FEMC

Forest Ecosystem Monitoring Cooperative

Regional Monitoring Update 2017

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

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The Forest Ecosystem Monitoring Cooperative Regional Monitoring Update - 2017

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Acknowledgments

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The Forest Ecosystem Monitoring Cooperative Editorial Staff

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Introduction

The Forest Ecosystem Monitoring Cooperative (FEMC) was 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 mission of the FEMC is to facilitate collaboration among federal, state, non-profit, professional and academic institutions for long-term monitoring of forested ecosystems across the region and an improved understanding of forest ecosystems in light of the many threats they face.

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

Driven by its mission to aggregate the information necessary to monitor forest health, detect chronic or emergent forest health issues and assess their impacts on forested ecosystems, the FEMC staff have built on its experience developing monitoring reports for Vermont (see the 2017 Vermont report at https://www.uvm.edu/femc/products/long_term_update/2017/vermont). FEMC staff have brought together data on an initial subset of regional monitoring programs to expand the focus of its work and provide more insight into trends in ecosystem processes at a larger scale. This Regional Monitoring Update offers a sampling of four key long-term data sets that represents key aspects of the structure, condition and function of the forested ecosystem. Our goal is to include both a summary of the latest year's data on key forest, water, and air quality metrics, along with an analysis of the long-term patterns and trends in the data in order to provide a relevant and timely source of information on the current state of the region's forested ecosystems. This allows us to quantify metrics collected in 2017 in the context of long-term monitoring datasets.

The information in this Regional Monitoring Update is intended to be a snapshot of the larger body of monitoring and research that has been amassed over time, and which is growing daily. As an organization, FEMC believes that the regular analysis and reporting of such information is critical to identify emerging forest health issues, as well as understand the drivers and impacts of ecosystem change.

Staff Writer: Alexandra Kosiba

Precipitation Chemistry and Acid Deposition

National Atmospheric Deposition Program/National Trends Network

The ecological consequences of atmospheric acid deposition have been well studied in the northeastern US. Acid rain has led to the decline of red spruce in the 1970s and 80s, the leaching loss of calcium and other cations from soil, and the acidification of lakes and streams. The continental scale of NTN sites reveals spatial and temporal trends in acid deposition in 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. Two measures of acid deposition are sulfate (SO_4^{2-}) and nitrate (NO_3^-). When emitted as air pollutants, these molecules can form acids through reactions with water in the atmosphere, creating what we know as 'acid rain'. Recognizing this serious environmental threat, regulations were enacted to control emissions of sulfur and nitrogen oxides, which react in the atmosphere to produce acidic compounds; as a result, acidic deposition has declined and ecosystem recovery is underway.

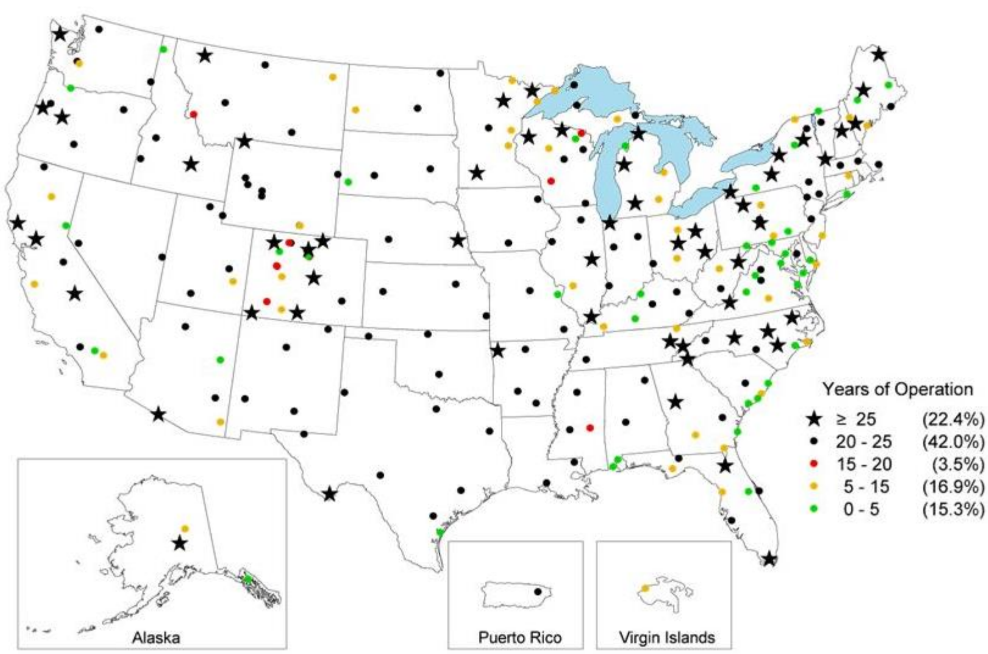

Figure 1. Locations of National Trends Network monitoring sites. Source: NADP.

The Data

National Atmospheric Deposition Program (NADP) has been monitoring precipitation chemistry in the US since 1978 through the National Trends Network (NTN) program. The 250 national NTN sites collect data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation (Figure 1).

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

This report details current year and long-term trend statistics for Maine, Massachusetts, New Hampshire, New York and Vermont.

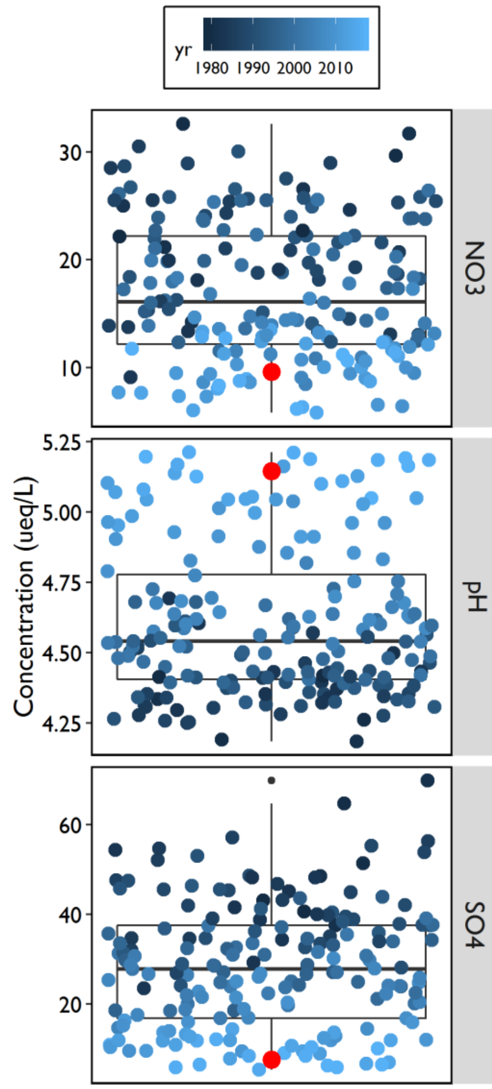

Figure 2. Average annual concentration of nitrate (NO_3^-), pH, and sulfate (SO_4^{2-}), for the NADP sites in the region, displayed with quantile box plots. The most recent year's (2017) average measurements are indicated in red, and shades of blue correspond to the year, with lighter values corresponding to more recent data. Solid horizontal line indicates the long-term mean across all monitoring sites; any points outside vertical bars at top and bottom of boxes show values that are statistically outside of the range for that parameter.

2017 in Summary

For all three metrics of acid deposition (NO_3^-, pH, SO_4^{2-}), 2017 continued the trend of reduced concentration compared to the high values experienced in the historical record (Figure 2).

The lowest amount of nitrate concentration in the regional record occurred in 2010 (8.8 ueq/L), signaling a considerable decline from a peak of 32.0 ueq/L in 1980 (Figure 3). However, following this nadir in 2010, NO_3^- concentration rose slightly and then plateaued. Yet, during this period, NO_3^- concentration continued to remain much reduced compared to the historical record. In 2017, we again saw a decline in concentration, with the second lowest amount in the record (10.1 ueq/L; Figure 2, Figure 3). This may signal improved reductions in other sources of nitrate emissions.

In comparison, 2017 marked the lowest mean sulfate concentration in the regional record (8.3 ueq/L), which continued the trend begun in 2015 of lower sulfate concentration compared to nitrate (Figure 3). This a considerable decline from peak sulfate concentration in 1980 of 62.0 ueq/L.

The regional average pH was the second highest in the record at 5.17. While 2016 marked the highest pH value in the record (5.19) the average value in 2017 was nearly the same as the previous year. These results indicate that precipitation in the form of rain, snow, or ice is less acidic than in the historical record and improvements on limiting acidic emissions are working. However, while the pH has increased considerably from the record's low of 4.2 in 1980, "unpolluted" rain typically has a pH of 5.6; therefore, there is still room for 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, sulfates accounted for about 66% of the acidity in precipitation, while nitrates contribute the other 33%. While upwind emissions of both sulfur oxides (SO_X) and nitrogen oxides (NO_X) have declined over time, reductions in SO_X have been greater than NO_X. While the stress imposed by SO_X deposition has been greatly reduced, it is unclear how the continued deposition of NO_X will impact forested ecosystems. Further, it is unclear how low these values could fall before they plateau; indeed, this may have already occurred for deposition of nitrate.

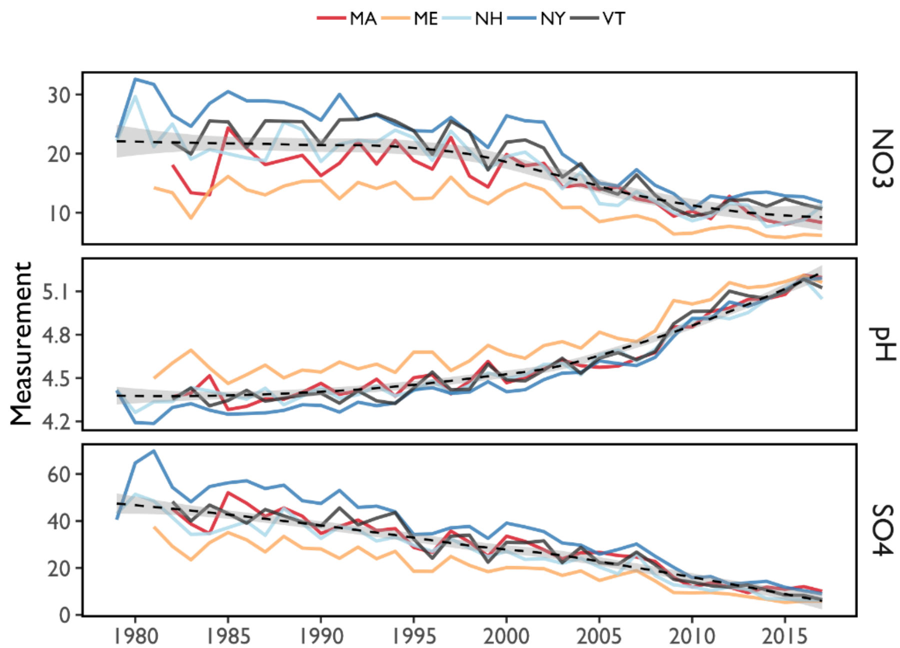

Figure 3. Long-term precipitation chemistry showing annual mean concentrations (ueq/L) of nitrate (NO_3^-) and sulfate (SO_4^{2-}), and mean pH (solid colored lines) for the five states in the region. Black dotted line shows regional trend (LOESS function) with 95% confidence intervals (grey shading.)

Long-term Trends

Since precipitation chemistry was first measured in the region, rain has become less acidified (Figure 3). These changes reflect declines in sulfur- and nitrogen-based emissions due to the Clean Air Act (1977) and subsequent amendments (1990). The most significant reductions have occurred for sulfate concentration, which has fallen from nearly 62.0 ueq/L in 1980 to less than 9 ueq/L currently. Concurrently, there has been a dramatic increase in precipitation pH (Figure 3). Note that for certain years, there is higher variability, which shows the variation in the region based on aspect and location of the monitoring site (see Figure 4). Sulfuric emissions have been easier to control through regulation of emissions from the burning of coal, natural gas, and other fossil fuels. Looking forward, it is likely that reductions in SO_4^{2-} may continue (Figure 3), along with resultant decreases in precipitation acidity.

More modest changes have been measured for nitrate deposition (Figure 3) and it appears that reductions in NO_3^- concentrations may have plateaued. 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. This diffuse nature of nitrogenous pollution means that continued reductions may require additional legislative or regulatory action.

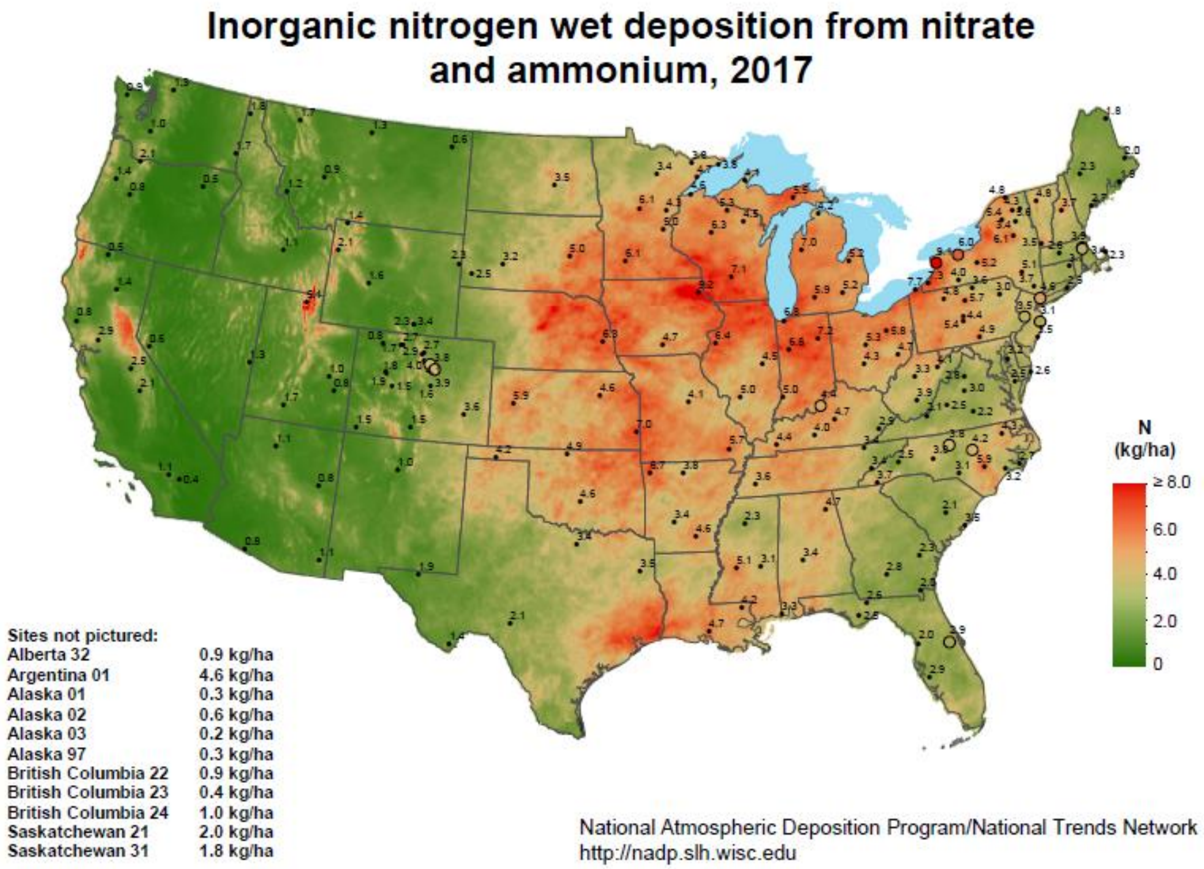

Figure 4. Spatial distribution of inorganic nitrogen wet deposition (kg/ha) across the continental US in 2017. Source: NADP.

Implications

The region is in relatively good shape compared to nitrogen pollution loads nationwide (Figure 4). However, high elevation forests are still 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. Further, there are some areas of the region, particularly western and southern portions of New York, which have continued to receive elevated nitrogen deposition (Figure 4).

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. Continued reductions in nitrogen deposition may require additional regulation to control widely dispersed sources.

Acid deposition continued to decline in 2017. The average pH of precipitation was 5.1, well above the historical low. Nitrate deposition reductions may have plateaued and should continue to be monitored.

Additional Resources

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

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

FEMC Project Database Links

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

Staff Editor: Charles Nicholson &
Alexandra Kosiba

Water Quality in Acid-Sensitive Lakes

The Acid Lakes Long Term Monitoring Program

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

The Data

When high-elevation lakes in geologically sensitive areas were becoming acidified, the Environmental Protection Agency (EPA) enacted the Acid Lakes Monitoring Program in Vermont, New York, and Maine under the Long-Term Monitoring Program (LTM). Note that data from Maine only extends up to 2016 and not all yearly parameter values were available from each state.

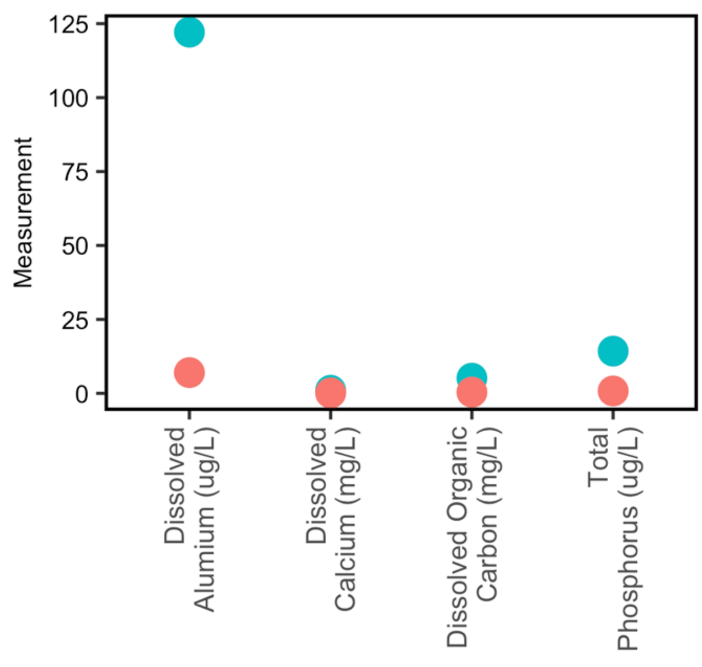

Figure 5. 2017 water quality measurements from acid lakes/ponds in Vermont (blue) and New York (red) for four selected variables. Note that Maine acid lakes data was only available up to 2016.

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

2017 in Summary

In 2017, we saw a range of values for water quality measurements in the lakes and ponds in the regional Acid Lakes Monitoring Program. This reflects the variability in the different water bodies in the region, as well natural variability in the parameters measured. For some, but not all, of the measured water quality parameters, average values among the regional acid lakes improved from 2016.

A good indicator of improving water quality, dissolved aluminum has continued to decrease precipitously, although we see a large range in values depending on location (Figure 5). Vermont acid lakes contain a great deal more dissolved aluminum compared to acid lakes in New York. As we do not have access to 2017 data in other states, we cannot assess if there are similarities with other states. Yet, in 2016, Maine acid lakes showed a range of dissolved aluminum values that are similar to Vermont's mean concentration, which may indicate that New York concentrations are on the low end regionally.

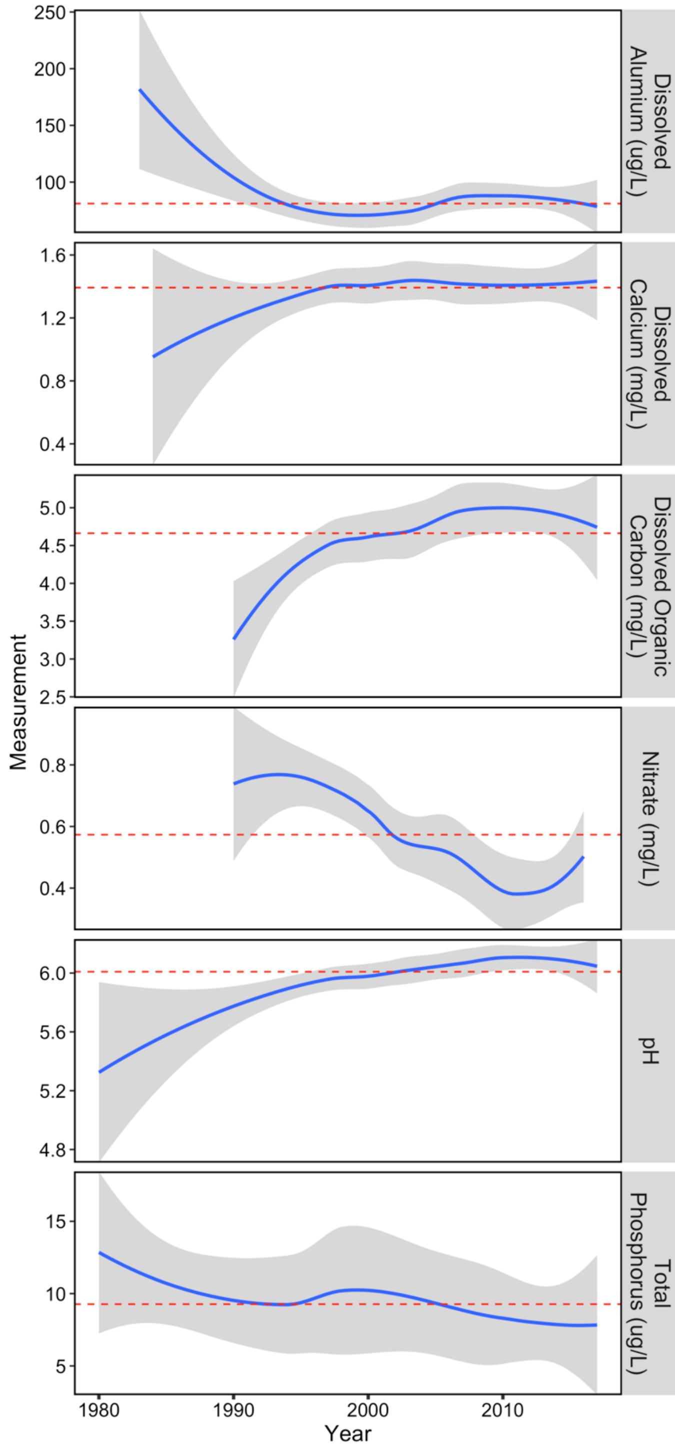

Figure 6. Average water quality measurements from the lakes/ponds in the regional (VT, NY, and ME) Acid Lake Monitoring Program (blue line, smoothed with LOESS function), plus 95% confidence interval (grey shading). Red dashed line indicates the long-term average per measurement type.

For both New York and Vermont, dissolved calcium concentrations are similar in 2017 (Figure 5), and show a slight reduction from the previous year. This is a positive sign of decreasing acid deposition.

Dissolved organic carbon is a broad grouping of organic molecules resulting from decomposing organic matter. It is not only a food source for aquatic microorganisms, but is an indicator of terrestrial health. In 2017, Vermont had much a higher mean concentration of DOC compared to New York (5.15 and 0.39 mg/L, respectively) (Figure 5), with both states showing an increase from the previous year. For context, mean DOC concentration in Maine in the most recent year of data (2016) was 4.8 mg/L, which is comparable to Vermont. Why New York acid lakes contain much less DOC is unclear.

Vermont also had higher concentrations of phosphorus compared to New York (14.3 and 0.8 ug/L, respectively; Figure 5). Vermont and New York values were slightly higher than in 2016.

Long-term Trends

The data from the regional acid lakes show evidence that acid accumulation and cation leaching have declined over the long-term record (1980-2017). Water pH has been increasing over time and has surpassed the regional mean of 6.0 in recent years (Figure 6). Concurrently, dissolved aluminum has been decreasing precipitously since it was first measured in the mid 1980s. Surprisingly, we are not seeing a similar regional reduction in dissolved calcium, although concentrations have plateaued and are declining in the last few years. This may reflect the spatial variability among the states, including different bedrock materials and soil types.

Another good indicator of ecosystem health, dissolved organic carbon has been increasing since it was first measured in the early 1990s; however, in recent years there is a slight decline in this trend (Figure 6). Mean nitrate concentration has been showing a declining trend, which is a good indication of less acid loading.

Total phosphorus shows a varied pattern, but overall there is a decrease in concentration from a peak in 2003 (Figure 6). The concentrations detected in the regional acid lakes are below the threshold for ecosystem issues. Phosphorus, which is easily transported in water, is an essential nutrient for all life, however, excessive concentrations can lead to algal blooms.

Implications

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

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

In 2017, most water quality indices have improved. However, limited datasets among the states mean that results should be taken lightly. Overall, the long-term data (1980-2017), provide support that vulnerable lakes and ponds in the region are recovering from decades of acid rain. Moving forward, phosphorus may become more problematic as acidic inputs decline.

Additional Resources

New York Long Term Monitroring Program Data, Adirondack Lakes Survey Corporation website, http://www.adirondacklakessurvey.org/

EPA Clean Air Markets – Monitoring Surface Water Chemistry: https://www.epa.gov/airmarkets/clean-air-markets-monitoring-surface-water-chemistry

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

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

Data Credits

The US EPA–USGS LTM/TIME and portions of the HELM project was funded by EPA ORD to J.S. Kahl, W. McDowell, S.J. Nelson, K.E. Webster; and EPA CAMD to W.H. McDowell, J.S. Kahl, S.J. Nelson (IAG 06HQGR0143), processed through Grant/Cooperative Agreement G11AP20128 from the United States Geological Survey

Broad-Scale Forest Disturbance

Insect and Disease Surveys of Forest Disturbance

Damage to trees caused by insects, disease, animals, and weather are a natural and common occurrence in the region's forests. Such disturbances can result in changes to biodiversity and species composition, and allow for cycling of nutrients from trees to soil. However, forest disturbances can also negatively affect timber quality, damage infrastructure, and impact important ecosystem services. There is concern that climate change and continued introduction of non-native insects and diseases could alter the frequency and severity of forest disturbances.

The Data

Insect and Disease Surveys (IDS) (formerly, Aerial Detection Surveys, ADS) have been used to map the cause and extent of forest disturbances in the US for many years. Annual sketch-mapping surveys are collected by the individual state agencies, and by the US Forest Service on federal lands, via fixed-wing airplane by trained technicians. The US Forest Service Forest Health Monitoring Program sets survey methods and standards. Mapped polygons include information on the disturbance cause, type, size, and severity, and are confirmed with ground assessments. Causal agents of disturbance can range from insects and disease, to weather events, wild animals, and humans. Surveys are a cost-effective and vital tool for detecting emerging forest health issues and tracking trends. However, surveys are not comprehensive of all forest damage and cannot capture subtle or patchy disturbance or light decline.

We examined forest disturbances via IDS for the five states in the northeastern region (Massachusetts, Maine, New Hampshire, New York, and Vermont). Please note that survey scope and coverage are not uniform between the five states; therefore, it can appear that some states have more disturbances than others, which is a result of differing priorities and methods implements during surveys. While all these states have data going back in time to different years, 1997 was the first year in which methods were largely standardized across the region, so we use that as the first year in any trend analysis.

2017 in Summary

In 2017, 38 different causal agents of forest disturbance were mapped in the five-state region. Together, these damages amounted to 585,488 hectares (1,446,770 acres), which is an increase from 2016 when only 341,356 ha (843,507 ac) were mapped. However, damage in 2017 amounted to a little more than 3% of the region's forestland (Figure 7), which is equal to the average forest damage per year from 1997 to 2017, averaging 3.1% or 598,381 ha/year.

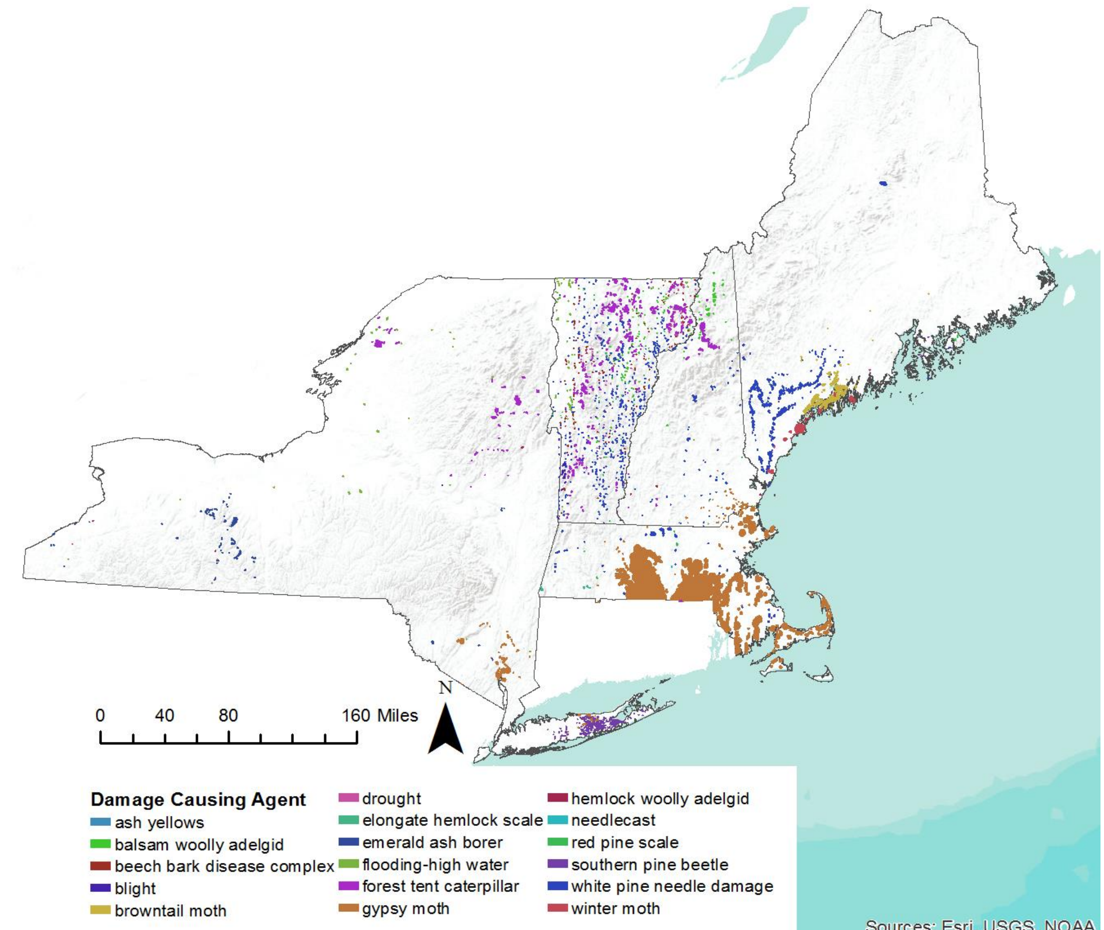

Figure 7. Locations of select forest disturbance agents in 2017 from region-wide Insect and Disease Surveys. Only agents with considerable disturbance area are shown. Note that disturbance polygons were increased in size for visibility, but also states have had differing methods for quantifying disturbance.

As in 2016, we saw substantial damage caused by introduced (non-native) pests. In 2017, introduced insects and diseases caused nearly 10 times more disturbance (481,187 ha) compared to those of native origin (49,067 ha, Figure 8), which is an increase from the previous year.

Gypsy moth (*Lymantria dispar*) was mapped on the most area of all disturbance agents -- 437,349 ha (1,080,712 ac) of forestland -- primarily in Massachusetts (Figure 7). While this is a considerable increase from 2016 (150,510 ha), it is possible that some of this change is due to shifts in the way disturbance polygons are mapped with the latest technology. For more information on gypsy moth defoliation in Massachusetts, see the report by MA Department of Conservation and Recreation (2018).

Damage attributed to another invasive insect, browntail moth (*Euproctis chrysorrhoea*), was mapped on 21,031 ha (51,968 ac) of forestland, which was a slight decrease from the previous year (28,329 ha) (Figure 8) and may suggest that this outbreak, which is primary situated in southern Maine, may be waning.

However, some native insects also caused considerable disturbance (Figure 8). Forest tent caterpillar (*Malacosoma disstria*) was the second most damaging agent in 2017, mapped on 41,641 ha (102,896 ac), marking the second year of an outbreak. The majority of this disturbance occurred in Vermont (Figure 7).

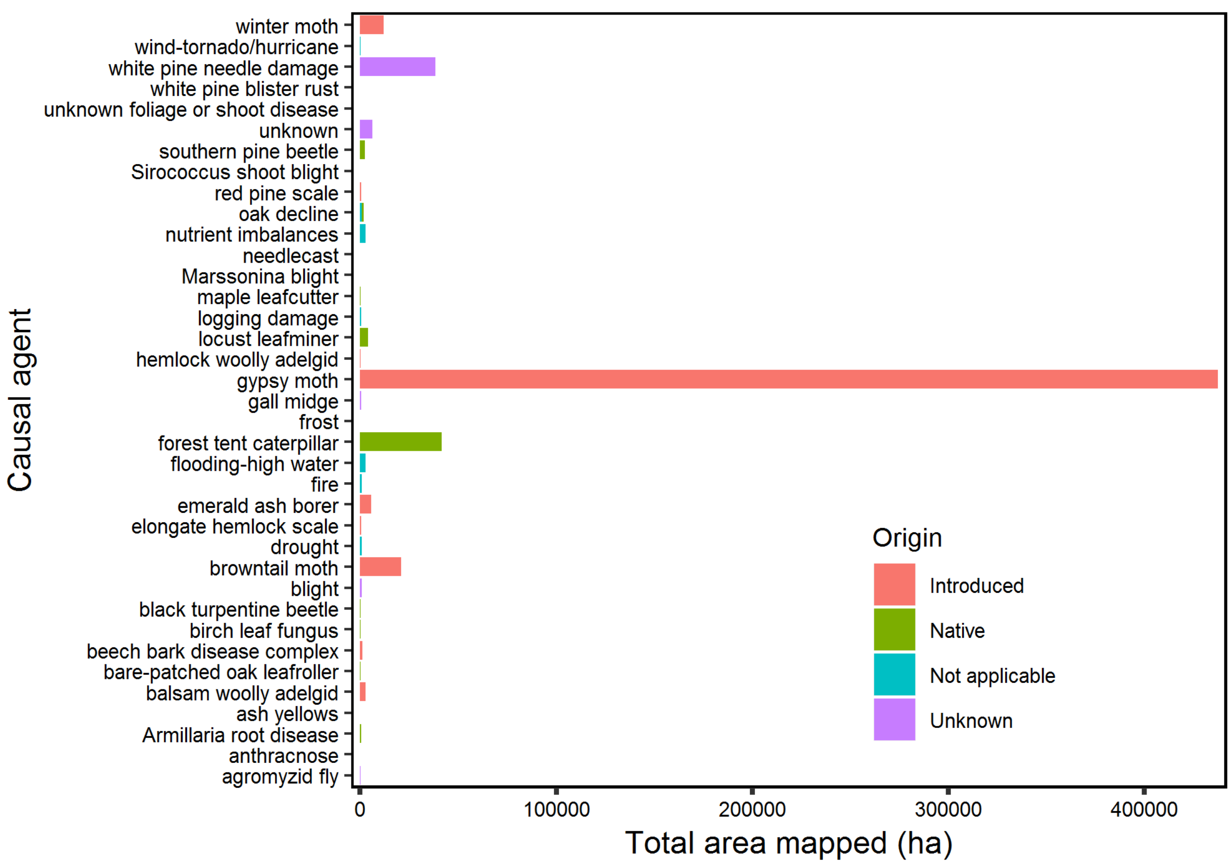

Figure 8. Total mapped disturbance (in hectares) by causal agent from 2017 Insect and Disease Surveys in the Northeast. Color of bar corresponds to the origin of the agent.

A positive finding was that the area mapped with white pine needle damage area declined from 2016 (38,375 ha in 2017, 71,364 ha in 2016). White pine needle damage has been attributed to a complex of fungal pathogens, which are dependent on moisture availability. The dry conditions in spring 2016 may have reduced disease severity in 2017.

Long-term Trends

Total disturbance mapped per year (1997-2017) shows substantial year-to-year variability in total forest damages (Figure 9). This is partially to do with divergent forest health priorities and differing amount of forestland surveyed between the five states. In addition, several causes of forest disturbances are episodic, like weather events (e.g., late spring frost events, drought) and many insect outbreaks, (e.g., balsam wooly adelgid, *Adelges piceae)*. The year of the greatest disturbance occurred in 2005 during an outbreak of the non-native insect, balsam wooly adelgid that affected 1,860,334 ha.

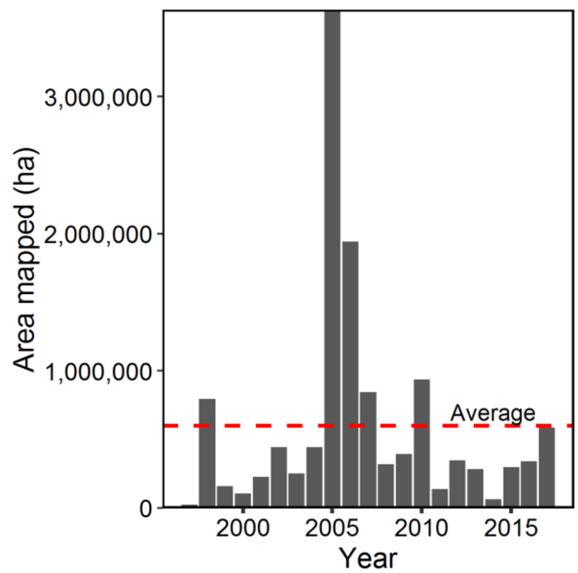

Figure 9. Total area mapped as disturbed according to Insect and Disease Surveys (grey bars; hectares) by year in the Northeast. The red dashed line indicates the average disturbance over the entire timeframe (1997-2017).

Region wide, around 200 damage agents have been mapped during Insect and Disease Surveys since 1997. Only three agents have been detected regionally every year in the 21-year period: gypsy moth, flooding/high water damage, and beech bark disease (a complex between *Cryptococcus fagisuga* scale and *Neonectria* fungi [*N. faginata* and *N. ditissima*]; Figure 10). 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 10). In general, insects and abiotic agents have had the largest effect on the region's forests. The three most damaging agents overall have all been insects: balsam wooly adelgid (3,150,140 ha), forest tent caterpillar (1,576,846 ha), and skeletonizer (1,107,655 ha; species unknown).

Abiotic disturbance agents, like ice-snow loading, frost events, and drought have also had a sizable impact on the region's forests. Unlike biotic agents, abiotic disturbances typically affect trees regardless of species. As a result, abiotic agents can cause widespread disturbance when they do occur (Figure 10).

Only 13 agents have resulted in total damage greater than 100,000 ha in the 21-year period (Figure 10). Many tree diseases identified in the region have not caused large disturbance extents despite frequent occurrence. Of diseases, beech bark disease and anthracnose (G*nomonia* spp.) have resulted in the largest disturbance area, and white pine needle damage is becoming more widespread (Figure 10).

The large effect of introduced insects and diseases over the 21-year period is cause for concern: introduced agents affected over twice the amount of forestland (4,938,800 ha) compared to those of native origin (2,151,235 ha). However, as new pests and pathogens emerge, often the origins of agents are unknown; agents of unknown origin have caused substantial disturbance overall (3,328,415 ha). These results demonstrate the destructive nature of introduced pests and support the need for continued monitoring.

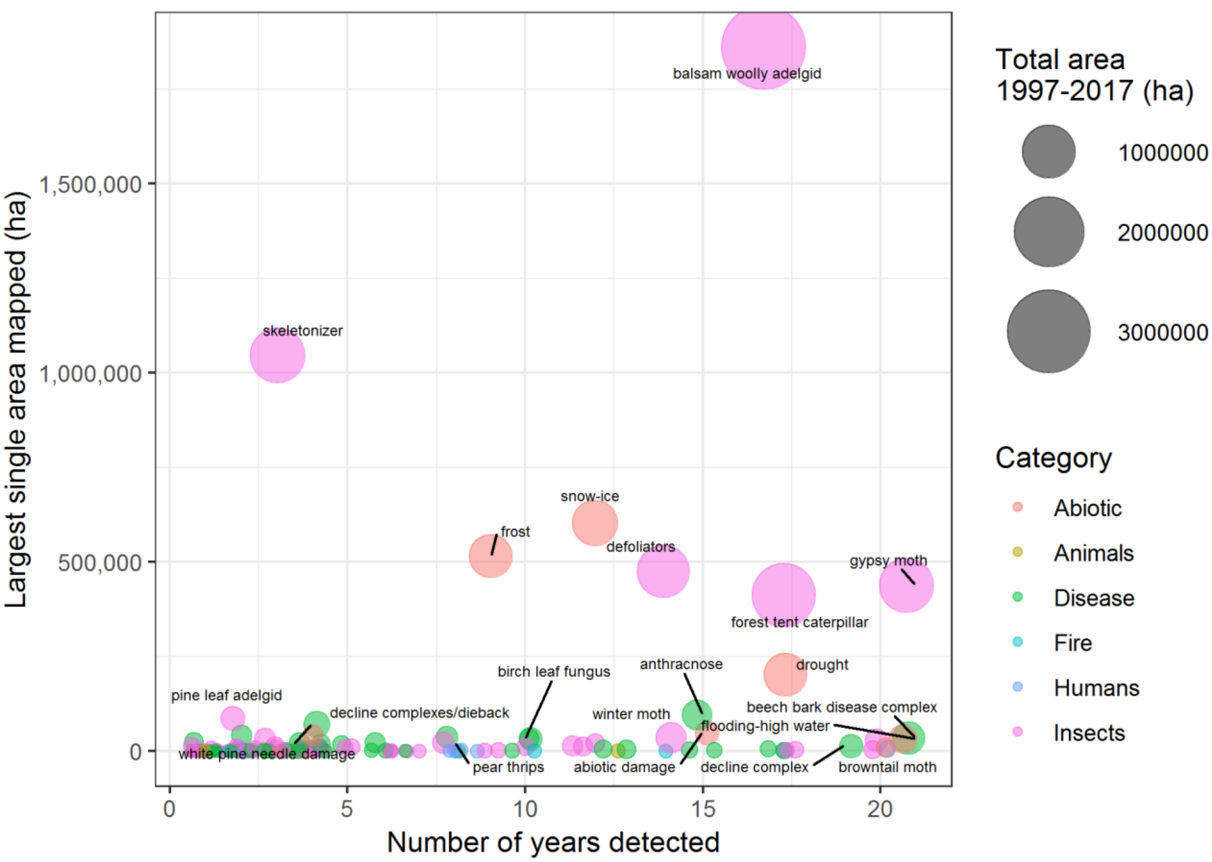

Figure 10. Mapped disturbance agents from region-wide Insect and Disease Surveys (1997-2017) plotted by the frequency (number of years detected) and largest single area mapped (ha; e.g., largest single polygon identified for that agent). Circle size corresponds to the total area recorded for that agent over the 21-year period and color corresponds to the agent category. Only agents that have affected >50,000 ha in total are labeled for clarity.

Staff Editor: Alexandra Kosiba

Implications

IDS data provides the longest region-wide annual record of forest disturbances. Over the past 21 years, relatively low levels of total forest disturbance have been mapped, with most agents causing small damage extents and minor total damage.

Disturbance agents that lead to repeated and extensive damage are more likely to have significant impacts on forest health and productivity. Many biotic agents tend to be chronic or episodic, while abiotic events are often less predictable, yet can result in large disturbed areas. 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 10). It is only as we continue to monitor disturbances over time can we begin to understand the patterns of various types of events and how they may be changing.

Many invasive insects and diseases have been detected in the region, or have been detected nearby. These pests and pathogens have caused much more disturbance to the region's forests than those of native origin, and we could see widespread declines of specific species, such as ash (*Fraxinus* spp.) with the continued spread of emerald ash borer. The good news is that we are not seeing increases in total disturbance over time. The high species diversity in many forest stands and continued vigilant monitoring may be helping to mitigate widespread issues and to identify problems before they become widespread.

In 2017, there was an increase in forest disturbance compared to 2016, primarily driven by more gypsy moth damage. There was also 10 times more damage attributed to invasive insects and diseases compared to those of native origin. Continued monitoring is essential to examine trends and detect novel agents.

Additional Resources

Massachusetts Department of Conservation and Recreation (MA DCR). 2018. A Guide to Gypsy Moth in Massachustts. Available online at https://www.mass.gov/guides/gypsy-moth-in-massachusetts

Northeastern Forest Health Atlas. 2018. Available online at https://www.uvm.edu/femc/forest-health-atlas

FEMC Project Database Links

Northeastern Regional Aerial Detection Surveys: https://www.uvm.edu/femc/data/archive/project/northeastern_ads

New York Aerial Forest Health Surveys: https://www.uvm.edu/femc/data/archive/project/nydec-aerial-survey

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

Staff Editor: Charles Nicholson

Climate

Climate Monitoring in the Northeast

Weather and climate are related but very different phenomena. Weather describes the the condition of the atmosphere (e.g., temperature, rainfall, snow) 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.

The Data

The Northeast Regional Climate Center[1] (NRCC) provides detailed information on trends in climate and weather for the Northeast. We expanded the climate summary for 2017 beyond the FEMC monitoring stations in Vermont to include trends from the surrounding 11 states (Maine, New Hampshire, New York, Massachusetts, Connecticut, Rhode Island, New Jersey, Pennsylvania, West Virginia, Delaware, and Maryland) using records from the NRCC. This regional summary provides a broader picture of emerging trends across a larger region. Much of the following regional summary is adapted from the NRCC annual summary[2] .

2017 in Summary

The climate pattern in the Northeast during 2017 is generally one of warmer than normal temperatures (Table 1) with extreme local precipitation events (Figure 12). Most areas emerged from a warm winter to a cool spring. Although there were local extreme snow events, the winter did not follow a single trajectory across the region.

The region's average temperature was 48.8°F, which was 1.5°F above normal (Table 1). Nine out of twelve states ranked 2017 among their top ten warmest years on record.

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[1] http://www.nrcc.cornell.edu/

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

Climate

Table 1. Average temperature in 2017 for the 12 states in the Northeast (°F). Table credit: NOAA, Northeast Regional Climate Center at Cornell University.

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

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

The year started with a warmer than normal winter: winter 2016-17 was the fifth warmest on record for the Northeast with an average temperature of 30.6°F (4.7°F above normal). Five out of six New England states each had at least a fifth warmest winter on record, while Maryland, New York, Pennsylvania and West Virginia all had at least their third warmest winters. Snowfall varied across the region, with five states (Maine, New Hampshire, New York, Pennsylvania and West Virginia) receiving above average snowfall (Figure 11).

The 2017 spring was slightly warmer than average for the Northeast, with an average temperature of 46.0°F , which is 0.5°F above normal. Notably, several states had a very

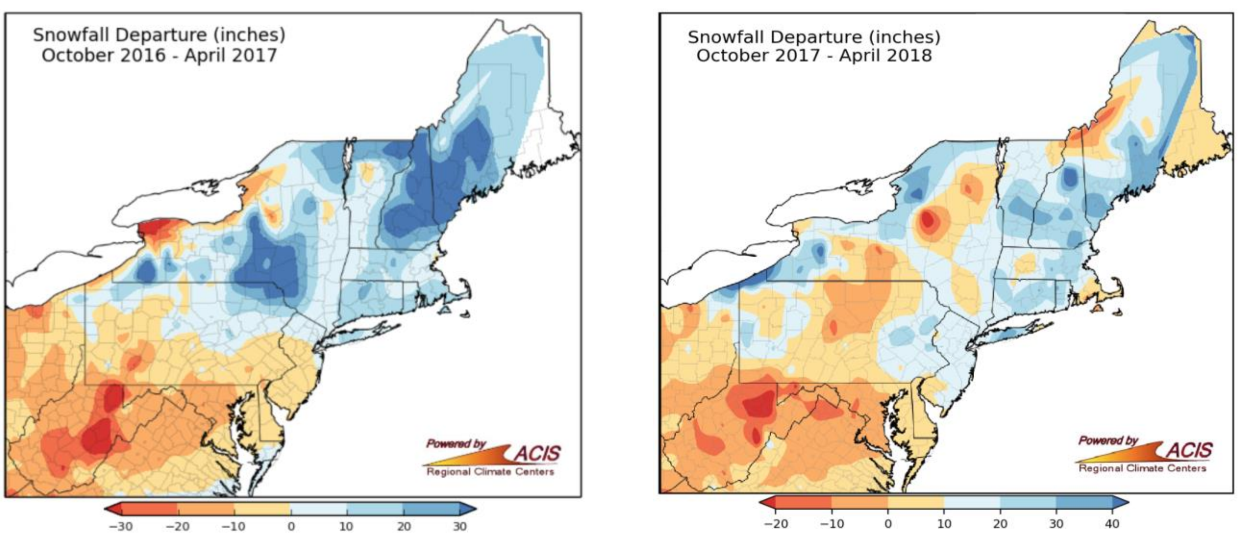

Figure 11. Regional snowfall departure from long-term normal for the winters at the beginning and end of 2017. The winter going into 2018 had variable snow accumulation across the region, while the winter at the beginning of 2017 saw more snow fall in the northeast and less snowfall in the southwest of the region. Note the different scales in the two maps. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University.

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

Rainfall

The Northeast wrapped up 2017 with an average of 46.35 inches of precipitation, 1.91 inches above the long term average (Figure 12). Four states (Connecticut, Maryland, Massachusetts, New Jersey) were slightly drier (1.45-5.48 inches below average), while nine states had slightly wetter (0.02-3.20) than normal years. Notably, New York had one of its top ten wettest years (Figure 12).

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

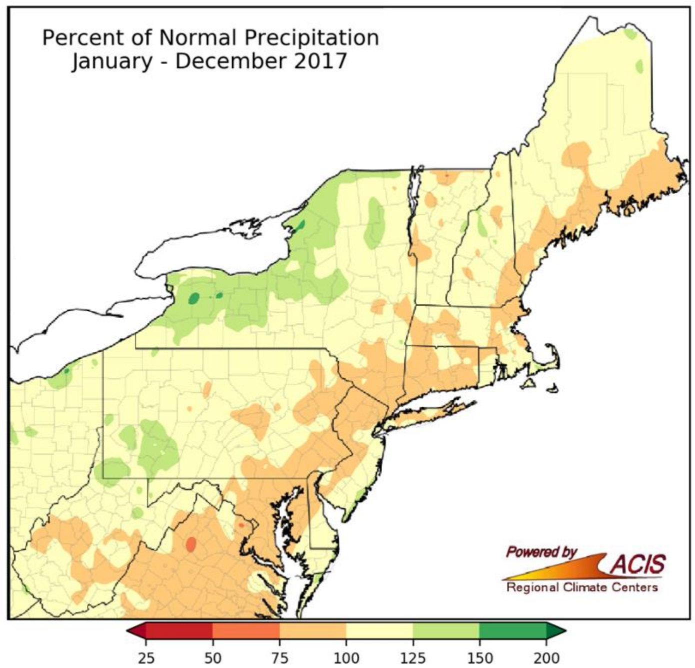

Figure 12. Across the 12 state region, the northeast saw below-average precipitation in 2017. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/monthly/monthly.html)

Implications

While climate variability is high, both temporally and spatially, meteorological measurements witnessed across the Northeast are in agreement with local and national assessments indicating that temperatures have increased over the past several decades (Betts, 2011; EPA, 2014; IPCC, 2014). However, it is not the general warming trends that will likely impact forested ecosystems the most in the near future. Instead, it is the increased frequency and severity of extreme climate events that are of concern for forest ecosystem condition. The increase in extreme temperatures witnessed in 2017 are an example of the increase in variability we will continue to see under a changing climate.

These extremes represent an additional stress for species adapted to cold weather dormancy, increased risk of winter injury following winter warm spells, and frost damage during spring freeze events. Even when climate conditions remain within a species' natural tolerance, differences in competitive advantages among species due to phenological changes or erratic and unseasonable temperature fluctuations could alter ecosystem structure and function (Pucko, 2014).

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

Acknowledgements

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Additional Resources

Vermont State Climatologist: http://www.uvm.edu/~vtstclim/

Northeast Regional Climate Center (NRCC): http://www.nrcc.cornell.edu/

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

NOAA Climate At A Glance: https://www.ncdc.noaa.gov/cag/time-series/

FEMC Project Database Links

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

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

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

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

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

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Great blue heron fly by. 2016. John Truong.

Broad-Scale Forest Disturbance

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Climate

A little frosty. 2017. Photo by Nicholas Erwin from flickr (https://www.flickr.com/photos/nickerwin/37620787982/) and licensed under Creative Commons BY 2.0 license (https://creativecommons.org/licenses/by-nc-nd/2.0/).

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