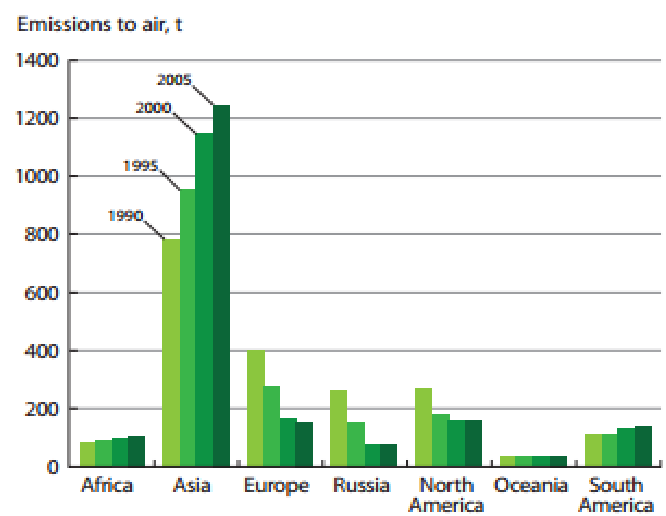

Figure 14. Estimates of annual anthropogenic mercury emissions from different continents/regions, 1990-2005. 2013 Global mercury assessment. http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf

Hg

Mercury Deposition

deposition are lower than measured in previous years, a higher baseline average for most precipitation events has the tendency of slightly (although not significantly) increasing.

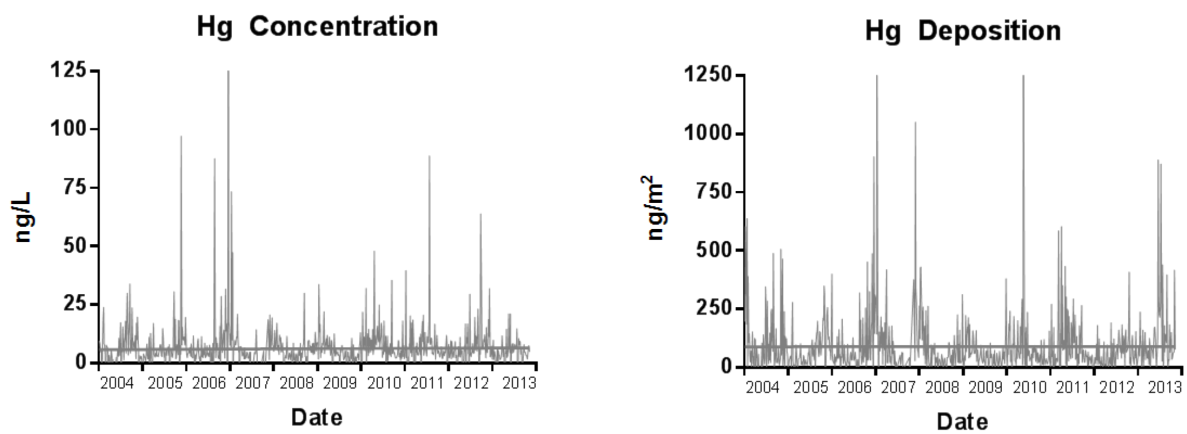

Figure 15. Long-term trends in Hg concentration and total Hg depositions for all precipitation events at the VT99 MDN site.

Implications

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

Wet deposition can account for the overwhelming majority of mercury input into the system, so beyond the trend information in wet deposition of mercury, there is more to learn about the legacy mercury already cycling through the system, and the trend in dry deposition since more precise measurements of dry deposition have only recently been initiated. Since 2008, VMC has been collecting data on elemental, gaseous oxidized and particulate mercury as part of the Atmospheric Mercury Network (AMNet), and VMC partners have studied trophic connections (Rimmer et al. 2009) and surface water dynamics (Kamman and Engstrom 2002) that could paint a fuller picture. Continuation of AMNet will allow for the determination of dry deposition rates (under consideration currently by NADP).

Mercury levels in precipitation show no clear trends in either direction, though occasional spikes and Network-wide highs and lows continue to appear.

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Additional Resources

VMC Project Database Links

Wet Deposition of Mercury at Proctor Maple Research Center (Mercury Deposition Network-MDN) http://www.uvm.edu/vmc/research/summary.php?id=319

Amphibians

The red eft (terrestrial larval phase of the eastern newt), a common denizen of the forest floor. Data from Mt Mansfield drift fences shows a slight long term decrease in newt populations at that site.

Amphibian Monitoring on Mt. Mansfield

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

The Data

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

This is the longest-running set of amphibian monitoring data in the state. We have drift-fence data from Mt. Mansfield from 1993 to the present, with the exceptions of only 2004 and 2009. For more detailed information on methods, locations of drift fences, and survey results, see the 1995 VForEM annual report at:

http://www.uvm.edu/vmc/reports/1995_AmphibianMonitoring_Inventory_LyeBrook_Report.pdf.

2013 in Summary

In 2013, all monitored salamander species were caught (Table 4), including four rare Spring Salamanders (*Gyrinophilus porphyriticus*). Young of all of the salamander species except Northern Dusky (*Desmognathus fuscus*) and Spring Salamanders were also caught for the second year in a row.

All monitored anuran (frog) species young of the year (YOY) were found in 2013 excluding Pickerel Frogs (*Lithobates palustris*) and Spring Peepers (*Pseudacris crucifer*). The absence of YOY Spring Peepers in 2013 is of particular concern because it marks the sixth consecutive year of absence following a long period of gradual decline. Only 8 adult Spring Peepers were caught in 2013, up from 3 in 2012. While the total number of American Toad adults has increased since 2012 only one YOY was found in 2013.

Although always rare at this site, the number of abnormalities remains very low.

Table 4. Monitoring results from drift fences on Mt. Mansfield in 2013.

Common Name	Scientific Name	# of all ages	# young of year	% young of year
Caudates (Salamanders)				
Spotted Salamander	*Ambystoma maculatum*	32	8	25
N. Dusky Salamander	*Desmognathus fuscus*	13	0	0
N. Two-lined Salamander	*Eurycea bislineata*	13	3	23
Spring Salamander	*Gyrinophilus porphyriticus*	4	0	0
Eastern Newt	*Notophthalmus viridescens*	14	5	36
E. Red-backed Salamander	*Plethodon cinereus*	224	9	4
Group totals	Group totals	300	25	8
Anurans (frogs)				
American Toad	*Anaxyrus americanus*	93	1	1
Green Frog	*Lithobates clamitans*	52	39	75
Pickerel Frog	*Lithobates palustris*	8	0	0
Wood Frog	*Lithobates sylvaticus*	101	38	38
Spring Peeper	*Pseudacris crucifer*	8	0	0
Group totals	Group totals	262	78	30
Amphibian totals	Amphibian totals	562	103	18

Long Term Trends

Analyses of the trends in abundance indices from 1993-2013 show that between 1993 and 2010 the Spring Peeper had all but disappeared from our fences. A good catch in 2011 and moderate catch in 2013 are not sufficient to indicate that this trend has reversed (Figure 16).

Previous trend analyses in 2001 (see 2001 VForEM annual report), indicated that three species (American Toad, Green Frog, and Wood Frog (*Lithobates sylvaticus*)) were increasing overall. This current analysis indicates that these trends have not continued. The Green Frog and the American Toad show no significant trends, although they do display large annual variation. The Wood Frog shows a dramatic decline as a result of particularly low abundance in 2005, 2006, 2008, and 2010. Wood frog catches in 2013 are up, but not enough to reverse the declining trend (Figure 16).

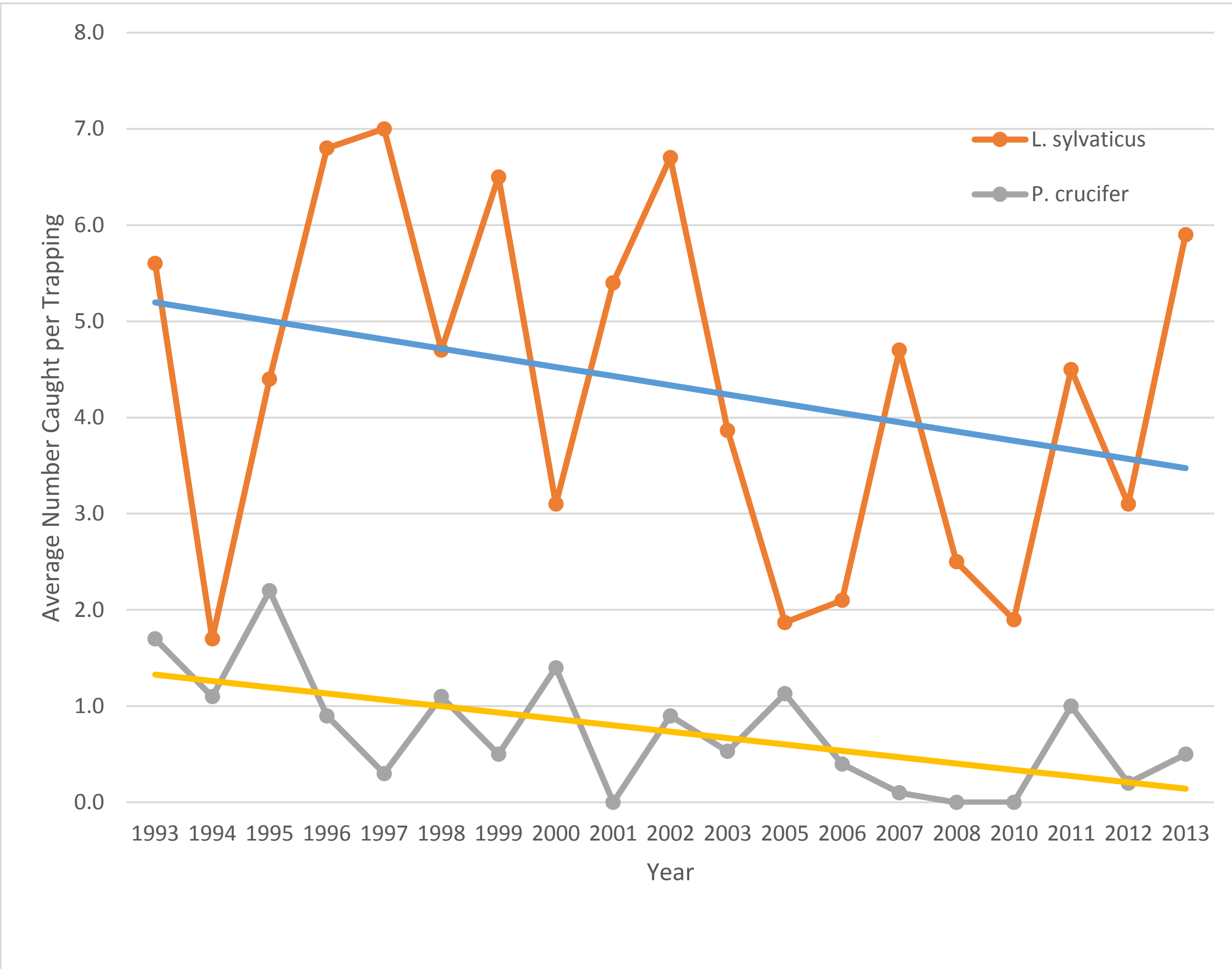


Figure 16. Long term trend lines for the Wood Frog and Spring Peeper continue to decline despite recent increases in specimens caught in drift fences on Mt. Mansfield.

The data gathered suggest that the Eastern Red-backed Salamander (*Plethodon cinereus*) shows a significant increase, with counts in 2013 nearly double 2012 totals. Spotted Salamanders, which can live up to 20 years and whose populations do not express the type of variability seen in shorter lived species, have neither declined nor increased over time. Other species such as Pickerel Frogs and Northern Two Lined salamanders are caught so infrequently that their small sample size precludes defining long term trends.

Life history differences and similarities between species will help us rule out some potential causes of these changes and suggest others, but at this point, little is known about what is driving these changes. Possibilities include aging forests, loss of edge or foraging habitat, overwintering issues, developmental problems, and predation or other changes in breeding pond condition, such as short term droughts.

Implications

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

Most species of reptiles and amphibians on Mt. Mansfield maintained or increased their population abundance, but continued declines in wood frogs and spring peeper populations remain of concern.

Additional Resources

Vermont Reptile and Amphibian Atlas http://community.middlebury.edu/~herpatlas/

VMC Project Database Link

Amphibian monitoring at the Lye Brook Wilderness and Mount Mansfield http://www.uvm.edu/vmc/research/summary.php?id=0

Climate

The Diamond Island meterorological station began operation in 2004 and provides data from the southern end of Lake Champlain.

The VMC Meteorological Network

The Vermont Monitoring Cooperative has been monitoring weather conditions in and around Vermont for over 20 years. We operate seven meteorological stations independently and coordinate on several more. We maintain several real-time data streams and dispense data to myriad users throughout the state. Weather and climate are related but very different phenomena, weather being the condition of the atmosphere (precipitation, temperature, cloud cover or humidity for example) over the short term, while climate refers to longer-term averages and expected seasonal patterns. Without long-term records it would be impossible to tease out yearly fluctuations from a bigger trend making this information critical to scientists and planners of all kinds.

The Data

Meteorological observations are taken at seven VMC sites from Lake Champlain to Mount Mansfield. Although the stations are not identical, variables collected include wind, air temperature, relative humidity, barometric pressure, solar irradiance, precipitation and on the lake, water temperature. These variables are logged as 15 minutes averages for most of the stations. The longest record comes from the Mt. Mansfield summit station that is supervised by the National Weather Service going back to 1954. The stations operated by the VMC started in the early 1990s with the newest stations added in 2010. The Underhill station predates the VMC; established in 1988, the VMC began operating it in 1992.

Climate

2013 in Summary

After a relatively mild winter and relatively dry spring, the big story in 2013 was one of excessive rain throughout the first half of the summer. May, June and July reported more than 200% the amount of rain typical for those months. By the middle of the growing season, trees stressed by excessive soil moisture and increased incidence of leaf diseases were evident (FPR 2013).

Table 5. Precipitation totals recorded at the Mt. Mansfield West met station for 2013 in comparison with the 1997-2013 long-term mean (normal).

Month	Normal Total Monthly Precipitation	2013 Total Monthly Precipitation	Magnitued of Difference
May	57	172	3.0
Jun	122	300	2.5
Jul	97	157	1.6
Aug	80	87	1.1
Sep	66	119	1.8
Oct	132	96	0.7

Winter months were relatively mild, rarely approaching the minimum extremes recorded in previous years, and nine degrees warmer than normal. Fall months were slightly cooler than normal, with average daily temperatures falling a full degree and maximum temperatures almost 4 degrees lower than average. Several high wind events in the spring and fall resulted in scattered forest damage across the region (FPR 2013)

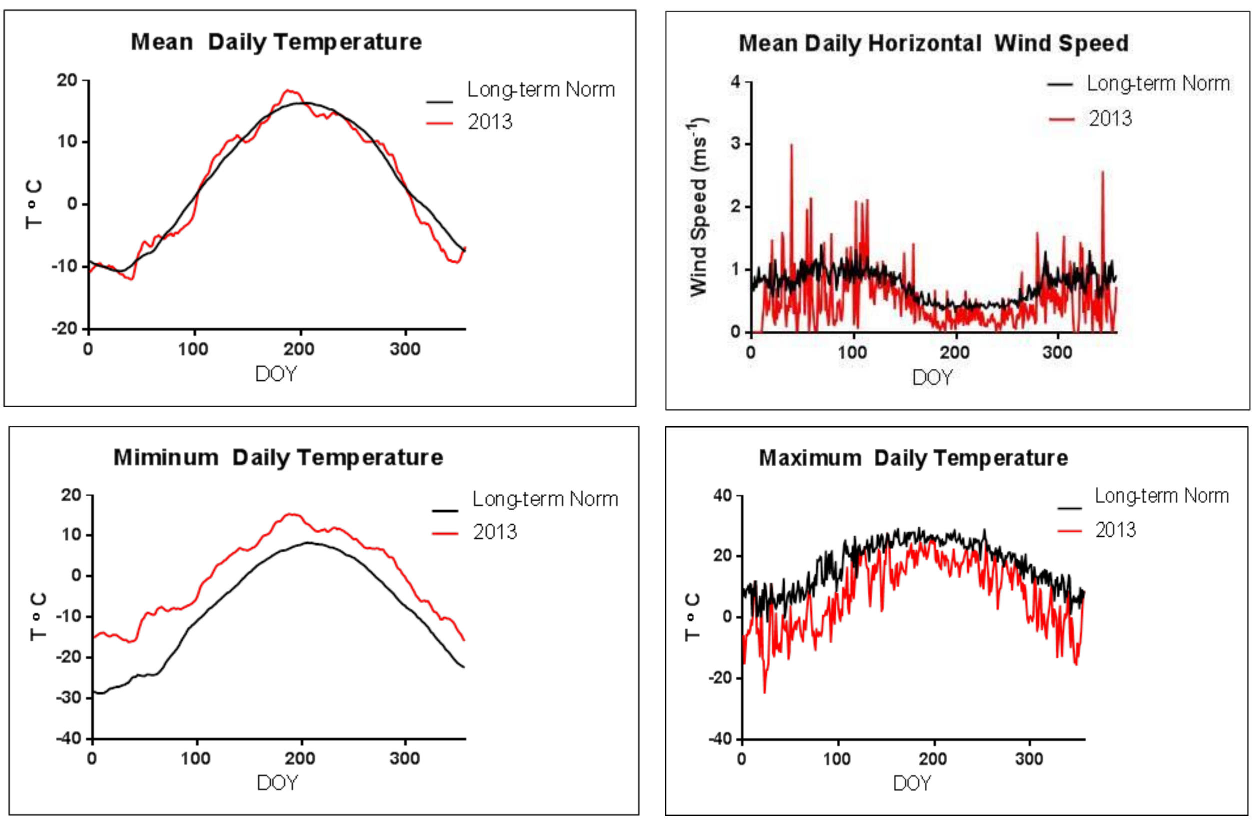


Figure 17. 2013 Daily climate metrics compared to the long-term mean at the Mt. Mansfield West meteorological station.

Climate

Long Term Trends

Because it contains one of the longest data records, long-term trends are primarily analyzed for the Mt. Mansfield West met station. Based on the daily data between 1997 and 2013, we have seen a consistent (although not significant) rise in mean, max and min daily temperatures. The most extreme change is in daily minimum temperatures, up 3 degrees on average over this data record. Most of this increase occurs in the spring and summer on Mansfield, with July reporting the strongest (and only significant monthly) long-term increase in mean temperature (p = 0.03).

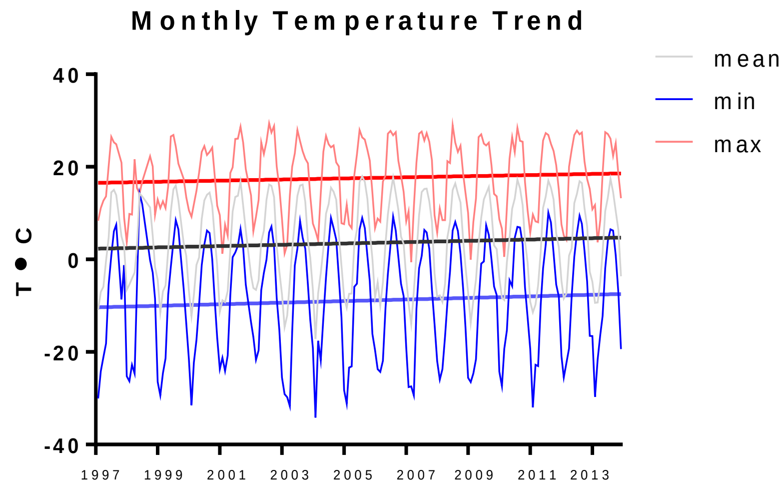


Figure 18. Monthly temperature trends at the Mt. Mansfield West met station.

While these assessments were based on the Mt. Mansfield West site, trends witnessed across the 5 VMC met stations analyzed showed similar increasing trends in temperature, except for Mt. Mansfield East. This may be due to the close proximity of this station to trails and snow making equipment at Stowe Mountain resort and changes in snow making patterns over the duration of the climate record.

Those sites with shorter data records show the strongest warming trends, indicating that the most recent years have been particularly warm compared to earlier in 2000.

Table 6. A comparison of the five VMC met stations across the region show similar warming trends, in spite of the disparity in record length. The one exception is Mt Mansfield East, which trends opposite the remaining stations for almost all records.

Full Record Change

Site	max T	mean T	min T	precip	Recorded Since
Mt. Mansfield W	1.01	1.21	1.53	-21.36	1997
Mt. Mansfield E	-1.02	-1.46	-2.48	21.70	1999
Diamond Island	1.81	0.52	1.29	5.52	2005
Colchester Reef	2.91	1.16	1.58	-7.57	2006
Burton Island	4.64	4.84	3.98	-9.67	2010

Implications

Because climate variability is high, both temporally and spatially, conditions witnessed in 2013 and the longer term trend are not necessarily indicative of a new climate regime. However, the widespread warming witnessed across the VMC meteorological network are in agreement with regional and national assessments indicating that temperatures have increased over the past several decades.

If this trend continues, for species at either the far northern or southernmost portion of their range, climate instability could make survival challenging. Even when climate conditions remain within a species' natural tolerance, changes in competitive advantages among species could alter ecosystem structure and function.

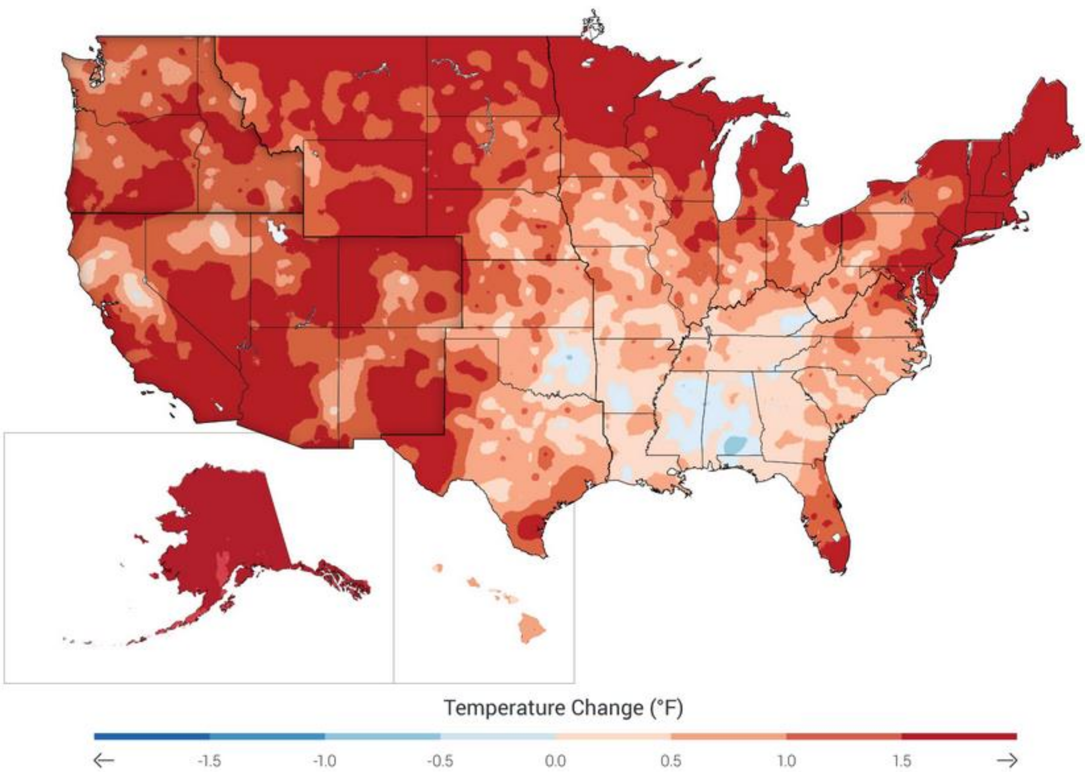


Figure 19. Observed change in mean annual temperature. Colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average (NOAA, NDCD, http://nca2014.globalchange.gov/report/our-changing-climate/recent-us-temperature-trends).

Most climate assessments use a 1960 – 1990 30 year average as a baseline. The increasing trends in more recent VMC data indicate that temperatures continue to increase, even when milder baselines such as those in the IPCC assessment are not considered. Climate continues to be the primary driver of forest growth, productivity and small scale gap dynamics. As such, understanding how conditions continue to change is imperative to sustainably managing the forest resource into the future.

As the primary driver of forest growth and productivity, we must strive to understand how climate continues to change and how that will impact the region's forests.

References

Vermont Department of Forests, Parks and Recreation (FPR). 2013. Vermont Forest Health Highlights. VT ANR, Montpelier, VT. Available online: http://www.vtfpr.org/protection/documents/2013vtforesthealthhighlights.pdf

Additional Resources

VMC Project Database Links

Burton Island http://www.uvm.edu/vmc/research/summary.php?id=234

Colchester Reef meteorological monitoring http://www.uvm.edu/vmc/research/summary.php?id=80

Diamond Island meteorological monitoring http://www.uvm.edu/vmc/research/summary.php?id=168

Mount Mansfield east slope mid elevation forest meteorological monitoring http://www.uvm.edu/vmc/research/summary.php?id=113

Mount Mansfield summit meteorology
http://www.uvm.edu/vmc/research/summary.php?id=117

Mount Mansfield west slope mid elevation forest meteorological monitoring
http://www.uvm.edu/vmc/research/summary.php?id=70

Proctor Maple Research Center meteorological monitoring
http://www.uvm.edu/vmc/research/summary.php?id=4

Watershed Hydrology

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

The Mt. Mansfield Paired Watersheds Study

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

The Data

Supported as a collaboration between the VMC and the US Geological Survey, stream 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 informs the monitoring of long-term hydrology patterns and water quality trends including: baseline conditions, trends in stream acid/base status, cations (Ca, K, Mg, Na, Si), anions (Cl, NO_3, SO_4) suspended sediment output, snowpack and snowmelt and extreme climate events. These gauging stations provide a watershed framework for other VMC efforts including nutrient cycling, forest health assessments, forest fragmentation and biological monitoring.

2013 in Summary

Water year (WY) 2013 (October to September) had none of the floods that characterized the 2008-2011 period, but it did have many large events (Figure 20), and overall runoff was greater than the long-term average. A winter that was fairly dry in the first half and snowier than average in the second half was followed by a cold early spring and a late snowmelt. Snowmelt was muted because April and early to mid-May were quite dry, so there were few rain-on-snow events that typically augment snowmelt. A very wet period began on May 20 with more than double typical rainfall during the next 7 weeks. The mid-July through September period was drier than average. The wet late spring and early summer period, coming on the heels of snowmelt, resulted in well over half of the annual runoff occurring in a 3-month period (Figure 20)

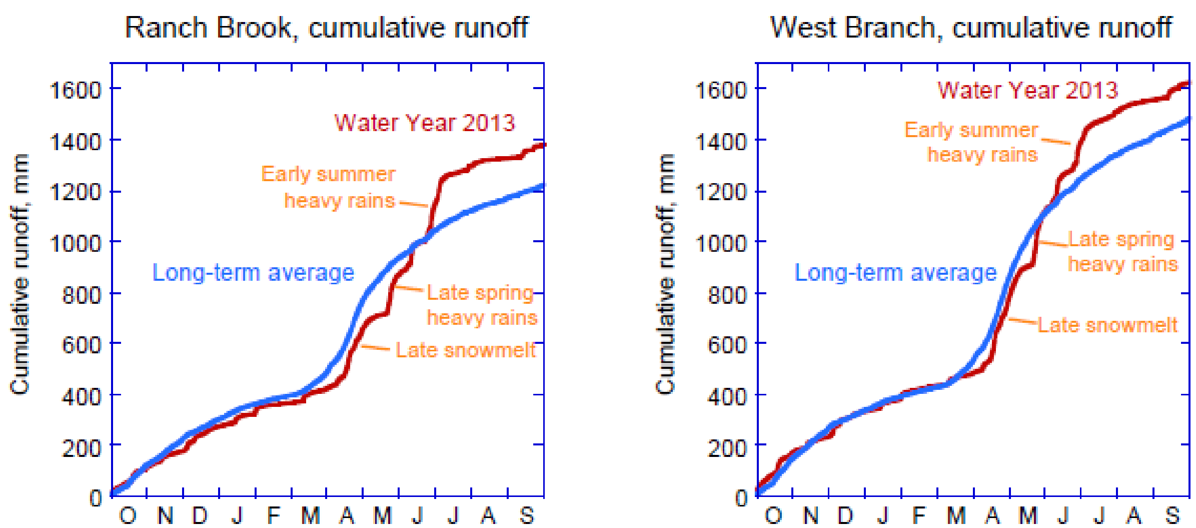


Figure 20. Cumulative runoff for Water Year 2013 at Ranch Brook (left) and West Branch (right) plotted on the long-term (2001-2013) average at each site (blue lines).

Long Term Trends

Throughout the 13 years of streamflow monitoring, West Branch has consistently yielded higher runoff (flow normalized to watershed area) than Ranch Brook (Wemple et al., 2007) (Figure 21). Over the long-term, the average difference has been 21% greater runoff at West Branch. After much greater differentials in WY11 and WY12, the difference in WY13 was below average at 18% (Figure 21). The runoff differential peaks during the snowmelt period in April and May (Figure 21), partly as a consequence of the enhanced snowpack from machine-made snow, and the prolonged melt of skier-compacted snow. The low to negative differentials in late fall and early winter result from historic water extraction from West Branch for snowmaking.

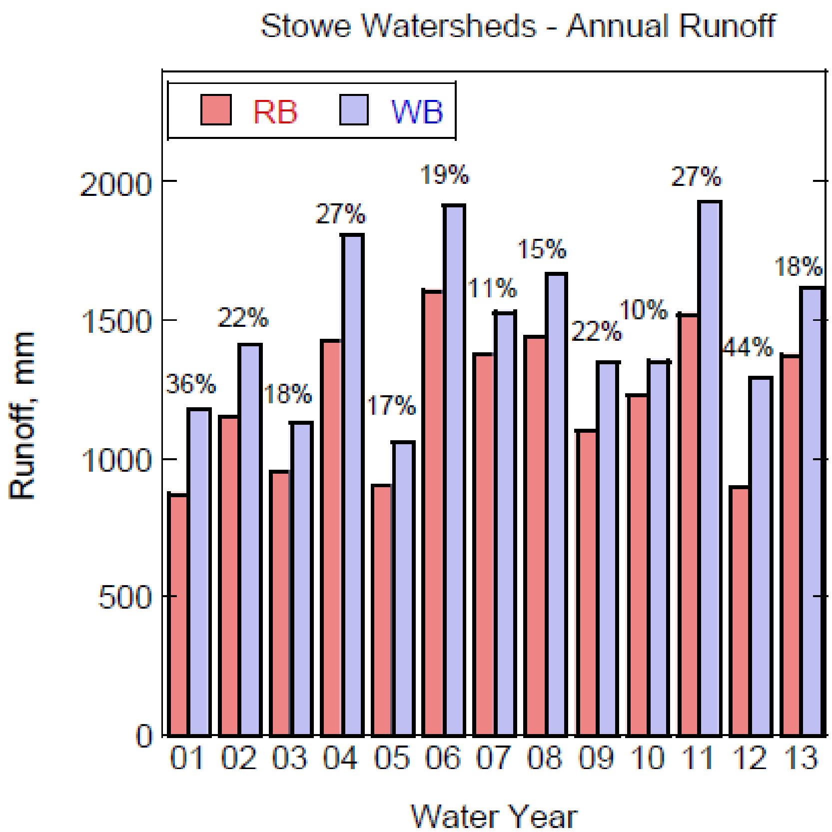


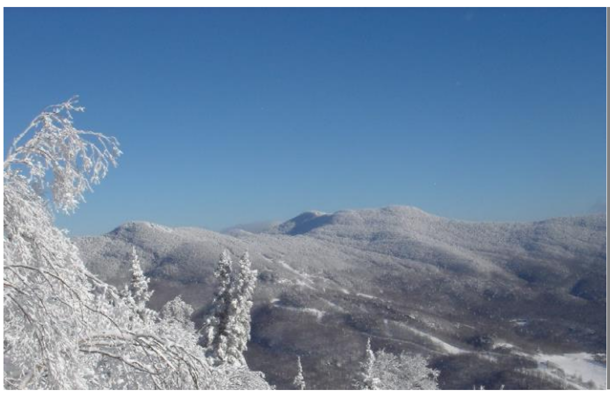
Figure 21. Annual runoff in mm at West Branch (WB) and Ranch Brook (RB) for the duration of study though the present report year. Percentage of greater runoff at WB relative to RB is given over each pair of bars.

Implications

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

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

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



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

References

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

Additional Resources

VMC Project Database Links

Paired Watershed Study on the East Slope of Mount Mansfield: http://www.uvm.edu/vmc/research/summary.php?id=111

Water Quality

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

Table 7. Data from Bourn and Branch Ponds, hyperlimnion values only.

Year	mean pH	Mean Dissolved Ca	Mean IMAI	Mean DOC
1986	5.14	1.03		
1987	5.04	0.89		
1988	4.96	0.84		
1989	4.87	0.92		
1990	5.06	0.78		
1991	4.99	0.92		
1992	5.23	0.84		
1993	5.14	0.74	128.67	4.86
1994	4.99	0.73	118.38	5.13
1995	5.32	0.77	140.63	5.11
1996	5.10	0.72		
1997	5.12	0.67		
1998	5.14	0.66	202.50	6.05
1999	5.29	0.70	246.63	6.01
2000	5.14	0.70	275.75	6.26
2001	5.16	0.63	250.38	4.77
2002	5.35	0.67	237.29	5.19
2003	5.29	0.69	305.50	6.15
2004	5.22	0.64	312.38	6.15
2005	5.23	0.60	282.86	5.55
2006	5.28	0.64	286.25	5.91
2007	5.38	0.62	228.88	4.84
2008	5.35	0.60	258.50	5.73
2009	5.58	0.62	283.88	6.10
2010	5.44	0.58	274.90	6.17
2011	5.45	0.60	306.47	6.79
2012	5.62	0.63	268.85	5.75
2013	5.55	0.61	293.13	6.76
Long-term average	***5.24***	***0.71***	***255.48***	***5.83***
2013 percentile	***0.93***	***0.15***	***0.83***	***0.94***

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

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

The Data

Long-term water chemistry monitoring has been carried out at two acid-sensitive lakes in the Lye Brook Wilderness area since the 1980s. The ponds, Bourn and Branch Ponds, are approximately 9.0 and 12.0 meters deep respectively, dark colored, have low pH and stratify in the spring and summer. Samples are collected three times a year in the spring, summer and fall, using a Kemmerer water sampler, at 1 m from the surface and 1-2 m from the bottom in the summer when the lake is stratified. The variables measured include field pH, Lab pH, gran alkalinity, specific conductance, calcium, magnesium, sodium, potassium, aluminum (both speciated organic and monomeric, and total dissolved), nitrate, sulfate and chloride. The methods of collection, processing and analysis have remained consistent for nearly 30 years.

2013 in Summary

Water quality at Bourn and Branch Ponds in 2013 was consistent with long- term trends. Both mean pH and dissolved organic carbon (DOC) values reported levels in the highest 10% of all observations over the near 30 year record. While toxic monomeric aluminum was also in the top 20% of highest values, it did not approach the 300mg/L witnessed in 2003 and 2004. In contrast, dissolved calcium concentrations in 2013 were among the lowest on record, continuing a long, steady decline in this critical base cation.

Long-Term Trends

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

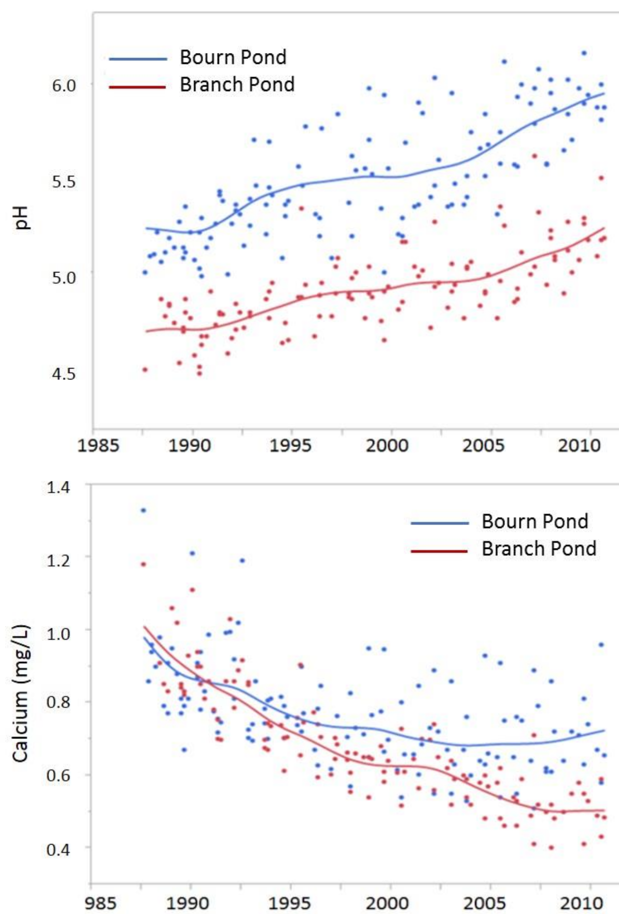


Figure 22. Long-term increases in pH (top) are offset by decreases in dissolved calcium (bottom, mg/L) at the VMC water quality sites.

off since 2005 in Bourn Pond, although it continues to decrease in Branch Pond.

Dissolved Organic Carbon (DOC) mediates the impacts of the toxic form of aluminum (IMAL) to biota. DOC levels have been increasing at both Bourn and Branch Ponds, which could aid in biological recovery. However the rate of increase in IMAL exceeds the rate of increase in DOC by a factor of 10 over the 20 year duration of our monitoring efforts. But because recent increases in IMAL appear to have leveled off, while increases in DOC continue, it is possible that this trend could be reversing.

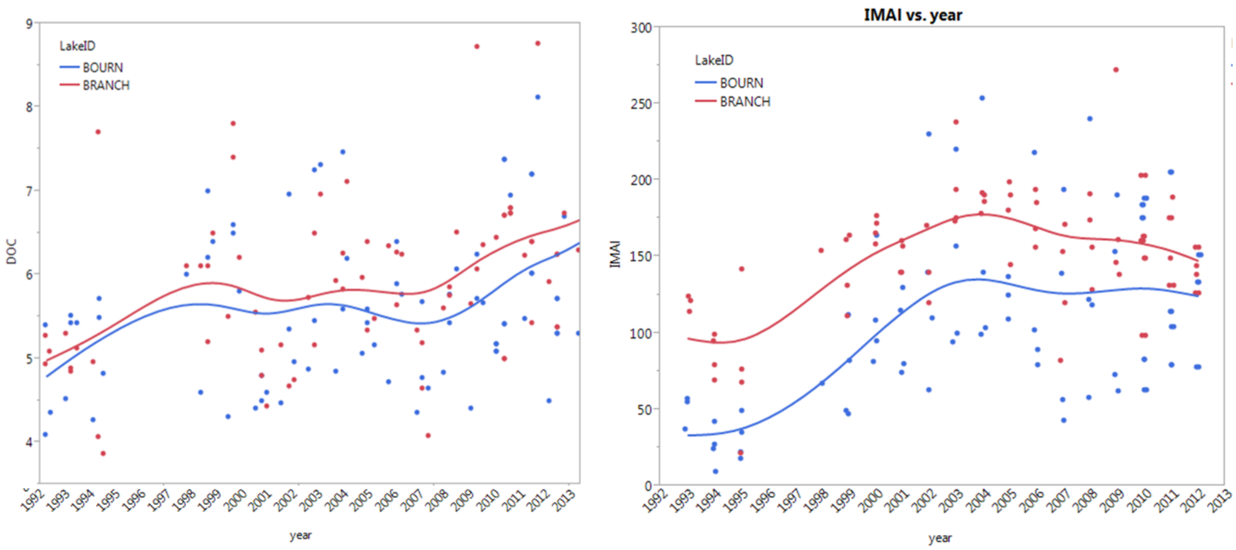


Figure 23. Long-term trends in dissolved organic carbon (DOC) (left) and Inorganic Monomeric Aluminum (right) provide additional indicators of the health of high elevation surface waters.

Implications

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

Acid-sensitive lakes have improved significantly since the 1990 Clean Air Act Amendments. But, because of the loss of calcium and magnesium throughout the watershed and in the lake itself, sensitive fish, snails, and insect species will not recover until further reductions in sulfur and nitrogen occur. In addition, time is needed to allow bedrock and soils to resupply calcium and magnesium to the lakes through the weathering process. Analysis of air and water quality by means of chemical and biological inventories on these sensitive lakes will be maintained. Monitoring the lakes in Lye Brook Wilderness can not only be used to document trends resulting from emission reductions required by the Clean Air Act, but any potential new sources of stress or pollution that may come on line. Such indicator trends are being used to inform management about the recovery of these water bodies.

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

Additional Resources

VMC Project Database Links

Biological and Chemical Survey of Selected Surface Waters in Lye Brook Wilderness Area: Water chemistry of water bodies
http://www.uvm.edu/vmc/research/summary.php?id=10

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***Forest Birds* Section**

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***Mercury Deposition* Section**

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