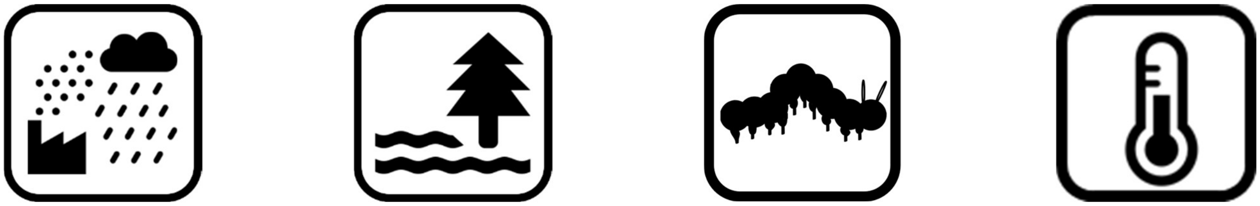
FEMC

Forest Ecosystem Monitoring Cooperative

Regional Monitoring Update

2018

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



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

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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 2018 Vermont report at https://www.uvm.edu/femc/products/long_term_update/2018/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 2018 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.

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. Through these investigations, it was discovered that acid rain has led to the decline of red spruce in the 1970s and 80s, the leaching loss of calcium and other cations from soil, and the acidification of lakes and streams. Two measures of acid deposition are sulfate (SO_4^{2-}) and nitrate (NO_3^-). When emitted as air pollutants, these molecules can form acids through reactions with water in the atmosphere, creating what we know as 'acid rain'. Recognizing this serious environmental threat, regulations were enacted to control emissions of sulfur and nitrogen oxides, which react in the atmosphere to produce acidic compounds; as a result, acidic deposition has declined, and ecosystem recovery is underway.

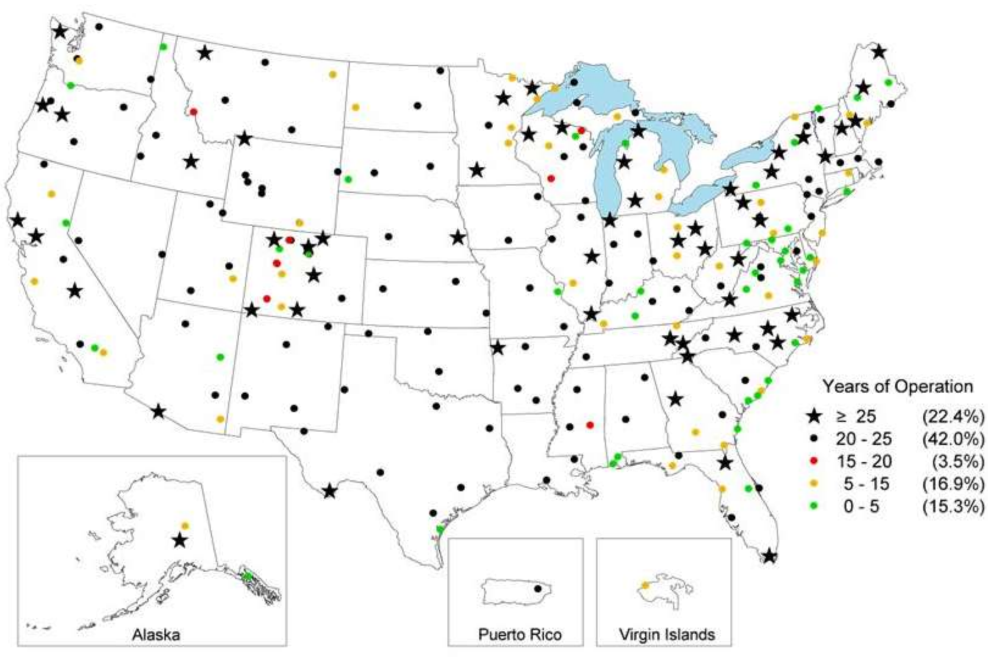

Figure 1. Locations of National Trends Network monitoring sites. Source: NADP.

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

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

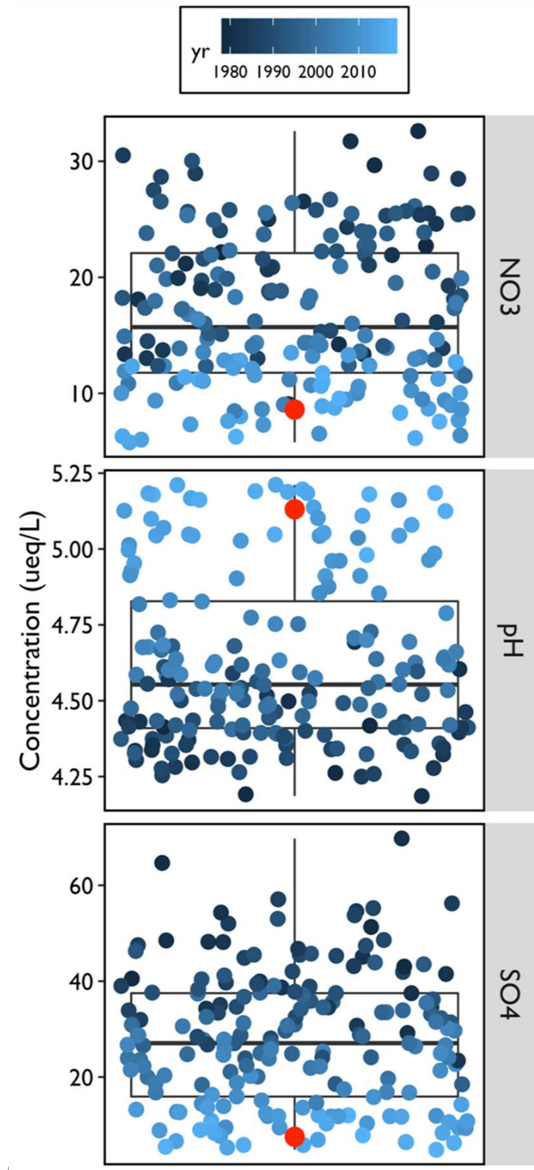

Figure 2. Annual deposition of nitrate (NO_3^-), pH, and sulfate (SO_4^{2-}), for the NADP sites in the region, displayed with quantile box plots. The most recent year's (2018) average measurements are indicated in red, and shades of blue correspond to the year, with lighter values corresponding to more 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.

2018 in Summary

For all three metrics of acid deposition (NO_3^-, pH, SO_4^{2-}), 2018 continued the trend of reduced deposition compared to the high values experienced in the historical record (Figure 2).

Nitrate deposition in the region has been declining from the peak of 32.0 ueq/L in 1980 recorded in New York State (Figure 3). Regional average NO_3^- deposition declined steadily until leveling off in 2010 (9.06 ueq/L). After a two-year increase NO_3^- deposition, records indicate a six-year declining trend regionally, with 2018 representing the lowest recorded average NO_3^- levels across the five-state region (8.6 ueq/L; Figure 3).

Mean sulfate deposition in 2018 continued a declining trend and remained stable following 2017's regional record low (7.5 ueq/L). 2018 marks a continued trend of lower sulfate deposition compared to nitrate, which began in 2015 (Figure 3). This is a considerable decline from the regional peak mean sulfate deposition in 1981 of 57.9 ueq/L.

The regional average pH in 2018 was the third highest in the record at 5.13. Regional pH levels did not decline over the past year which further supports the historic trend of pH stabilization. This trend likely indicates 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 continued improvement in lowering the acidity of precipitation. As pH is a logarithmic scale, this increase represents a roughly fivefold improvement in precipitation acidity.

In the early years of acid rain monitoring, 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.

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 deposition, 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.

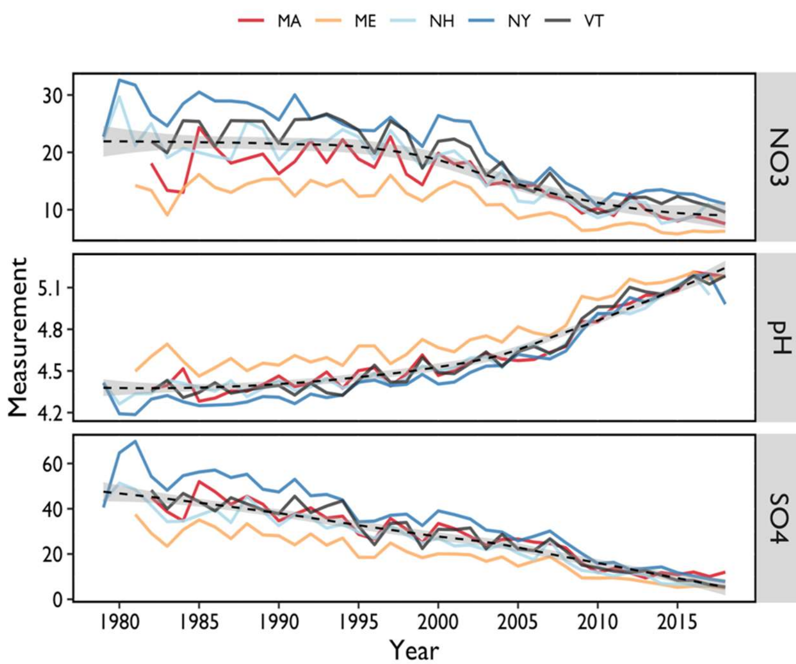

Figure 3. Long-term precipitation chemistry showing annual mean concentrations (ueq/L) of nitrate (NO_3^-) and sulfate (SO_4^{2-}), and mean pH (solid colored lines) for the five states in the region. Black dotted line shows regional trend (LOESS function) with 95% confidence intervals (grey shading.)

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.

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.

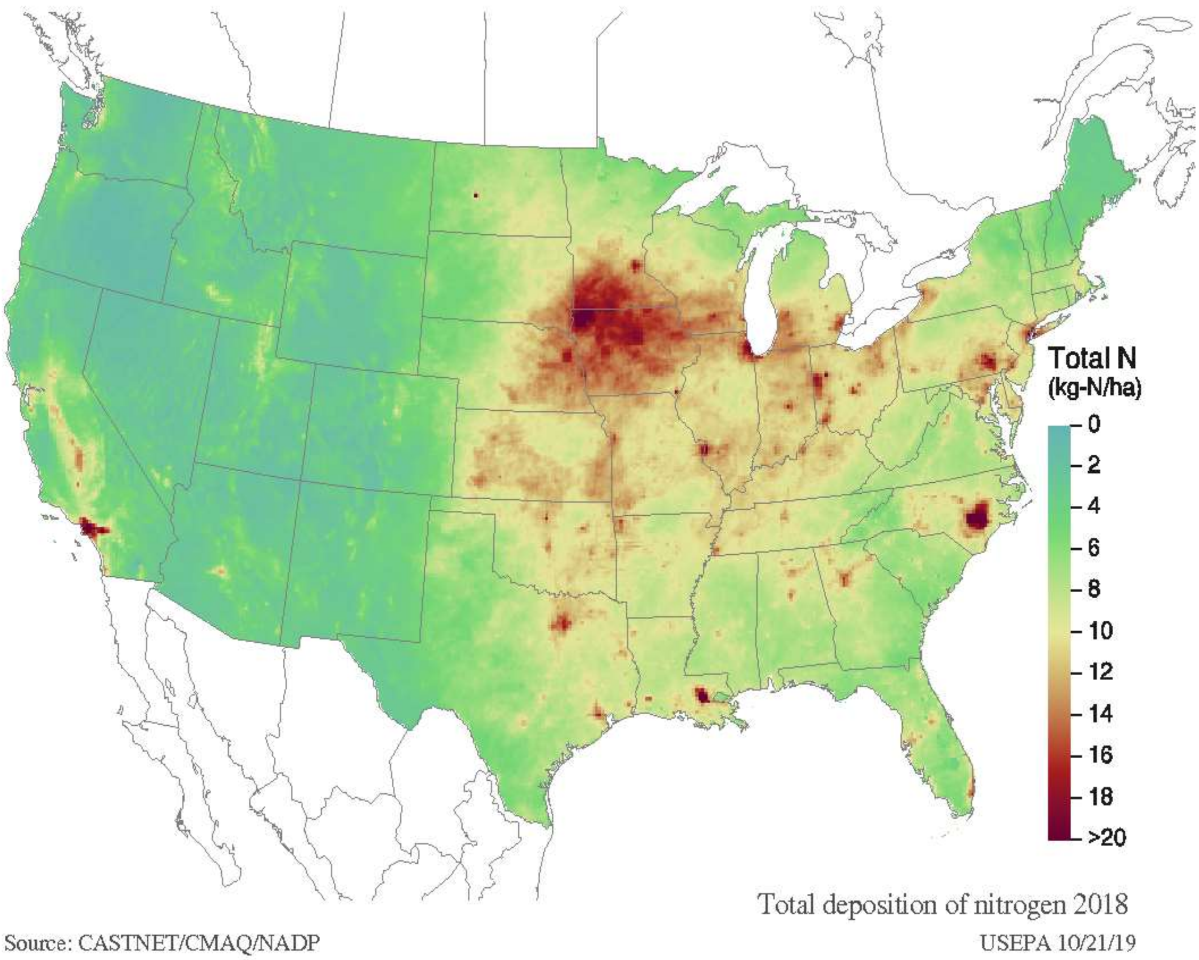

Figure 4. Spatial distribution of total nitrogen (N) deposition (kg/ha) across the continental US in 2016. Source: US EPA.

- **Acid deposition continued to decline in 2018**
- **The average pH of precipitation was 5.13, well above the historical low**
- **Nitrate deposition reductions may have plateaued despite lower regional levels in 2018 compared to 2017 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

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 (Lesk et al. 2017, Tran et al. 2007, Wyka et al 2017).

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 small aircraft by trained observers. The US Forest Service Forest Health Monitoring Program has set survey methods and standards which all states follow. 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. Data collected via IDS are submitted to the USDA Forest Service, Forest Health Program for verification and made publicly available for analysis and review. 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 IDS data collected by state and federal forest health programs for forest disturbances in five northern states in the northeastern region (Massachusetts, Maine, New Hampshire, New York, and Vermont). Please note that while survey methods are the same across the five states, interpretation by aerial sketch mappers does differ from state to state. Based on these differing interpretations of extent and intensity of observed disturbance, it can appear that some states have more or less disturbances than others. 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.

2018 in Summary

In 2018, 51 different causal agents of forest disturbance were mapped in the five-state region. Together, these damages amounted to 234,633 hectares (579,790 acres), which is a decrease from 2017 when 576,715 ha (1,425,092 ac) were mapped. Damage in 2018 amounted to approximately 1.2% of the region's forestland (Figure 5), which is less than the average forest damage per year from 1997 to 2018 (average is 3.0% or 581,387 ha/year).

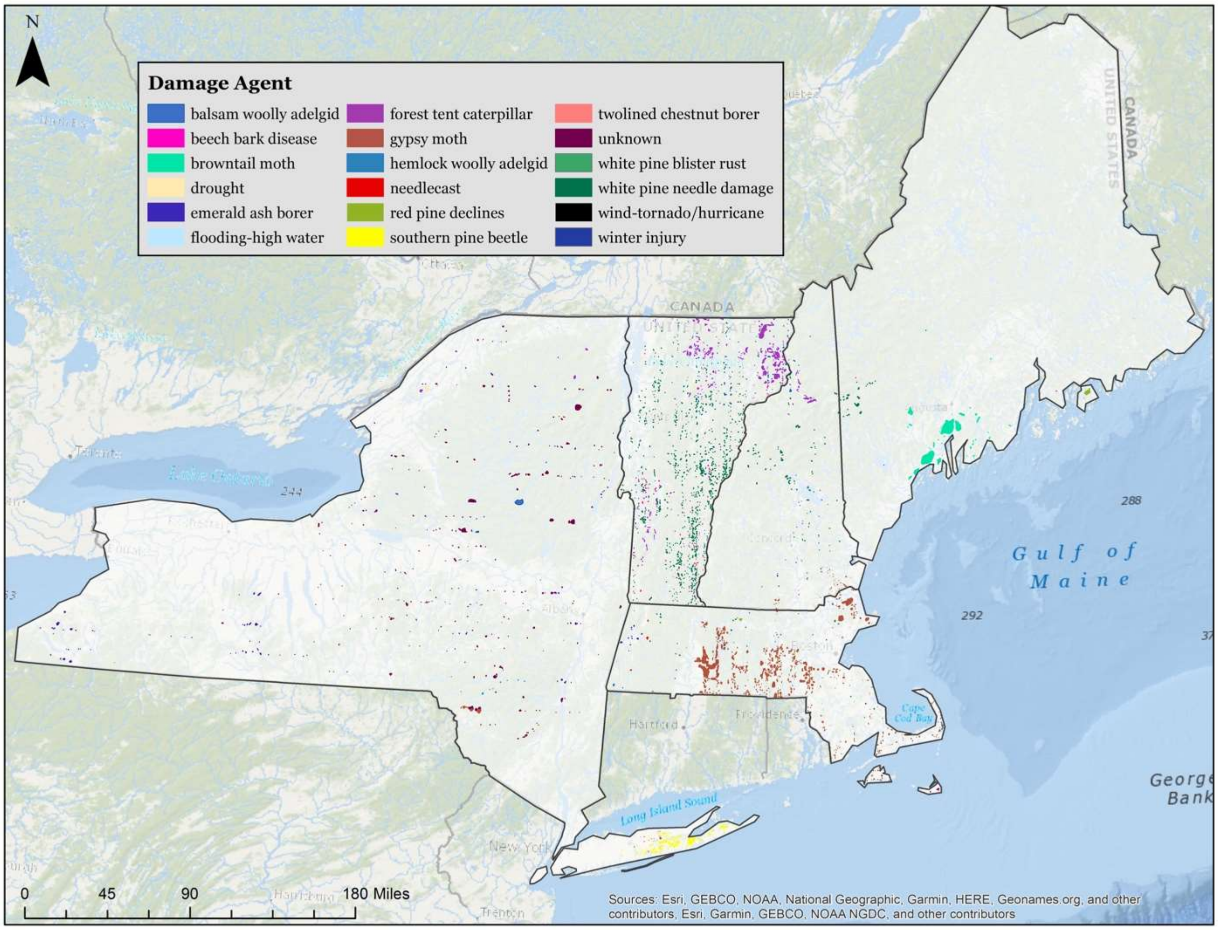

Figure 5. Locations of select forest disturbance agents in 2018 from region-wide Insect and Disease Surveys. Only agents with considerable disturbance area are shown. Note that disturbance polygons were increased in size for visibility, but also states do interpret extent of forest disturbance differently even though the same methods are used regionally.

In 2018, introduced insects and diseases (non-native) caused just over 3 times more disturbance (144,090 ha) compared to those of native origin (42,893 ha, Figure 6), although this was a decrease from the previous year.

Gypsy moth (*Lymantria dispar*) was mapped on the most area of all disturbance agents with 84,508 ha (208,824) of forestland disturbed in Massachusetts (Figure 5). The extent of damage mapped in 2018 decreased from the peak reported in 2017 (437,349 ha; 1,080,713) and from 2016 levels (150,510 ha; 371,918 ac), indicating that the outbreak may be waning but not over. It should be noted that since gypsy moth was so widespread in Massachusetts in 2017, the total damaged area mapped were quite large and included some non-forested areas giving slightly elevated acreage figures in that year. 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 46,016 ha (113,708 ac) of forestland, which was an increase from the previous year (21,031 ha) (Figure 6) and may suggest that this outbreak, which is primary situated in coastal southern Maine, may be more persistent than previously thought. Emerald ash borer, a more recently discovered pest that has a devastating effect on ash

Figure 6. Total mapped disturbance (in hectares) by causal agent from 2018 Insect and Disease Surveys in the Northern Forest region. Color of bar corresponds to the origin of the agent.

trees and is spreading quickly throughout the region. Emerald ash borer impacts were mapped on 2,657ha (6,566 ac) across the region. Impact from emerald ash borer was likely much greater as mortality caused by the invasive beetle can be difficult to map from the air.

Native insects also caused considerable disturbance in 2018 (Figure 6). Forest tent caterpillar (*Malacosoma disstria*) impacts in 2018 were mapped on 35,592 ha (87,950 ac), marking an increase, compared to 2017 (41,641 ha), in the third year of the outbreak (Figure 5).

A positive finding was that the area mapped with white pine needle damage area continued to decline region-wide from 2017 (21,406 ha; 52,895 ac in 2018 compared to 38,375 ha; 94,827 ac in 2017). White pine needle damage has been attributed to a complex of fungal pathogens, which are dependent on moisture availability. The drier than average conditions across the region in 2017 may have reduced disease severity in 2018 (Wyka et al. 2018).

Long-term Trends

Total disturbance mapped per year (1997-2018) shows substantial year-to-year variability in total forest damages (Figure 7). 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).*

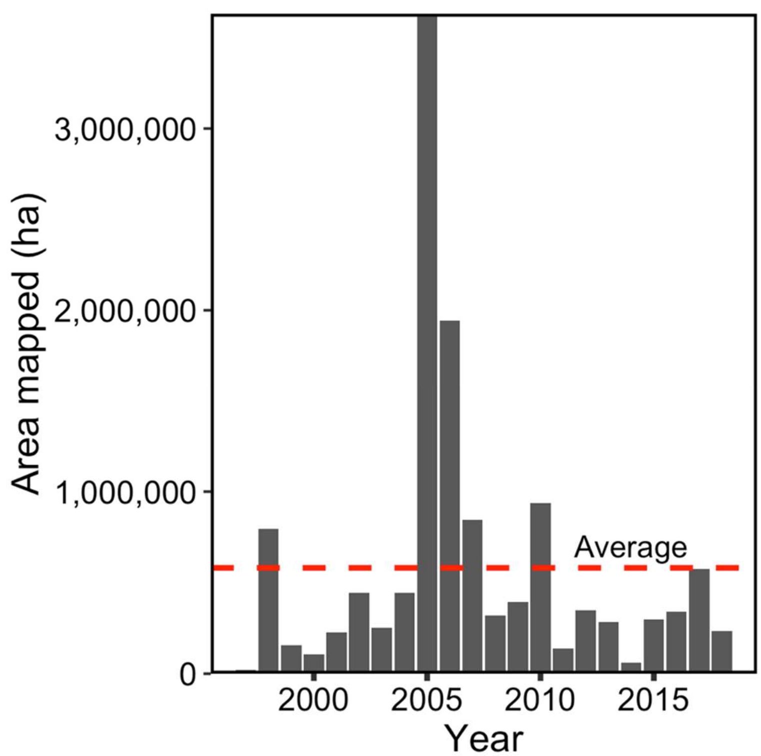

Figure 7. Total area mapped as disturbed according to Insect and Disease Surveys (grey bars; hectares) by year in the Northeast. The red dashed line indicates the average disturbance over the entire timeframe (1997-2018).

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 8). 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 8). 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 (3,154,644 ha, 7795295 ac), forest tent caterpillar (1,612,552 ha; 3,984,703 ac), gypsy moth (1,166,814 ha; 2,883,260 ac), and skeletonizer (1,107,656 ha; 2,737,078 ac; species unknown). While the total area impacted by damaging agents (extent) is an important metric to track, the intensity of damage varies between agents. For example, defoliation from tent caterpillars may be widespread impacting a large area but the forest can likely recover from these disturbances. Conversely, a very small area can be impacted by an agent causing a high intensity disturbance potentially resulting in high rates of mortality. When assessing the implication of forest disturbance, the extent (total area impacted) must also be placed in the context of intensity (i.e. percent mortality).

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 8).

Only 13 agents have resulted in total damage greater than 100,000 ha in the 21-year period (Figure 8). 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 8).

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 (5,076,053 ha; 12,543,200 ac) compared to those of native origin (2,192.792 ha; 5,418,507 ac). However, as new pests and pathogens emerge, often the origins of agents are unknown; agents of unknown origin have caused substantial disturbance overall (3,897,165 ha, 9,630,104 ac). These results demonstrate the destructive nature of introduced pests and support the need for continued monitoring.

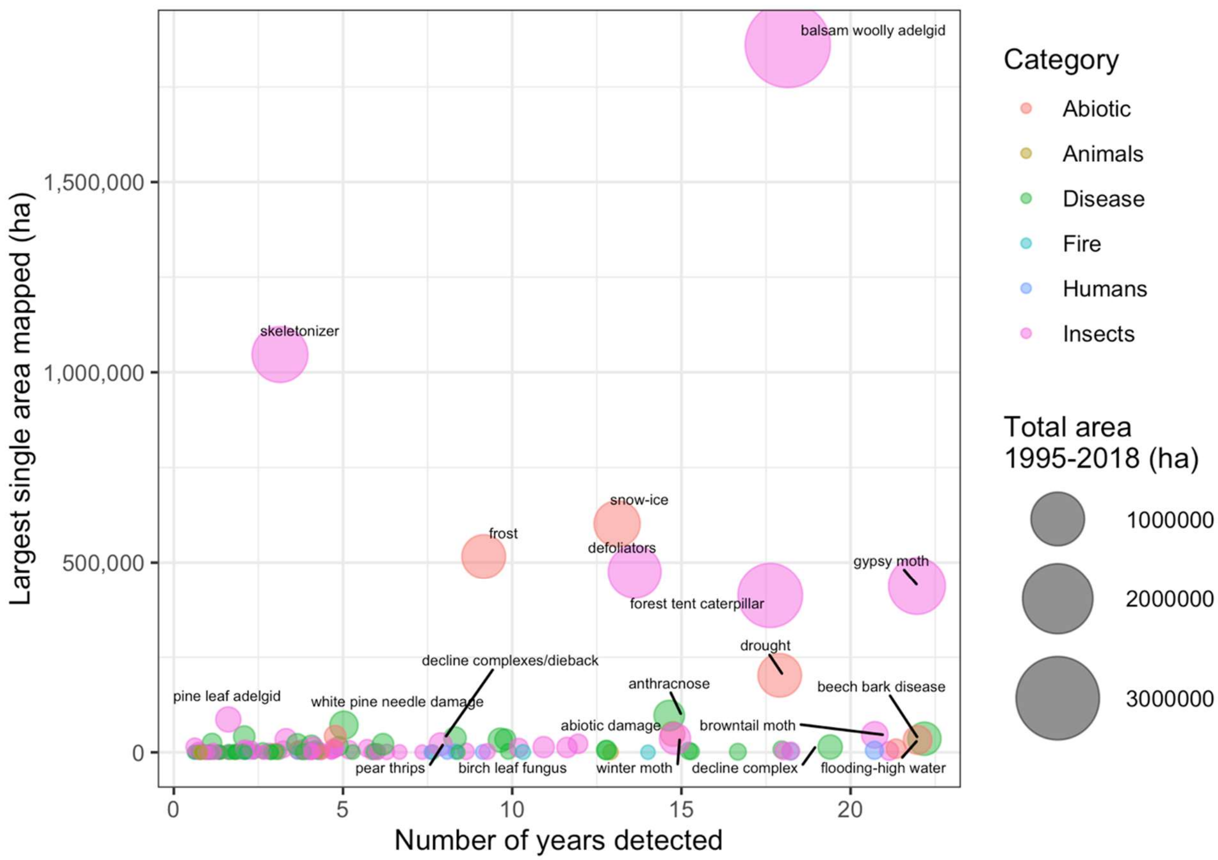

Figure 8. Mapped disturbance agents from region-wide Insect and Disease Surveys (1997-2018) plotted by the frequency (number of years detected) and largest single area mapped (ha; e.g., largest single polygon identified for that agent). Circle size corresponds to the total area recorded for that agent over the 21-year period and color corresponds to the agent category. Only agents that have affected >100,000 ha in total are labeled for clarity.

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 caused 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 maximum and lowest winter minimum 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 8). 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 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 2018, there was a decrease in forest disturbance compared to 2017, primarily driven by a major reduction gypsy moth damage.**
- **In 2018 there was 3.4 x 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.**

Acknowledgements

A special thank you to William Frament, Florence Peterson, Tom Luther, and Michael Bohne, from the U.S. Forest Service's Forest for providing the regional data and reviewing this section.

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Wyka, S.A., Smith, C., Munck, I.A., Rock, B.N., Ziniti, B.L. and Broders, K. (2017), Emergence of white pine needle damage in the northeastern United States is associated with changes in pathogen pressure in response to climate change. Glob Change Biol, 23: 394-405. doi:10.1111/gcb.13359

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

U.S. Forest Service Forest Health Assessment and Applied Sciecnes Team: National Forest Health Conditions & Highlights

https://www.fs.fed.us/foresthealth/applied-sciences/mapping-reporting/detection-surveys.shtml

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

Climate

Regional Climate

Climate Monitoring in the Northeast

Weather and climate are related but very different phenomena, weather being the condition of the atmosphere (precipitation, temperature, etc.) over the short term, while climate refers to longer-term trends and seasonal patterns. Without long-term weather records it would be impossible to tease out short term (i.e. yearly) anomalies from more ecologically significant climate trends, which makes this information critical to scientists and planners of all kinds.

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] .

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

Regional Summary

The climate pattern in the Northeast during 2018 is generally one of warmer than normal temperatures (Table 1) with annual precipitation varying from near to above-average regionally (2). The average temperature for the twelve-state Northeast region was 48.1 °F making it the 17th warmest since recording began in 1895. All states had a warmer than average year.

Table 1: Average temperature in 2018 for the 12 states in the Northeast (°F). Table credit: NOAA, Northeast Regional Climate Center at Cornell University.

Monthly/Seasonal Climate Summary Tables

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

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

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

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

The above average late summer and early fall temperatures shifted in November as an unseasonably cold air mass settling over the region resulting in some of the coldest November temperatures recorded in the region. Snowfall varied across the region in the beginning of 2018 with New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island experiencing above average snow fall (Figure 1). Snow fall was consistently above average across the region the winter of 2018-2019.

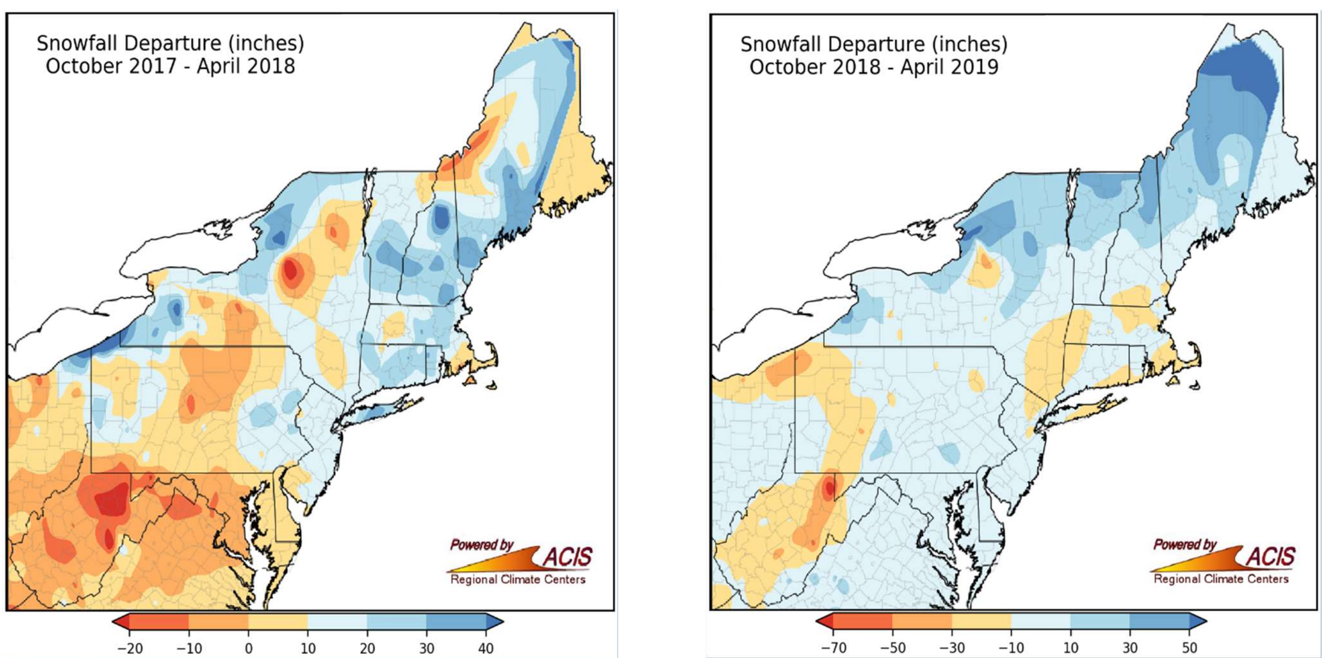

Figure 9. Regional snowfall departure from long-term normal for the winters at the beginning in the end of 2017. The winter going into 2019 had more than average snow accumulation across the region, while the winter at the beginning of 2018 was variable across the region. Note the different scales in the two maps. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University.

Rainfall

The Northeast experienced the second wettest year on record receiving 56.30 inches representing a 20% increase from the regional average. The majority of the increased precipitation occurred in the southern states while the northern state experienced precipitation at or slightly below average (Figure 2). Autumn in the Northeast was the wettest on record with 17.43 inches of precipitation received (50% increase from recorded mean).

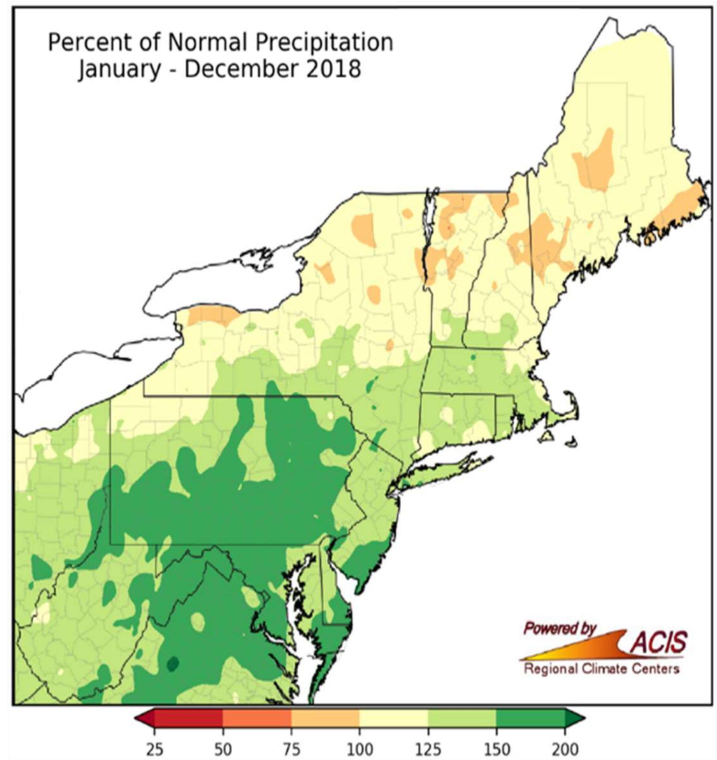

Figure 10. Across the 12 state region, the northeast saw below-average precipitation in 2018. Figure credit: NOAA, Northeast Regional Climate Center at Cornell University (http://www.nrcc.cornell.edu/regional/monthly/monthly.html)

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

Climate

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 2018 are an example of the increase in variability we will continue to see under a changing climate. These extremes represent an additional stress for species adapted to cold weather dormancy, increased risk of winter injury following winter warm spells, and frost damage during spring freeze events. Even when climate conditions remain within a species' natural tolerance, differences in competitive advantages among species due to phenological changes or erratic and unseasonable temperature fluctuations could alter ecosystem structure and function (Pucko, 2014).

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

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Additional Resources

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

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

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

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

FEMC Project Database Links

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

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

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

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

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

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

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Precipitation Chemistry and Acid Deposition

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

Broad-Scale Forest Disturbance

S-shaped galleries from larval feeding. 2013. Photo by Emilie Inoue, accessed from vtinvasives.org.

Climate

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