Forest Watch Data Book

2012-2013

Research with 2011 Needles

A Study of White Pine Health In New England

UNIVERSITY OF NEW HAMPSHIRE

New Hampshire Space Grant Consortium

Rock, B.N., and M. Carlson. 2013. Forest Watch Data Book 2012-2013: Research with 2011 Needles. Forest Watch, University of New Hampshire, Durham, NH.

The Forest Watch Data Book is published on the Forest Watch website, forestwatch.sr.unh.edu.

Students, teachers and others are welcomed to draw from the Data Book. All publications, posters, and other presentations which use data or ideas from the Data Book should cite the Data Book as shown above.

Contact Forest Watch at forestwatch@unh.edu, Room 466, Morse Hall, 39 College Rd., UNH, Durham, NH 03824.

Special Letter to Forest Watch Teachers and Students

February 2013

Dear Forest Watch Students and Teachers,

Congratulations! You have helped us make a discovery.

In the past two years, everyone in northern New England has noticed that white pines are shedding their older needles. Wind rows of needles piled up along sidewalks, roadways, and under pines. Hundreds of citizens called their Extension Service offices with questions:

- Why are the white pines shedding so many of their needles?
- Is this normal or unusual?

Thanks to your diligent and careful observations over the past 20 years, Forest Watch can answer the second question. Yes, this is really unusual. White pines usually retain their needles for two or three full years. Those needles usually are healthy green needles that contribute significantly to the photosynthetic process by the whole pine tree. White pines can grow half a meter a year in height and add 1 or 2 centimeters in new wood because first, second and third-year needles all make sugar throughout the year.

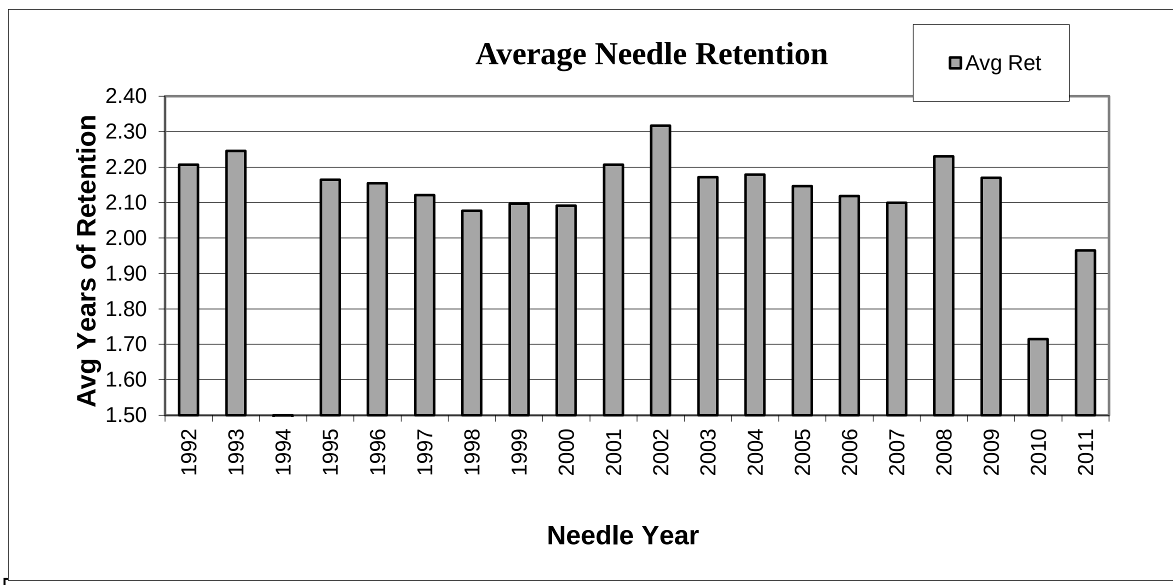

Figure 1: Average needle retention of trees in 2011 was 1.905, meaning that most schools saw some second-year needles along with current-year needles.

Your research finds that needle retention changed dramatically in 2010 (Figure 1 above). As can be seen from the Figure, that year was the first and only time older needles were not retained! Needle retention is a bit better this year (2011 collections) but still far below the average of all Forest Watch school measurements since 1992.

The Forest Watch measurement of needle retention is one of the most basic and perhaps the simplest measurement students and teachers make. When we started Forest Watch, we wanted to include a measurement that every student of any age could make and make well. Are there any second-year needles on the twig? Yes or No? Are there any third-year needles on the twig? Yes or No? Whether a twig had 10 or 100 needles on a third-year segment, that tree was rated as a 3. As Figure 1 shows, the ratings of 1, 2, and 3, with even an occasional 4, gave us a 20-year average that was well over 2.0.

In 2010, needle retention fell to 1.7. Many needles fell off the trees in June 2010 just as the new 2010 needles were expanding. It was the 2008 and 2009 needles that were cast. This year, you report that needle retention has improved somewhat but, at 1.94, it is still below 2.0. In northern portions of the region, schools are finding needle retention only at 1.0. All 2009 and 2010 needles were cast in the 2011-2012 school year.

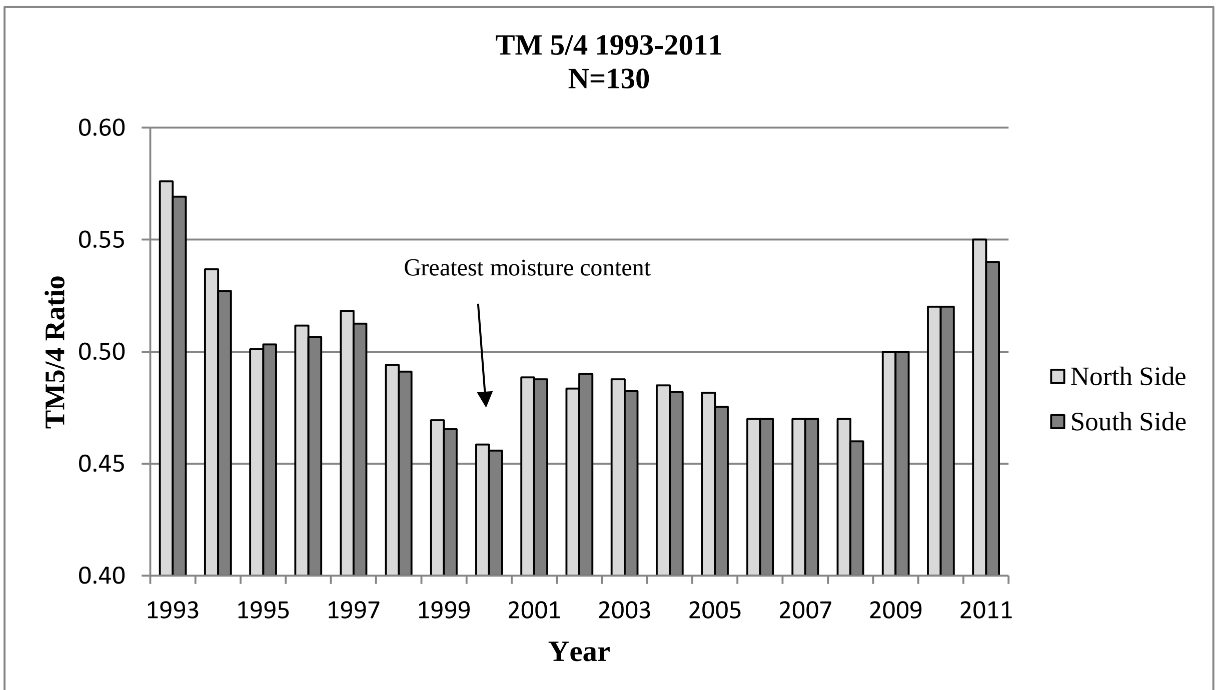

Figure 2: Water stress is apparent in the 2011 average TM5/4 ratio. At 0.55, the index is higher than at any time since 1993.

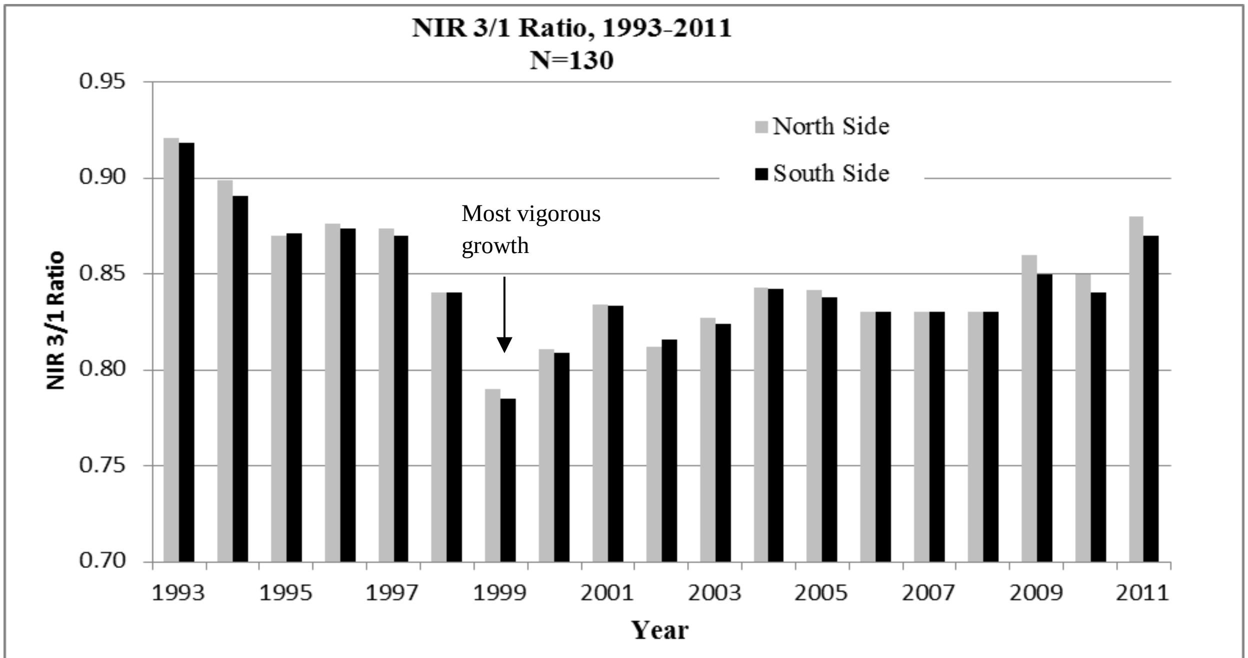

Figure 3: NIR 3/1 ratios are an indicator of cell maturity or senescence. 2011 1st year needles show unusually high NIR3/1 ratios.

Our measurement turns out to be immensely important. Yes, the needle cast that is occurring is not at all usual. That brings us back to the first question: Why did this happen in 2010 and to a lesser extent in 2011?

Forest Watch research provides some intriguing clues about why the needles are being cast. This year, for the first time since 1993, spectral measures of new first-year needles show signs of moisture stress when the 5/4 TM band ratios of these new needles are compared with previous years. Remember, in white pine, 5/4 ratio values above 0.50 are an indication of low water content of the needles.

In another test (Figure 3), 2009-2011 needles show signs of premature aging, Figure 3 indicates that in the early years of Forest Watch (1993-1997) similar pre-mature aging was indicated by the NIR 3/1 ratio measurement. Six years after Forest Watch started, in 1998, this ratio value dropped below 0.85 for the first time and remained below that value until 2009. Using the NIR 3/1 ratio, the lower the value (such as in 1999) means more active and vigorous growth, while a ratio value above 0.90 means slower, less vigorous growth, approaching senescence.

When we collect pine needles either in the Fall or the Spring, the current-year needles studied are in a condition typical of the end of their first growing season. We might surmise that high ozone levels in the early 1990s caused premature aging. Then in the late 1990s, as the Clean Air Act took effect, ozone levels fell and needles maintained vigorous growth longer.

Why would NIR3/1 ratios be rising now? Thanks to Forest Watch careful sampling of pine foliage, we can see a change over time in the pines' health. Something very serious is stressing them. Not since the early to mid-1990s, when ozone levels were extremely high, have we seen these kinds of measurements of stress.

Your reports, samples and measurements indicate that some new stressor is present in our environment. That stressor appeared in spring 2010 and continues to be present. It is stressing new needles that opened in 2010, in 2011 and now in 2012.

Various theories point to possible causes. We observed an air pollution event in May 2010 which defoliated sugar maples. We believe that peroxyacetyl nitrate (PAN), a powerful oxidant produced by wild fire smoke from Canada in combination with unusually high temperatures, might have heavily damaged those leaves. PAN might also have stressed the pines. And other pollutants from a growing number of wild fires might be stressing the pines.

Another theory is that unusually wet weather in 2009 released a population explosion of fungi which are clearly now feasting on the pine needles. In 2010 and 2011, the US Forest Service reported a new occurrence of pine needle cast fungi on the older needles. We are now working with the Forest Service to try to understand what is causing the dramatic increase in reported cases of needle cast fungus. Such fungi normally only attack needles that have been weakened by some other factor. And the fungi usually only damage a small percentage of the needles, not the large percentages we are seeing.

Recently, we find strange orange blisters on needles you submitted in the fall of 2012. We also are beginning to see a loss of chlorophyll in first year needles that expanded in the Spring of 2012. Forest Watch teachers, students and other citizen scientists who observe and report these unusual changes in white pine health are making an important contribution to science.

You can learn more about our recent findings in this year's Data Book.

Forest Watch and our long term study of the pines, our careful protocols for measuring and sampling, will help us test these theories and find the answers. Our research is now more important than ever. Now is a wonderful time to be doing Forest Watch together!

Congratulations! You are participating in a true scientific study. And your findings are revealing important answers to big questions.

Let's keep working together,
Proudly,

Dr. Barrett Rock, Founder and Director　　　　Martha Carlson, Coordinator

2012-2013 Forest Watch Data Book
Contents

Special Letter to Forest Watch Teachers and Students

Chapter One: Introduction 1
- 2011 Needles 2
- Highlights of Forest Watch in 2011-2012 3
- Schools Participating in 2011 Needle Studies 5

Chapter Two: Ozone Basics and Atmospheric Conditions
- The Basics: What Is Ozone? 6
- How Does Ozone Cause Damage? 9
- Monitoring Ozone Events 10
- Changing Ozone Conditions in 2011-2012 12

Chapter Three: Fungi and White Pine Needle Cast 17
- *Eastern White Pine Needle Damage Survey, 2011, by Dr. Isabel Munck* et al.*, a study of fungal predation as a cause of needle cast.*

Chapter Four: A Case for A Stressor Other Than Fungi 23

Chapter Five, Spectral Analysis
- Reading Light 41
- Long-Term Spectral Analysis 46

Chapter Six, Biometric Data Analysis
- Histograms of Tree Size 51
- Histograms Graphed from Student Measurements 55
- Other Histograms 57
- Long-Term Biometric Analysis 59

Chapter Seven, Biometric and VIRIS Data 66

FOREST WATCH DATA BOOK 2012-2013

Published January 2013
Research with 2011 Needles

Chapter One - Introduction

The *Forest Watch* program studies the effects of ground-level ozone on the health of New England's forests. K-12 students, teachers and University of New Hampshire researchers have been working together each year since 1991 collecting large amounts of data annually from white pine (*Pinus strobus*) trees all across New England. National Acid Precipitation Assessment Program (NAPAP) research in the 1980s demonstrated that the white pine is a bio-indicator, sensitive to air pollution and ground-level or tropospheric ozone exposure. Many other species of trees in the New England forest are able to close their stomata against tropospheric ozone when levels climb. White pine, research finds, may close stomata at very high levels of ozone but maintain open stomata at levels of 60 to 80 parts per billion (ppb).

Forest Watch has confirmed the connection between variations in tropospheric ozone levels and white pine health. Over the past two decades, in all but a few drought years, white pine needle health during summers has declined when ozone levels were high (between 60- 80 ppb). White pine needle health has improved during summers when ozone levels were low (generally below 60 ppb). When white pine needles are damaged, they exhibit distinct and measureable tip necrosis and chlorotic mottle. Ozone damages needle mesophyll cells internally, reducing chlorophyll and cellular water concentrations. With reduced photosynthesis and less water, the needles make less sugar. The pines show reduced growth in needle length and reduced needle retention (fewer years of needles are retained). Internal damage is visible in yellow chlorotic mottling along the length of needles and in brown tip necrosis (See Chapter 2). These biometric measures of plant health correlate with spectral measures of light reflected from needle surfaces (See Chapter 5).

In addition to student measurements of tree and needle biometric data, each participating school sends a duplicate set of branch and needle samples from their trees to UNH for spectral analysis. Freshly-collected samples from each of five tagged trees are placed in Ziplock bags along with a wet paper towel, placed in a small picnic cooler (supplied by the program), and sent to the Forest Watch Program Coordinator by next-day mail. Once received at UNH, the first-year needles are scanned with the Visible Infrared Intelligent Spectrometer (VIRIS) to collect high-resolution reflectance spectra for each of the five trees. These spectral reflectance data are then analyzed to determine a range of needle characteristics, including chlorophyll concentrations, state of cellular health, and water content (See Chapter 5). The student biometric data are then compared with the reflectance data, resulting in an overview of the state of health of each of the five trees for the summer of 2011.

K-12 students, teachers and UNH scientists have collaborated to build a 22-year-long data base of white pine measurements, tracking the impact of tropospheric ozone on the white pines of New England's forests. Forest Watch Data Books provide a remarkable history of our measurements and findings and evidence of changing needle health over the past two decades.

2011 Needles

Current data presented in this report was collected by participating schools in either the fall of 2011 or the spring of 2012. These data are based on first-year needles which matured during the summer of 2011. The information in this booklet represents the work of students who have collected forestry data from63 white pines near 12 schools. Long term spectral and biometric analysis represents the work of thousands of students and hundreds of teachers who have contributed time and effort to the Forest Watch program over the last 22 years.

This year's report begins with an explanation of what ozone is, how it is formed, the differences between "good" ozone in the stratosphere and the "bad" ozone in the troposphere. The chapter explains how tropospheric ozone causes problems for humans and for plants. The chapter also includes a history of how ozone is monitored by the U.S. Environmental Protection Agency (EPA).

Chapters Three and Four examine troubling new findings about the white pines. As we discovered in 2010, the pines continue to show a drop in needle retention. And, as we will explore in Chapter Five, spectral measures show numerous first year needles exhibited water stress and early senescence, a first since 1993. In Chapter Three, we are honored to reprint here an article produced by Dr. Isabel Munck, a U.S. Forest Service plant pathologist, Barbara Burns of the Vermont Department of Forests, Parks and Recreation, William Ostrofsky, of the Maine Forest Service, and Kyle Lombard and Jennifer Weimer of the New Hampshire Division of Forests and Lands. The essay by Munck *et al,* 2011, explores several species of fungi which they have linked to the widespread needle cast reported by timberland owners across the region.

In Chapter Four, Forest Watch explores a bit further. Why are the pines suddenly so vulnerable to fungal attacks by species which have probably lived with the pine for centuries? Is something else stressing the pines? We consider atmospheric pollutants, both oxidants such as ozone and acid rain or fog as well as other possible contaminants carried in wildfire smoke. In opening this possible cause of stress, Forest Watch examines needles from four of our schools both in 2011 and 2012. In addition, we introduce a new web resource for interpreting atmospheric conditions and remote sensing information, The Smog Blog, produced by U.S. Air Quality, a daily diary and analysis provided by the University of Maryland, Baltimore County Atmospheric Lidar Group.

As always, the Data Book presents our analysis of spectral measures, including comparison of Red Edge Inflection Point (REIP) data with ozone reports, Chapter Five. Spectral measurements and the indices by which we "read" light reflectance are explained. We examine what spectral measurements tell about the health of pine needles in 2010 and compare these new data with long term data.

The Data Book also presents biometric data gathered by schools, with our analyses of tree heights, live crown, diameter at breast height (dbh), foliar water content, needle retention, needle length and needle damage symptomology, Chapter Six.

Each school's spectral and biometric data are presented in Chapter Seven.

The stress which Forest Watch finds among the pines is distressing. *Pinus strobus* is a key species in the New England forest and a critical part of the timber industry. Our research may assist plant pathologists such as Dr. Munck in detailing the causes of recent needle cast and declining health. In using new access to remote sensing through The Smog Blog, we may develop pioneer ground truthing evidence of the impacts of atmospheric conditions. Like so many things in our trees' environment, atmospheric chemistry appears to be changing. Forest Watch, teachers, students and your partners at the University of New Hampshire are in the forefront of understanding these changes.

Highlights of Forest Watch in 2011-2012

Forest Watch held a second Forest Watch Student Convention in May 2012. Students from Gilmanton School and Josiah Bartlett School came to UNH to display projects and to talk about their research. These young scientists visited labs and scientists in the Institute for the Study of Earth, Oceans and Space. They also toured the Chase Ocean Engineering Laboratory to learn how robotic submarines are built and tested at UNH and how ocean floor mapping can be directed and monitored from a computer control center right in Durham. We will hold another convention this year on May 31.

Forest Watch teachers joined EOS scientists for a day of scientific fun early in June. Dr. Michael Palace and Dr. Crystal McMichael explained their latest research in the Amazon, finding and mapping terra preta, ancient soils made by farmers, still identifiable with remote sensing tools. The visiting teachers toured Dr. Ruth Varner's laboratory, meeting graduate and undergraduate students who were busy building and packing gear for their trip to Norway to measure how much methane is escaping from melting Arctic peat bogs. Lastly, the teachers trimmed their fingernails with Dr. Erik Hobbie and graduate student Andrew Quimette to learn about isotopes, chemical markers that could discern who is a vegetarian and who is eating corn-fed beef. This first treat for Forest Watch teachers was so successful we will repeat it in June 2013.

In August, 12 new teachers joined Forest Watch for a three-day workshop. Two more helped us pilot the workshop in June. We are delighted to welcome these 14 environmental science educators to the program. In the coming year, we hope all of them as well as many Forest Watch teachers who have not participated lately will help us to rebuild our research network.

Lastly, Forest Watch celebrated the formal retirement of Dr. Barrett Rock, founder of Forest Watch. Many founding Forest Watch teachers, staff members and graduate students honored him with gifts and reminiscences at a party in October 2012. With approval from the UNH Foundation, we have established a permanent Forest Watch Fund to support the annual work we do and, if the Fund grows, to endow its research and outreach in the future.

The New Hampshire Space Grant Consortium continues to support Forest Watch. We greatly appreciate their help and encouragement. Thanks to the website which Space Grant funds, we were able to share our protocols with two young researchers in Greenwich, CT. We scanned spruce needles for these students and helped them to interpret the data for their forest health research project.

Lastly, Forest Watch continues to provide stout roots for our emerging Maple Watch Program. Eight schools now plan to participate as pilot schools with Maple Watch. We also had interest in partnerships from the Rocks Estate in Bethlehem, NH, and Monticello, Charlottesville, VA. A grant proposal is now pending with the National Science Foundation. Maple Watch work with our pilot teachers and New Hampshire sugar producers was presented at the American Geophysical Union's 2012 annual meeting in San Francisco. The sprout is growing.

Thank you, Forest Watch teachers and students. You have helped Dr. Rock, now Professor Emeritus, to build a unique school to university partnership. Together we are doing important research with vibrant new horizons. Thanks, Forest Watchers!

The UNH Forest Watch Team

A small crew of personnel at UNH runs Forest Watch and produces the Data Book:

Dr. Barry Rock	Director, Forest Watch	barry.rock@unh.edu
Martha Carlson	Coordinator, Forest Watch	martha.carlson@unh.edu

Email Forest Watch at forestwatch@ unh.edu.

Schools Participating in 2011 Studies

Connecticut	Town	In Forest Watch since…	# Trees Reporting
RHAM High School – Frank Schmidt	Hebron, Andover, Marlborough	1997	10
Tolland High School – Fred Szezciul	Tolland		5
Maine			
Morse High School – Carolyn Nichols	Bath	2008	5
Massachusetts			
Hanson Middle School – Wes Blauss & Russ Young	Hanson	1996	5
Springfield Central School – Naomi Volain	Springfield	2007	8
New Hampshire			
Community School – Kathy Flaccus	Tamworth	1993	5
Gilmanton Middle School – Mary Fougere	Gilmanton	1993	5
Lyme School – Skip Pendleton	Lyme	1994	5
Monadnock Regional High School- Gerry Babonis	Swanzey		
Salem High School – Norma Bursaw	Salem	1994	5
Sant Bani School – Robert Schongalla	Sanbornton	1992	5
Vermont			
St. Johnsbury School – Otto Wurzburg	St. Johnsbury	1997	5
Number of Trees			**63**

Chapter 4 also includes data from Prospect Mountain High School, Barnstead, NH, where Sarah Thorne and her students sampled 10 new Forest Watch trees in November 2012. These 2012 needles provide evidence of new damage to young white pine needles.

Chapter Two – Ozone Basics and Atmospheric Conditions, 2011-2012

The Basics

Tropospheric ozone is a principal component of smog, a word derived from the words “smoke” and “fog.” Such ozone is located in an atmospheric layer located next to Earth’s surface, the troposphere (See Figure 2.1). This ozone is not to be confused with stratospheric ozone, located in a layer of the upper atmosphere, the stratosphere. Both layers contain the same chemical (O_3) but the ozone in the stratosphere is beneficial as a filter of ultraviolet (UV) rays while the tropospheric ozone is harmful to living tissues.

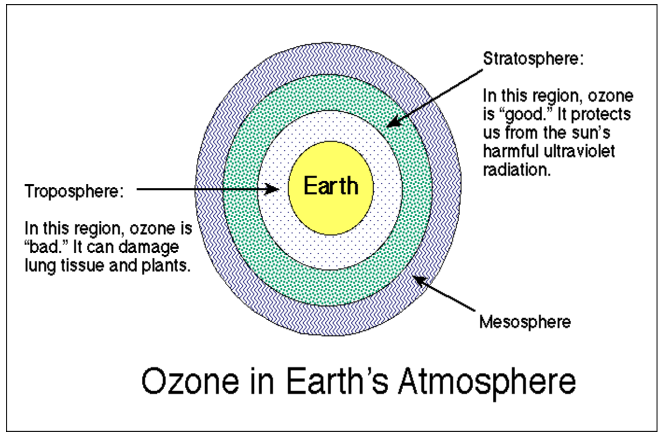

Figure 2.1: Ozone occurs in both the troposphere and the stratosphere. The Earth’s entire atmosphere is about 80 km thick. The troposphere is 10 to 15 km from the surface of the Earth. The next atmospheric layer is the stratosphere, 15 to 30 km thick. Beyond the stratosphere, are the mesosphere and a thin outer layer called the exosphere. Note that the depths of each layer are not to scale. (Figure taken from http://spso.gsfc.nasa.gov/NASA_FACTS/ozone/fig1.gif).

What Is Ozone?

Ozone gas is a molecule of three atoms of oxygen. The oxygen we breathe is a molecule of two oxygen atoms. Ozone, O_3, naturally occurs in the upper atmosphere (the stratosphere) approximately 10 to 30 miles above the Earth’s surface. Ultraviolet light breaks normal oxygen molecules, O_2, apart. The free oxygens, O_1, joins with O_2 molecules to form O_3. This ozone protects Earth from the sun’s harmful ultraviolet rays. In the lower atmosphere, the troposphere, ozone is harmful to people, animals, crops and other living things. We call ozone “Good Up High. Bad Near By.”

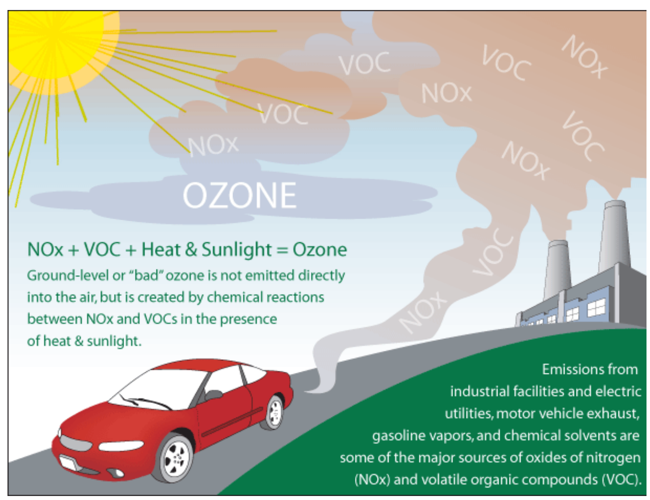

Figure 2.2: Tropospheric ozone is formed when high temperatures and bright sunlight allow NOx and VOCs to react. Image adapted from EPA 2010.

NOx + VOCs in 

and high heat = O_3

In the troposphere, ozone is created by the interactions of natural and anthropogenic (human-made) emissions of volatile organic compounds (VOCs) and nitrogen oxides. The nitrogens include nitrogen oxide (NO), nitrogen dioxide NO_2), and many other molecules based on nitrogen, so numerous we call them NO_x. VOCs and NO_x combine photolytically, in light and heat. Historically, the highest ozone levels in the troposphere occur when the temperature reaches 90^oF or more, when there is bright sun, and when both VOCs and NOx are readily available.

Volatile organics include natural gases produced by plants. White pines and other conifers emit isoprene, a delicious forest scent. Isoprene evaporates readily in the air on a hot summer day. It is volatile and organic. As mentioned above, human beings produce many other VOCs -- cleansers, preservatives, inks, fragrances, fabric softeners, hair dyes, fingernail polish, paint, glue, engine maintenance fluids—all of which evaporate quickly into the atmosphere. Human-made VOCs are made from fossil fuels, carbon compounds; thus they are called "organic" even though they are not made from living leaves or wood.

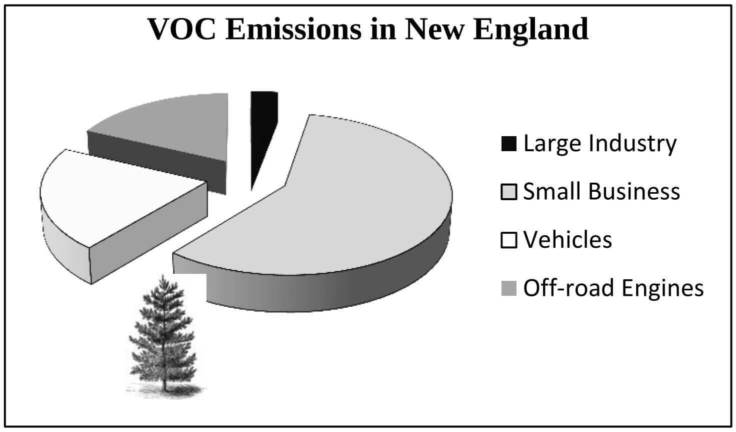

Figure 2.3: VOCs in New England come primarily from small business. Large amounts are produced by chemical plants in the mid-west. Homes also release VOCs. The New England forest also releases substantial amounts of VOCs. Graph built using EPA Region 1 data, http://www.epa.gov/region1/airquality/piechart.html.

As Figure 2.3 shows, the largest producer of man-made VOCs is small business—print shops, auto repair shops, hair salons, dry cleaners, and cabinet shops. If you use fabric softener, paint thinner or hair spray at your home, your home emits VOCs too.

Nitrogen oxides, NO_x, are produced by the interaction of atmospheric nitrogen and oxygen in high heat. NO_x is created when lightning strikes. It is released in forest fires. And it forms on the surfaces of hot engines. The largest sources of anthropogenic NO_x are generating plants, primarily coal-burning electric plants many of which are located in the Ohio Valley industrial belt. NO_x are soluble in water vapor and pass right through scrubbers which capture and contain other air pollutants produced in such plants.

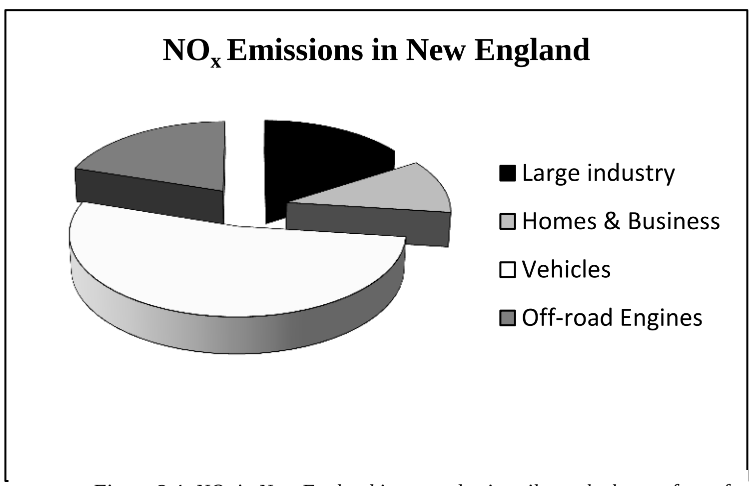

Figure 2.4: NO_x in New England is created primarily on the hot surface of automotive engines—cars and trucks in the densely populated urban corridor. Graph built using EPA Region 1 data, http://www.epa.gov/region1/airquality/piechart.html.

As Figure 2.4 shows, in New England, the major producers of NO_x are automobiles and trucks.

In Nature, plants and animals have been dealing with VOCs, NO_x and ground-level ozone for millions of years. In fact, these reactive gases cleanse the atmosphere, removing particulates and other pollutants from the atmosphere. Nature quickly deactivates and absorbs these gases, thus maintaining a balance in the chemistry of the atmosphere. For example, ozone which forms on a hot summer day is transformed to ordinary oxygen and water each night when the sun goes down and temperatures cool. Or it is transported high into the stratosphere where it becomes a helpful shield around the Earth.

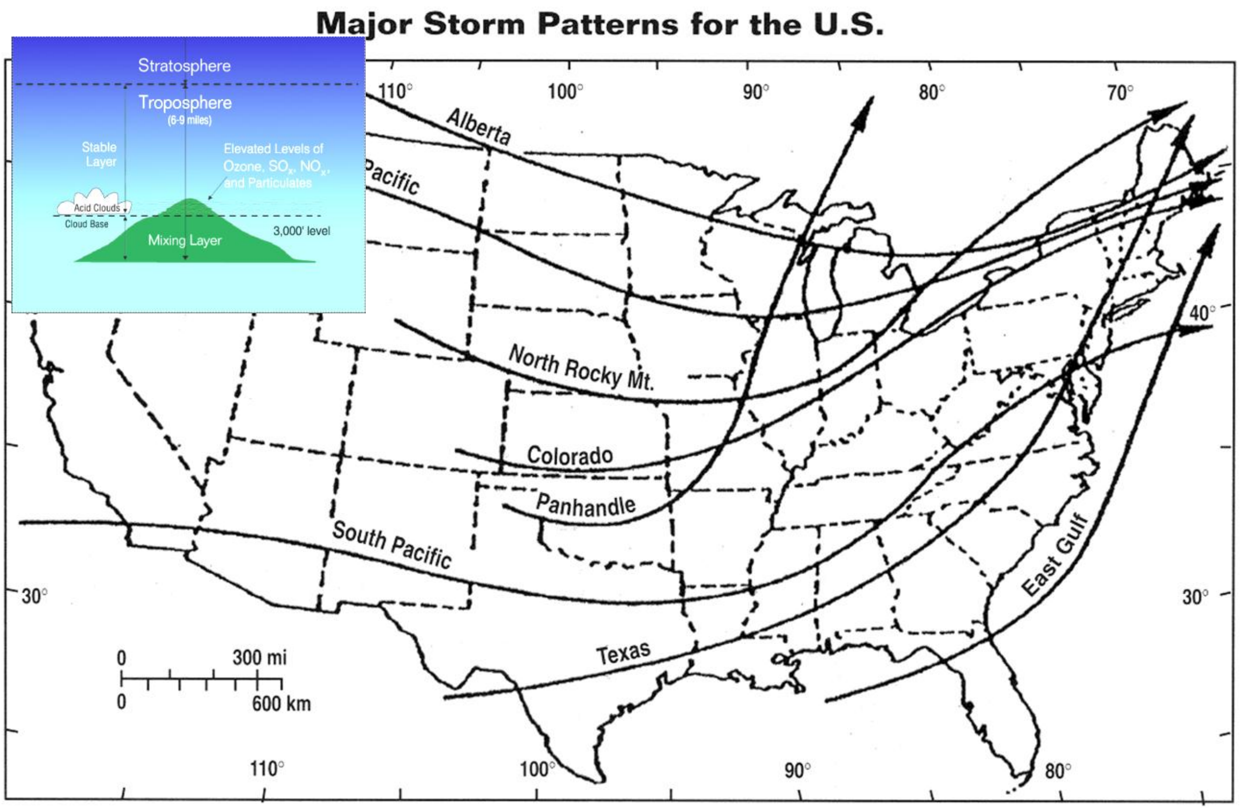

Figure 2.5: Westerly and southwesterly winds bring air pollutants from every part of the nation to New England. Pollutants are most heavily concentrated at about 3000 feet elevation.(NERA 2001).

Anthropogenic additions to the chemistry of our atmosphere have changed the natural balance. Air pollution has increased. Unfortunately New England experiences some of the worst air pollution in the United States. Wind patterns bring this region pollutants from the Gulf of Mexico, the far West, the Ohio industrial belt and the East coast's metropolitan corridor. Dr. Rock calls New England "the tail pipe of the nation," where all of the exhaust of all of our activities comes together. Wind patterns and cloud formations intensify the air pollutants most at about 3,000 feet. Ozone, dust and carbon particulates and sulphur and nitrogen gases which form oxidants and acids are most concentrated just below the peaks in our White Mountains. That is a sad piece of information for hikers and skiers.

How Does Ozone Cause Damage?

Ozone is a strong oxidant. Three atoms of oxygen in one molecule are unstable, a molecule looking for two extra electrons. Whatever a molecule of ozone encounters—delicate tissues around your eye, a mountain hiker's lung tissue, or a loosely bound molecule of lipid in a plant cellular membrane—ozone will steal electrons. Instantly the affected molecule will steal electrons from any nearby molecule, starting a chain reaction. Eyes sting. Lungs feel irritated. Plant cells begin to leak. Chloroplasts are de-activated.

In white pines, ozone enters the needle through the stomate which is open to draw in carbon dioxide and to transpire water and release oxygen. Inside the needle, in the intercellular space, the ozone encounters the delicate membranes of mesophyll cells. When the membranes are oxidized, water leaks out. The chain reaction may damage internal membranes of chloroplasts.

Forest Watch students recognize such damage in the yellow spots and smears of chlorotic mottling. When cells of the needle tips die, needles may exhibit brown tip necrosis. Figure 2.6 shows yellow spots and smears on either side of stomata, chlorotic mottle. Tip necrosis is visible as a brown and dry section at the outer or distal tips of needles. These cells are necrotic or dead. These particular types of damage are unique to ozone.

Forest Watch students measure the length of each damage on 30 different needles. Then they calculate the percent of each type of damage for the group of needles and the percent of needle lengths with both types of damage.

Living things, plants as well as animals, react quickly to oxidants. Cells call on anti-oxidant chemicals to stop and contain the chain reaction. Enzymes and phenolic compounds are produced to seal off the wounds. As Forest Watch students know, mildly damaged needles continue to make sugar and may stay on a branch for months or years.

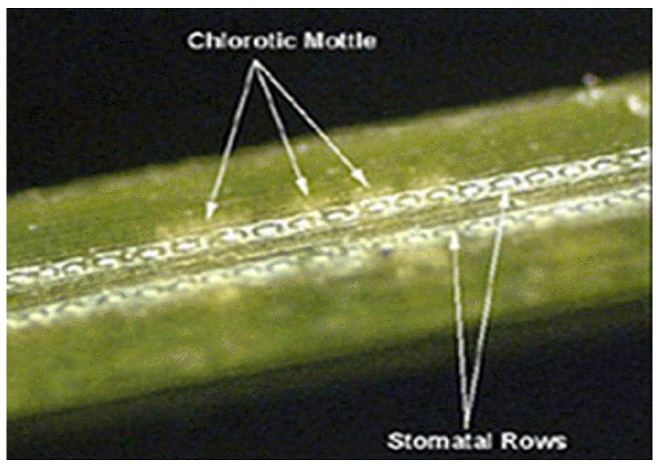

Figure 2.6: Chlorotic mottle at top and tip necrosis below are key indicators of ozone damage. Students measure both.

Chronic ozone exposure may cause enough damage to impair a plant's overall capacity to produce and store sugar and starch. Needles may drop prematurely and forest canopies become less dense. A tree may produce less wood and grow in diameter more slowly. And plants may have reduced capacity to cope with other stressors such as harsh weather, other air pollutants, to compete for light and water, and to protect themselves from insects, fungi and infections. Over time, populations of trees in heavily polluted forests will be eliminated. The ecosystem will lose biodiversity and resilience.

Monitoring Ozone Events

The Environmental Protection Agency began wide scale monitoring of ozone and the gases which form it in 1990 when the Clean Air Act was amended. The EPA rated ozone levels with the chart below, Figure 2.7. Today health officials and many weather stations make regular announcements of high ozone levels to help guide citizens who may have asthma or other health conditions that can be influenced by ozone. As the chart in Figure 2.7 shows, levels under 100 parts per billion (ppb) are considered only moderately concerning. Levels above 100 ppb are considered to be unhealthy. During the early 1990s, levels in the low 100-150 ppb area were measured frequently on hot summer days. In 1990, the EPA set 85 ppb as the maximum allowed level. This was a goal which the EPA and

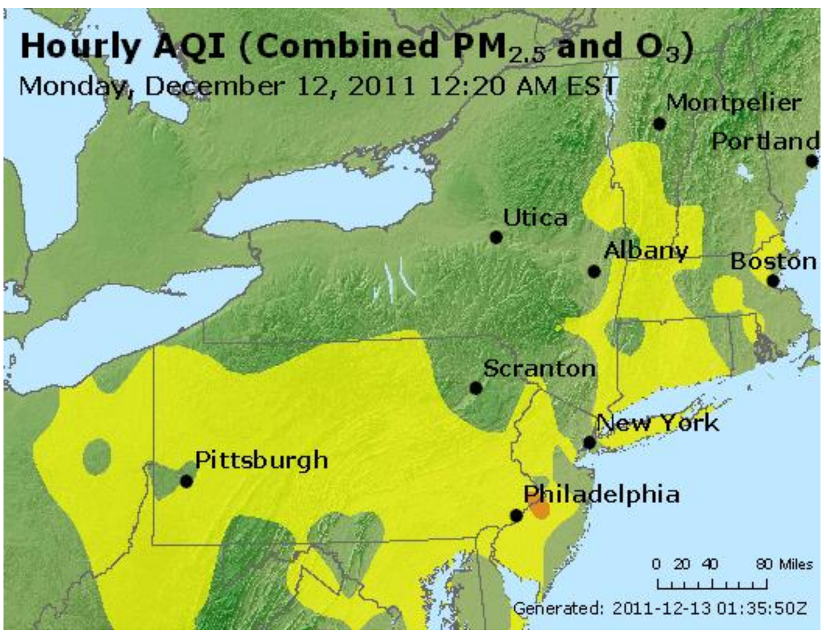

Figure 2.7: Ozone levels at peak concentrations on December 12, 2011. Source: www.epa.gov/airnow/2011.

8-hour Average Peak Concentration	
	0-50 ppb, good air quality
	51-100 ppb, moderate level of health concern
	101-150 ppb, unhealthy for sensitive species and humans.
	151-200 ppb, unhealthy for all humans and most plants.
	201-300 ppb, very unhealthy.

environmental advocates hoped would drive auto designers and industry to reduce production of NOx and VOCs. Slowly, ozone levels have fallen.

The EPA also has wrestled with how to define an ozone event which exceeds its standard. Ozone usually forms on a warm summer day. Levels begin to climb as the sun reaches peak heat, at about noon or 2 p.m. Levels may spike and then fall as the sun goes down. Or levels may remain high for several hours. Should a two-hour exceedance be recorded? Or is damage only done when plants and animals are exposed to high levels for numerous hours? The EPA settled on an 8-hour time frame. High levels of ozone are not counted as an exceedance unless levels over the limit last for 8 hours or more.

As research examined ozone more closely, scientists learned that lower levels of ozone could be harmful. We know from our research at UNH that gradual increases of ozone at relatively low levels are very significant. Plants and people are especially sensitive to tropospheric ozone between 60 and 85 ppb. In higher levels, plants can sense the pollutant and close their stomata, protecting delicate mesophyll cell membranes and chloroplasts. At high levels, human beings can also sense the feeling that they are having trouble breathing and wisely choose to stay inside. It is the mid-levels, around 75 ppb, when pines cannot close their stomata against ozone. Human beings may not realize they are having breathing problems when ozone is at these mid-levels.

It is also possible that repeated short peaks of ozone may be as irritating to living organisms as a single 8-hour exceedance. More research is needed. Responding to such questions, the EPA lowered its maximum from 85 to 75 ppb in 2006.

Across the country, ozone average "exceedances," hours or days when ozone levels exceeded federal standards, continue to decline. The annual average of exceedances measured at 507 ozone monitoring sites indicates a 17% decline in ground-level ozone since 1990 (EPA Airtrends ozone, 2011). The average has dropped from 86 ppb to 72 ppb. We are making progress in a highly sensitive zone of measurement. As Forest Watch students and teachers know, our white pine measures follow this trend clearly in increasing health of the trees.

Changing Ozone Conditions in 2011-2012

The U.S. Environmental Protection Agency reported in its 2011 Report on Air Quality in New England that a wetter, cooler summer in 2011 produced fewer high ozone days than we saw in 2010. In 2011, there were only 16 exceedances of the 8-hour ozone standard (0.075 ppm) compared with 29 exceedance days in 2010. The highest ozone event was measured in Madison, CT. The entire state of Connecticut failed to meet the ozone standard as did Dukes County in Massachusetts. Other states showed fewer exceedance days as shown in Table 2.1. When the New England exceedances are graphed, we see in Figure 2.8 a continuing decline in ozone events.

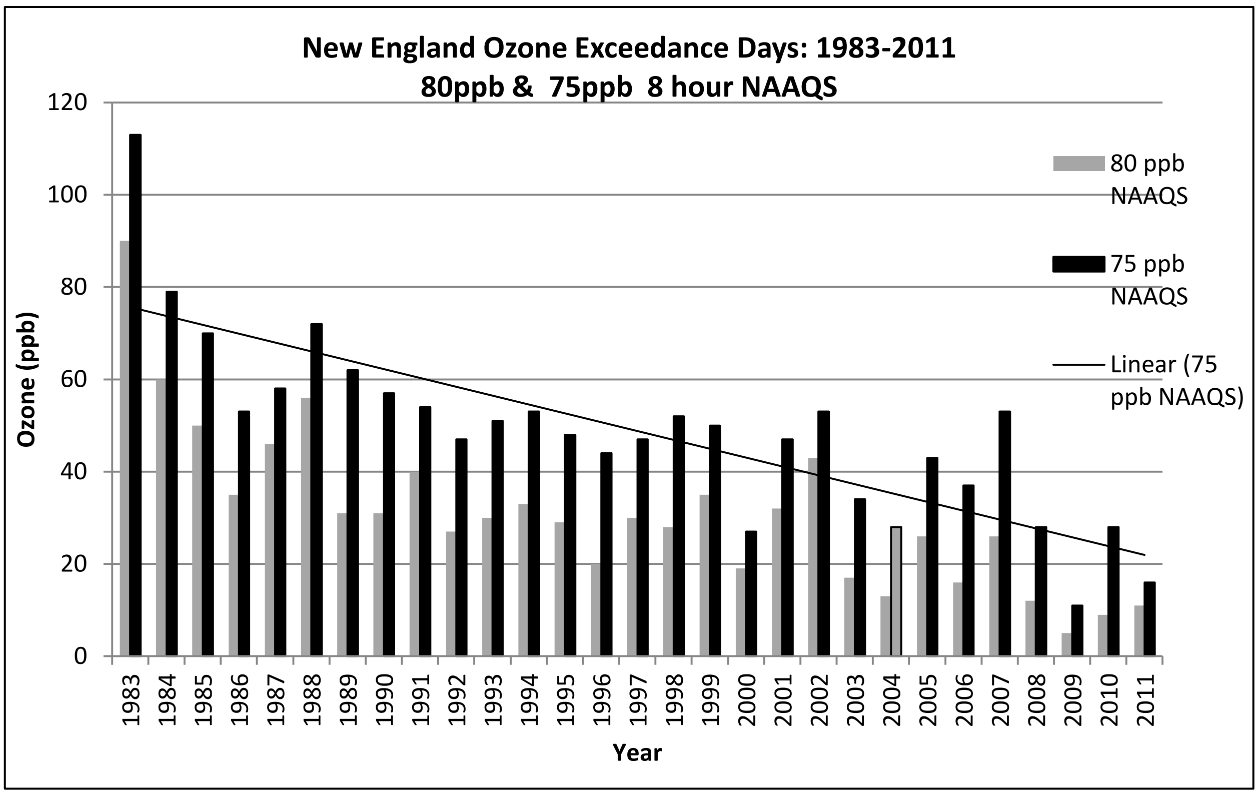

Figure 2.8: Exceedances continue a trend of fewer and fewer occurrences at lower and lower levels (EPA, Region 1, airquality) To allow for comparison of new national ambient air quality standards (NAAQS) against old standards, the EPA adjusts historic measures to fit new standards.

Table 2.1: Exceedance days 2000-2011 by New England State (EPA, 2011). The * indicates recent measurements which are still being confirmed. Historical Exceedance Days in New England, epa.gov/ http://www.epa.gov/region1/airquality/standard.html

Exceedance Days Per Area

	New England		CT		ME		MA		NH		RI		VT	
Year	# days >		# days >		# days >		# days >		# days >		# days >		# days >	
	0.084	0.075	0.084	0.075	0.084	0.075	0.084	0.075	0.084	0.075	0.084	0.075	0.084	0.075
1983	90	113	84	103	21	36	62	84	10	18	24	34	4	7
1984	60	79	54	63	25	34	44	65	10	20	28	42	4	10
1985	50	70	41	58	21	35	38	53	8	16	16	27	6	9
1986	35	53	28	41	9	17	24	32	9	16	12	22	1	6
1987	46	58	37	44	10	20	23	35	13	28	18	27	3	11
1988	56	72	50	62	35	40	43	63	27	37	19	29	14	26
1989	31	62	26	41	16	21	21	43	11	16	9	14	2	5
1990	31	57	24	44	15	21	22	37	9	20	13	18	5	8
1991	40	54	34	46	17	26	26	45	13	22	20	28	10	16
1992	27	47	19	29	12	22	20	36	8	18	5	12	6	11
1993	30	51	27	39	14	20	23	40	8	17	7	11	4	9
1994	33	53	28	39	10	22	20	39	9	19	8	21	2	13
1995	29	48	24	35	14	20	20	39	9	19	11	18	3	13
1996	20	44	16	33	5	20	15	28	6	14	4	12	3	4
1997	30	47	27	34	11	16	24	38	10	16	11	19	2	11
1998	28	52	25	44	11	16	12	36	7	14	5	11	0	5
1999	35	50	33	43	10	21	22	36	10	19	13	16	3	11
2000	19	27	13	23	3	5	5	16	1	5	8	14	1	2
2001	32	47	26	39	15	22	27	37	11	22	15	26	2	9
2002	43	53	36	49	17	28	30	43	13	23	17	33	5	13
2003	17	34	14	26	5	15	11	27	1	10	10	13	0	4
2004	13	28	6	20	1	11	8	16	5	10	4	5	2	4
2005	26	43	20	30	5	15	17	31	4	17	8	17	0	4
2006	16	37	13	29	2	10	12	26	2	10	3	13	0	0
2007	26	53	17	42	8	14	20	38	8	22	8	18	1	5
2008	13	30	8	22	0	4	9	18	2	10	4	6	0	3
2009	4	11	1	6	2	3	1	8	0	2	0	1	0	0
2010	9	29	5	24	2	8	4	14	0	8	1	6	0	0
2011	11	16	10	14	2	3	5	10	1	2	0	6	0	1
2012*	14	29	13	27	0	4	6	17	1	4	3	12	0	0

This is good news for Forest Watch researchers. Again this year, our chart of ozone in New Hampshire and spectral measurements of white pines shows a striking inverse relationship between the two: As ozone events have declined in number and intensity, the health of white pines, as measured from needle reflectance of light, indicates abundant chlorophyll, Figure 2.9

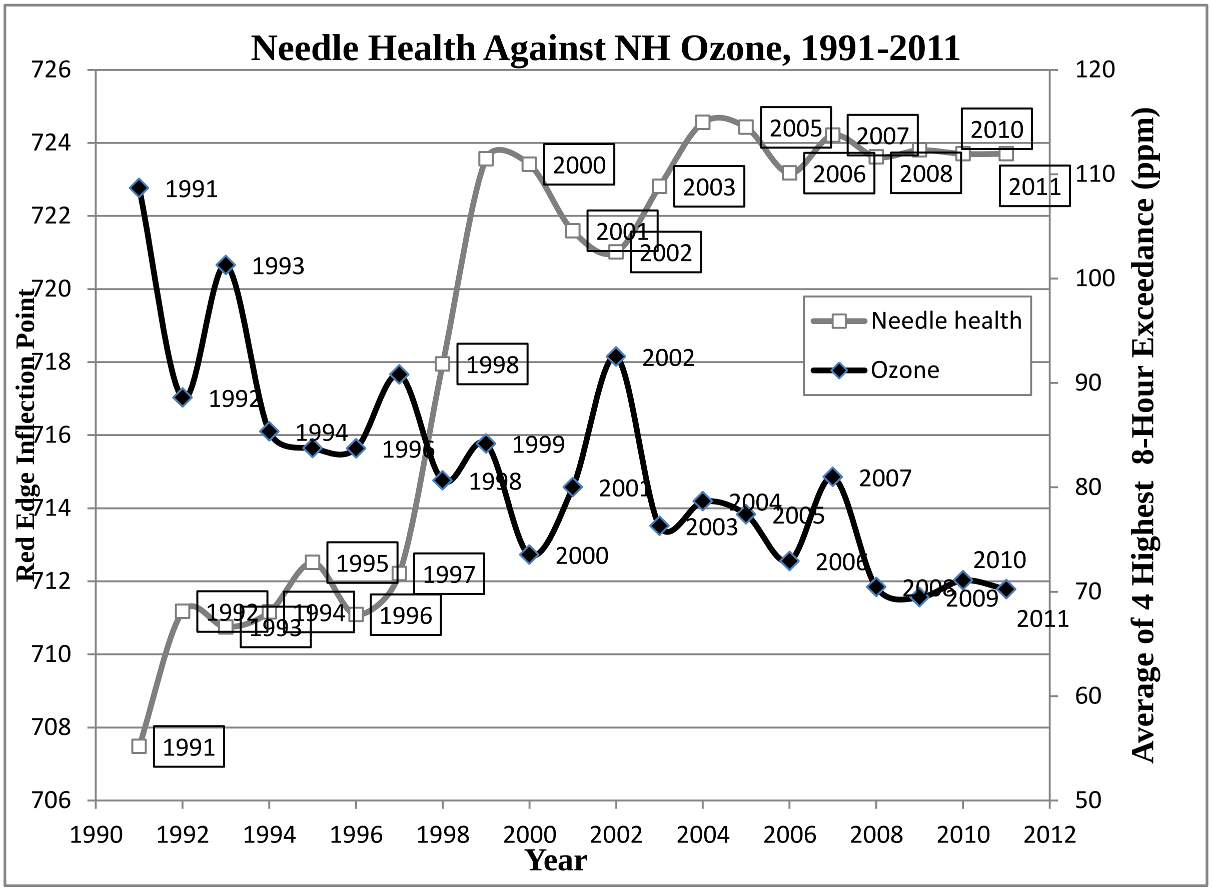

Figure 2.9: The inverse relationship between ozone levels and white pine health, continues to show strong improvement in air quality and tree health. White pine health is rated by the red edge inflection point, an index of light reflectance, to be explained in Chapter 4. These levels of ozone are an average of the four highest ozone events in seven monitoring stations in New Hampshire. This year, since measurements were no longer made in Manchester and Claremont, we used Lebanon and Laconia measurements to build our average. Other long-term monitoring stations include Concord, Keene, Nashua, where highest levels in New Hampshire were recorded, Portsmouth and Rye. The source for these data is the EPA, Region 1, Air Quality, NH_over, (http://www.epa.gov/region1/airquality/nh_over.html).

Forest Watch teachers know that ozone levels have fallen since the Clean Air Act was improved in 1996. Further emission controls were imposed on large utility plants in 2005. The satellite images interpreted in Figure 2.10 show dramatic evidence that it is working. The images were produced by Bryan Duncan, a researcher with the Air Quality Applied Science Team, AQAST, a recent offshoot developed by NASA's Applied Sciences Program. AQAST brings scientists from many disciplines together with data sets and tools from every satellite and monitoring station in the nation to provide rapid interpretation, response to and publication of air quality information. This study finds that annual mean observations of tropospheric nitrogen dioxide, the chief ingredient in ozone, has declined markedly since 2005. (http://acmg.seas.harvard.edu/aqast/docs/Bryan_Duncan_Lenticular_Sep2012.pdf).

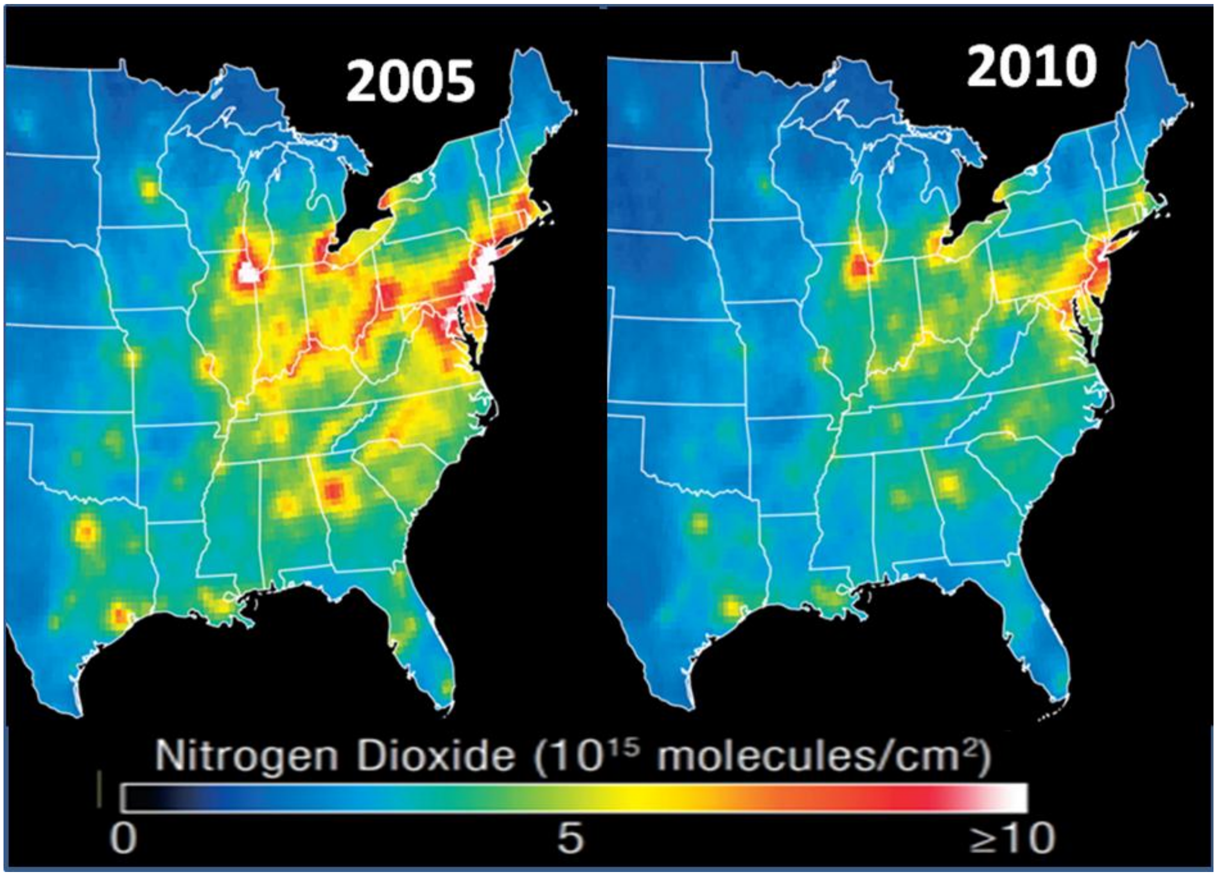

Figure 2.10: Nitrogen dioxide in the troposphere has declined between 2005 and 2010, as measured by interpretations of remote sensing imagery, NASA AQAST.

Duncan's study is not only good news for Forest Watch. It led us to AQAST and the remarkable information this new program is producing and publishing free of charge, with open access to all, on their web sites. Reported by The Smog Blog, which we'll meet in Chapter Four, sulfur dioxide has also been reduced, at least the SO_2 released from and measured near coal-fired power plants. AQAST scientists attribute the reduction to the Clean Air Interstate Rule which the EPA issued in 2005. This observation used the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite. Vitali Fioletov of Environment Canada, produced the maps of sulfur dioxide in Figure 2.11.

The EPA continues to strength air quality standards for these two pollutants. More monitors will be placed throughout New England. The agency reported that one monitor in Pembroke, NH, recorded SO_2 at 263 ppb for one hour in 2011, far exceeding air quality standards. Sulfur dioxide, the EPA reports, can cause wheezing, shortness of breath and chest tightness and is expecially harmful to older adults and children who suffer from asthma. SO_2 is also harmful to plants. As Dr. Rock's research found in Vermont, New Hampshire and the Czech Republic, SO_2 can cause extreme damage and needle cast to conifers.

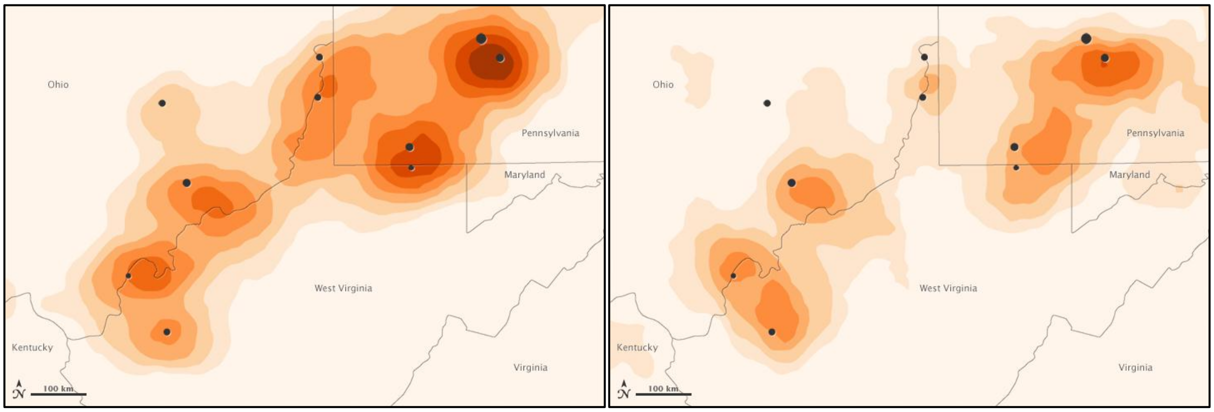

Figure 2.12. Sulfur dioxide levels from point sources, utility plants in Ohio, West Virginia and Pennsylvania, have fallen nearly half since the map at left, 2005-2007, compared to the map at right, 2008 to 2010 (The Smog Blog, Dec. 1, 2011).

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Chapter Three
Fungi and White Pine Needle Cast

Forest Watch is delighted to republish a research paper written by Dr. Isabel Munck, a plant pathologist in the U.S. Forest Service's Forest Health Protection, and her colleagues. We abridge the article by omitting several images. Notice that Dr. Munck uses the term one-year old needles. In Forest Watch, we would call these second year needles as of June, one year after they are formed.

Eastern White Pine Needle Damage Survey, 2011 In Maine, New Hampshire, and Vermont, Published May 16, 2012

Isabel Munck, Forest Health Protection, Durham Field Office, US Forest Service
Barbara Burns, Forest Health Insects & Diseases, Vermont Department of Forests Parks and Recreation
William Ostrofsky, Maine Forest Service, Maine Department of Conservation
Kyle Lombard and Jennifer Weimer, Forest Health Section, New Hampshire Division of Forests & Lands

Abstract

White pine needle damage is a current concern in New England and eastern Canada where *Pinus strobus* is of great historic, ecological, and economic importance. State natural resource agencies received hundreds of calls from concerned citizens during 2010 when damage was particularly severe following a very wet spring. Foliar damage was attributed to a needle cast (*Canavirgella banfieldii*) and brown spot needle blight (*Mycosphaerella dearnessii*, anamorph* *Lecanosticta acicola*). Both of these fungi cause similar symptoms, thus complicating diagnoses. In 2011, the USDA Forest Service coordinated a survey with Forest Health State Cooperators from Maine, New Hampshire, and Vermont to investigate the cause of the needle damage. Sixty trees from 13 sites with foliar damage the prior year were sampled from April to June by FH State Cooperators and then diagnosed at the USFS Northeastern Area Durham Field Office. The needles were found to be infected with *M. dearnessii* and *C. banfieldii*, and another needle cast causing pathogen, *Bifusella linearis*. At one location these three pathogens were all present and at another site more than one pathogen was found infecting the same tree. Long, dark hysterothecia* fruiting bodies formed by *B. linearis* and *C. banfieldii*, along with browning of the distal parts of the needles, were present in samples collected in May. *Mycosphaerella dearnessii* was the most frequently observed and widely distributed pathogen, also the most consistently associated with chlorosis and defoliation in early July. White pine needle damage will likely remain a problem in years with wet springs which favors development of the fungi.

*Anamorph: A fungus whose sexual reproductive stage has never been observed.
*Hysteriothecia: A mature fruiting body of a fungus that opens by a slit. Inside the hysterothecia, there are sacs containing spores. Fruiting body: Part of the fungus in which spores are produced.

Introduction

During the summer 2010, white pine needle damage was observed frequently throughout New England generating much public concern. Symptoms consisted of yellow and brown discoloration of one-year old needles [Notice, Forest Watch would call these second year needles which were formed in June 2009]. Affected needles dropped causing tree crowns to look thin a year after initial infection . Needles of both mature trees and regeneration were damaged.

White pine foliar damage has been attributed to frost and two foliar diseases, brown spot needle blight caused by the fungus *M. dearnessii* and Canavirgella needle cast caused by *C. banfieldii*. Diagnosing the damage agent is difficult because both fungi cause similar symptoms, although they can be differentiated by their fruiting bodies produced at different times in the growing season. The sexual fruiting structures of *C. banfieldii* are produced through the winter and are visible earlier in the spring, whereas *M. dearnessii* fruits in June (Merrill et al. 1996, Sinclair and Lyon 2005). Consequently, *C. banfieldii* fruiting bodies could be present in infected needles by April and fruiting bodies of both *C. banfieldii* and *M. dearnesii* could be present by June.

White pine foliar damage was mapped during 2010 aerial forest health detection surveys in New England. In Maine alone 60,116 acres were reported damaged. Because several fungi and frost were associated with the foliar damage, coding the damage consistently during the aerial surveys was challenging. There was a need to understand the extent of the damage that could be directly related to foliar pathogens. Consequently, the objective of this study was to determine the causal agent of the observed white pine needle damage.

Methods

Forest Health State Cooperators from Maine, New Hampshire, and Vermont collected samples from at least three to five white pine stands per State that exhibited damage during 2010, along with stand information (Appendix A). Because the pathogens associated with the damage fruit at different times, stands were sampled between April 25 and May 2 and again during June 13 and 22, 2011 [Forest Watch would call the 2010 year needles first year needles in April and May and second year needles in June 2011 if new needles have opened]. At each stand, samples were collected from at least three and up to five symptomatic trees. When available, samples were also collected from one healthy, control tree. Each sample consisted of a quart-size (1 L) bag full of branch tips.

Samples were sent to the Durham Field Office where they were processed for pathogen identification. All branch tips were visually examined for fungal fruiting structures. Disease incidence and severity were recorded. Twenty needles from one representative branch tip per tree were placed in a moist chamber, incubated at 25˚C for 24 to 72 hours, and then examined with the aid of dissecting and light microscopes. Moist chambers consisted of Petri plates with filter papers moistened with deionized water sealed with Parafilm.

Results

A total of 13 stands were sampled throughout northern New England. Most of these were

Figure 3.1: Necrotic needles (A) from Mast Yard, NH, infected by *Bifusella linearis*, fruiting bodies (B) are shinny and black (x7.5) and the ascospores (C) are constricted in the middle (x400). Spores are stained with methyl blue.

Figure 3.2: Needles (A) with chlorosis and necrosis from Sangerville, Maine, infected with *Canavirgella banfieldii*, fruiting body (B) is embedded in the needle (x20) and ascospores (C) are not constricted in the middle (x200). Spores are stained with methyl blue.

Figure 6. Sample (A) with defoliation and chlorosis from Waterbury, Vermont infected with *Mycosphaerella dearnessii* (anamorph *Lecanosticta acicola*), asexual fruiting body (B) (x35) and spores (C)(x200).

natural stands located in wetland areas, but trees on dry steep slopes in one plantation in Vermont were also sampled. Samples were taken from a total of 60 trees in all age classes. In

May, 729 branch tips and 1,153 incubated needles were examined. Similarly, in June 384 branch tips and 901 incubated needles were examined.

Signs and symptoms of *C. banfieldii* and *M. dearnessii* were frequently observed. A third fungus, *Bifusella linearis*, was identified by Mary Inman, diagnostician for the Connecticut Agricultural Experiment Station. Both *B. linearis* and *C. banfieldii* produce long, dark fruiting bodies (Figure 1 and 2)(Merrill et al. 1996). The fruiting bodies of *B. linearis* are shiny and black (Figure 1B), whereas *C. banfieldii* fruiting bodies are grey and embedded in the needle (Figure 2B). These two fungi can be distinguished by the shape of their ascospores*. *Bifusella linearis* ascospores are constricted in the middle (Figure 3.1C) (Horst and Westcott 2008), whereas *C. banfieldii* ascospores are not (Figure 3.2C) (Merrill et al. 1996). *Mycosphaerella dearnessii* produces *

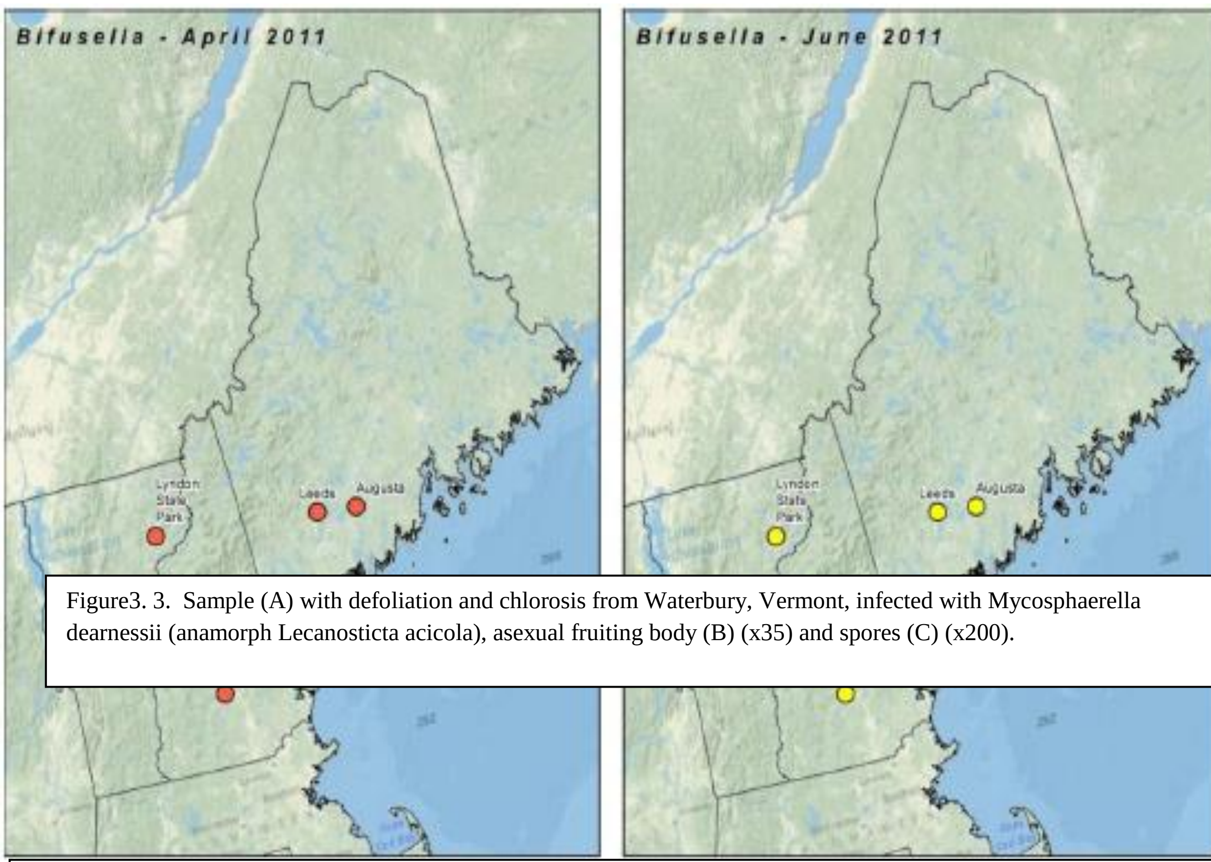

Figure3. 3. Sample (A) with defoliation and chlorosis from Waterbury, Vermont, infected with Mycosphaerella dearnessii (anamorph Lecanosticta acicola), asexual fruiting body (B) (x35) and spores (C) (x200).

Figure 3.4: Location of sites with Bifusella linearis. Infected white pine samples were collected in April and June of 2011.

smaller fruiting bodies (Figure 3.3B) and brown, banana-shaped spores* (Figure 3.3C) (Jankovsky et al. 2009, Jurc and Jurc 2010). Several other fungi were found fruiting on needles

*Ascospores: A sexual spore produced in a sac-like structure.
*Spores: Reproductive structures of fungi and some other organisms, containing one or more cells, similar to a seed for a plant.

but these fungi were not associated with needle blight or needle cast symptoms and appeared to be secondary invaders.

Diagnostic *B. linearis* fruiting bodies were present in samples collected in April and June from the same five sites (Figure 3.4). Similarly, *C. banfieldii* fruiting bodies were observed in samples collected in April and June from the same three sites . Both these needle cast fungi produce sexual fruiting structures that take a year to develop. In contrast, *M. dearnessii* was only found fruiting on four sites in April; however by June it was fruiting in samples from ten sites. Unlike the needle cast fungi, *M. dearnessii* produces asexual fruiting structures that result in more than one disease cycle though the growing season.

Samples were disease free from only one site, Clough State Park, which is in New Hampshire. *Mycosphaerella dearnesii* was the most widely distributed fungus as it was present in most sites alone or co-occurring with the needle cast fungi. All three fungi were present in one tree at one site, Lyndon State Park in Vermont.

In April, fruiting structures of all three fungi were found in less than 20% of the trees sampled (Figure 3.5). By June, 48% of the trees yielded samples with signs of *M. dearnessii*. Between April and June the proportion of trees with symptoms of chlorosis and defoliation increased from 25% to 50% and 0% to 45%, respectively (Figure 3.5). In April 68% of the trees yielded

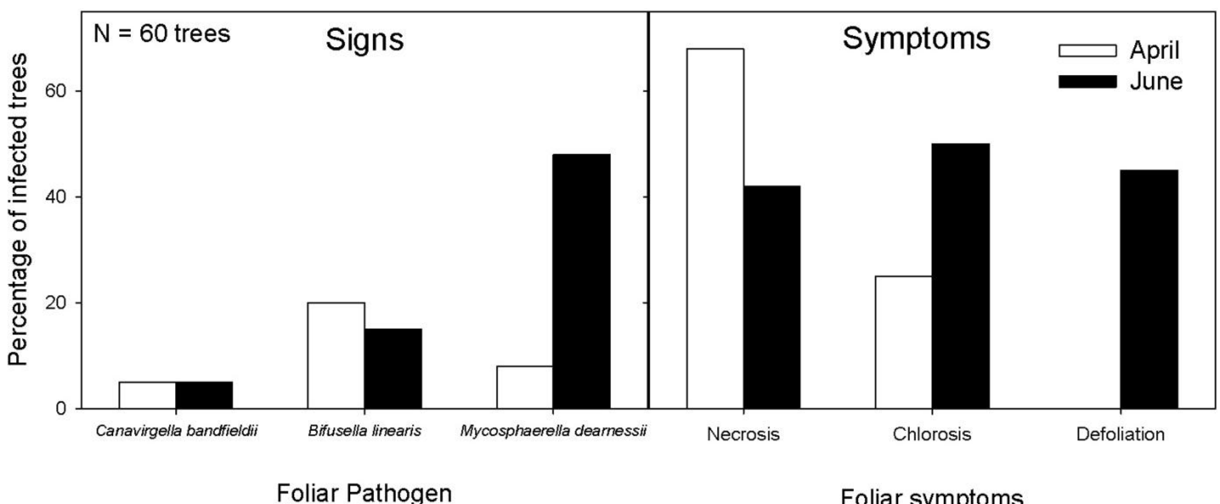

Figure 3.5. Frequency of foliar disease signs and symptoms on infected trees.

samples with necrotic needles, although the necrosis was limited to less than one third of the needle. In contrast, the chlorosis of samples collected in June exceeded more than two thirds of the needle. It is possible that the proportion of necrotic needles decreased due to the needle drop in June.

Conclusions

At one site all three pathogenic fungi were present and multiple pathogens were found on the same tree at another location. *Mycosphaerella dearnesii* was the most frequently observed, widely distributed pathogen, and most constantly associated with chlorosis and defoliation in late June. It is likely that wet spring weather, favorable to disease development, during several consecutive years has led to an outbreak of foliar diseases. Trees in a variety of sites across northern New England were affected. Thus, the observed foliar damage is probably not site related.

Prior to this outbreak, damage caused by *Canavirgella* needle blight was reported on less than 0.1% of eastern white pines (Merrill *et al.* 1996). Similarly, although brown spot needle blight is common on 2 and 3 needle pines, it typically is not associated with white pine. In addition, *Bifusella* needle cast is rarely reported in northeastern North America; however, this disease may have been misdiagnosed or overlooked in the past. The consequence of repeated defoliations by these pathogens is unknown. These fungi are expected to continue to cause damage in years following unusually wet springs. Thinning damaged trees during these conditions is not recommended as these trees are already stressed by repeated defoliations.

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Chapter Four
A Case for A Stressor Other than Fungi

Forest Watch data for 2011 needles lead us to hypothesize that something in the air has stressed white pines. Yes, fungi definitely are causing heavy damage. But why are our white pines suddenly susceptible to fungi with which the pines have lived for thousands of years? Why are the pines unable to protect themselves from fungi which in the past record have only damaged 0.1% of needles, one tenth of one percent?

The U.S. Forest Service reasons that 2009 was unusually wet, with many cloudy days, giving fungi reason to breed. That year another fungi, late blight, *Phytophthora infestans*, spread across New England, devastating the tomato crop. But our look at records indicates that 2009 was only the fourth wettest summer New England has had since 1993. September 2009 was the driest year in the group, as Figure 4.1 shows. April and May, 2010, when the needle cast fungi may have fruited and released spores, and June, 2010, when needles first began dropping, were also very dry, making conditions less than ideal for infecting 2010's new needles.

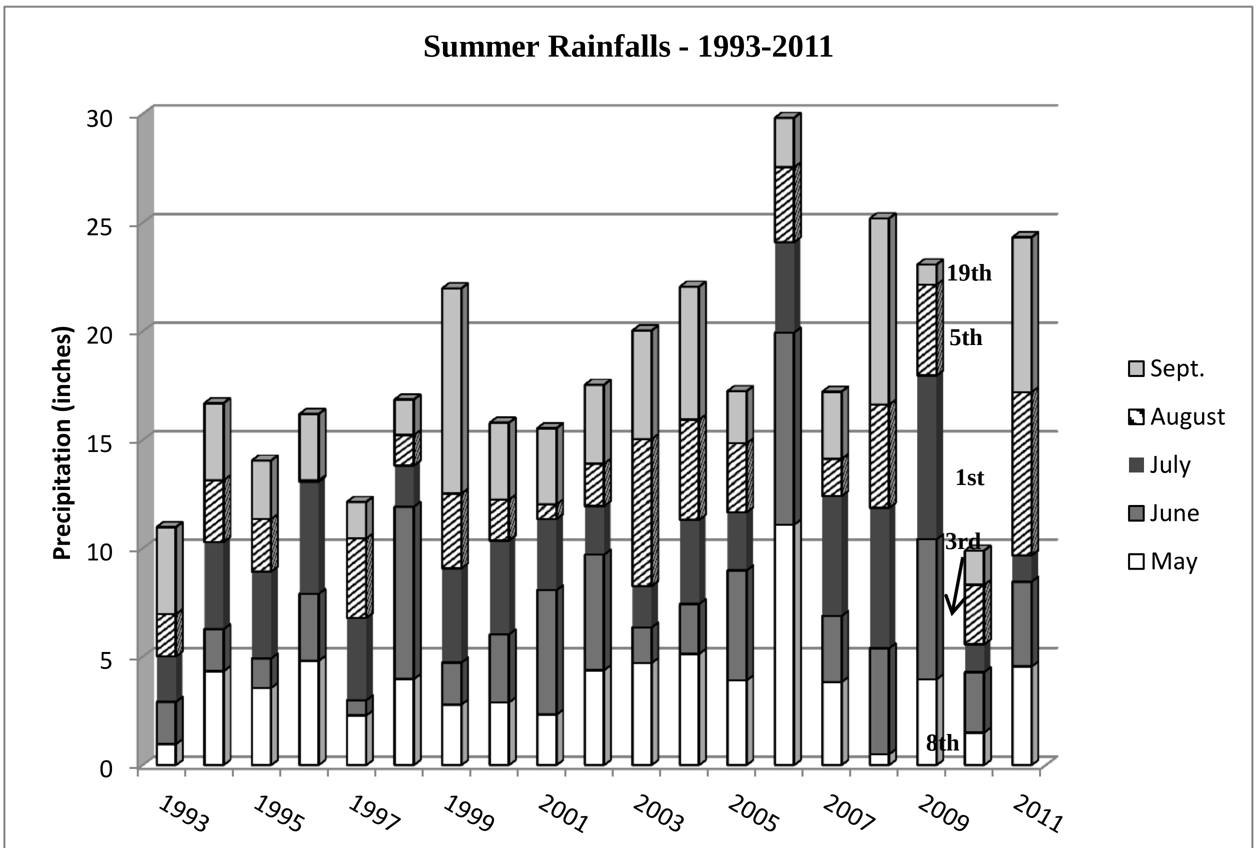

Figure 4.1: Rainfall May-September 1993-2011. In 2009, May was the 8th wettest month, June, the 3rd, July the 1st, August the 5th and September the 19th wettest month. Spring of 2010 was one of the driest years. (National Climatic Data Center, Annual Climatological summaries, www.ncdc.noaa.gov/cdo-web/quickdata, accessed 1-3-13).

We suspect that something else has occurred during the 2010 spring or summer and perhaps repeatedly since then to stress the pines and give the fungi an opportunity to have a population explosion and to continue reinfecting the pines since then.

Until very recently, tracing plant stress to atmospheric chemicals has been a limited science. Air pollution monitors provide point measures and these, as Forest Watch partners know, are mapped by the Environmental Protection Agency's AIRNOW. As we learned from Dr. Robert Talbot two years ago, air is also mapped by highly sensitive monitors on occasional aircraft flights by NASA. A variety of satellites collect information which could lead to information about atmospheric chemistry but interpreting the data has been spotty and disparate.

Now, just recently, air quality reports are being gathered from every available source by U.S. Air Quality, a daily diary and analysis provided by the University of Maryland, Baltimore County Atmospheric Lidar Group. USAQ obtains permission to use the many different satellite, weather and ground-based maps and models it presents. And new satellites provide better data about small particulates in the troposphere. We present a Forest Watch selection of recent USAQ images and statements and attribute the following chronology in large part to U.S. Air Quality Smog Blog (http://alg.umbc.edu/usaq). We intersperse The Smog Blog information with our own observations and findings with white pine needles, in italic.

Forest Watch encourages students and teachers to check The Smog Blog regularly. The images are stunning. The text is informative and quite easy to understand.

This chronology and selection of images offers some support for our hypothesis that atmospheric contaminants are indeed stressing the white pines. Ozone may be one of the culprits. Other pollutants, particularly sulfate, also may be stressors. Air pollution caused by smoke from widespread wild fires may be an issue.

We know from Dr. Rock's past research that a cloud of sulfates or nitrates can produce sulfuric or nitric acids. As cloud vapor, these acids can cause extreme damage to vegetation, particularly at high elevations. In building the chronology, Forest Watch has contacted scientists who produce many of the maps. We've asked them if they think the sulfates they

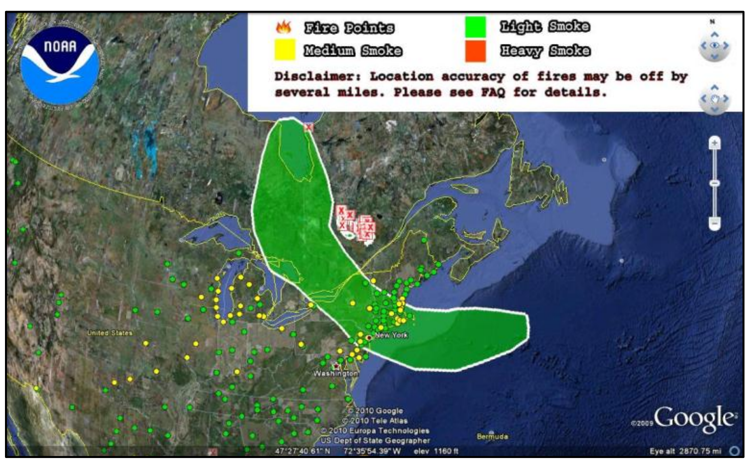

Figure 4.2: Aerosol cloud over Canada and New England, May 26, 2010. Smog Blog.

map are long-lasting enough and of high enough concentration to cause acid rain damage and other stress to white pines. Is anyone using The Smog Blog's maps to raise such a question? As atmospheric chemists, they may need help from Forest Watch to construct a full answer to this question.

We've also shown this chronology to Dr. Isabel Munck, whose article is presented in Chapter 3. Fungi are still her main concern. We include Dr. Munck's time line for fungal activities throughout the chronology. Our hypothesis might be incorrect. Whatever the answer, Forest Watch students and teachers might be the best people to help find it. We hope the chronology will offer clues as to how we should design our next investigative protocols.

Chronology

April and May 2010: Fungi which infected 2009 needles produce long fruiting bodies, producing spores.

May 26, 2010: *White pines in Londonderry release pollen. An atmospheric pollution event on Bald Mountain defoliates sugar maples. We link the defoliation to fires in Quebec with Hysplit (Figure 4.3) and identify peroxyacetyl nitrate (PAN) as the probable oxidant.*

The Smog Blog publishes a model produced by Hazard Mapping Fire and Smoke Product, National Oceanic and Atmospheric Administration, NOAA, showing a large mass of aerosol covering a large region from James Bay to the Great Lakes and across New England Using Hysplit and lidar measurements from their lab at the University of Maryland Baltimore County (UMBC), The Smog Blog team found smoke produced on May 24 sweeping south as far as New York and Baltimore.

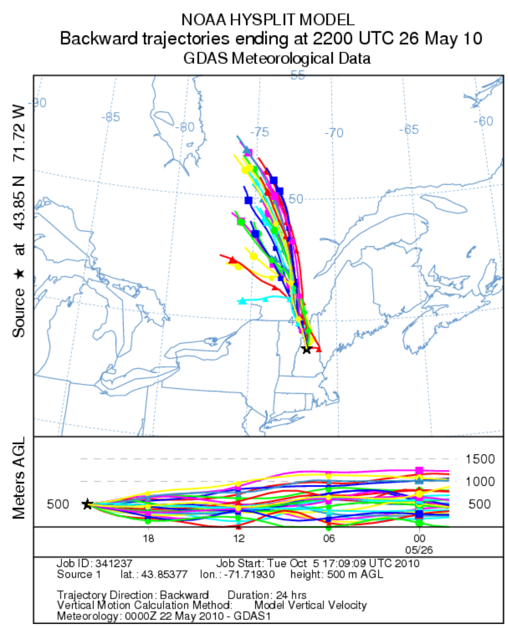

Figure 4.3: HYSPLIT of winds on May 26, 2010, show direct path from Quebec to Bald Mountain, West Campton, NH.

May 30, 2010: *White pines all over New Hampshire cast so many needles, the SandwichBoard, a Yahoo.com chat room for Sandwich, NH, is flooded with queries. So is UNH Extension.*

May 31, 2010: Canada fires continue to produce "unhealthy air quality."

Early June 2010: *White pines open 2010 needles. Spores on any remaining 2009 needles may infect new needles.*

June 26, 2010: Smog Blog releases an animation of carbon monoxide blowing south as far as Maryland from fires in Quebec. (Figure 4.4). They announce a program called BORTAS (Quantifying the impact of Boreal forest fires on Tropospheric oxidants over the Atlantic using Aircraft and Satellites).

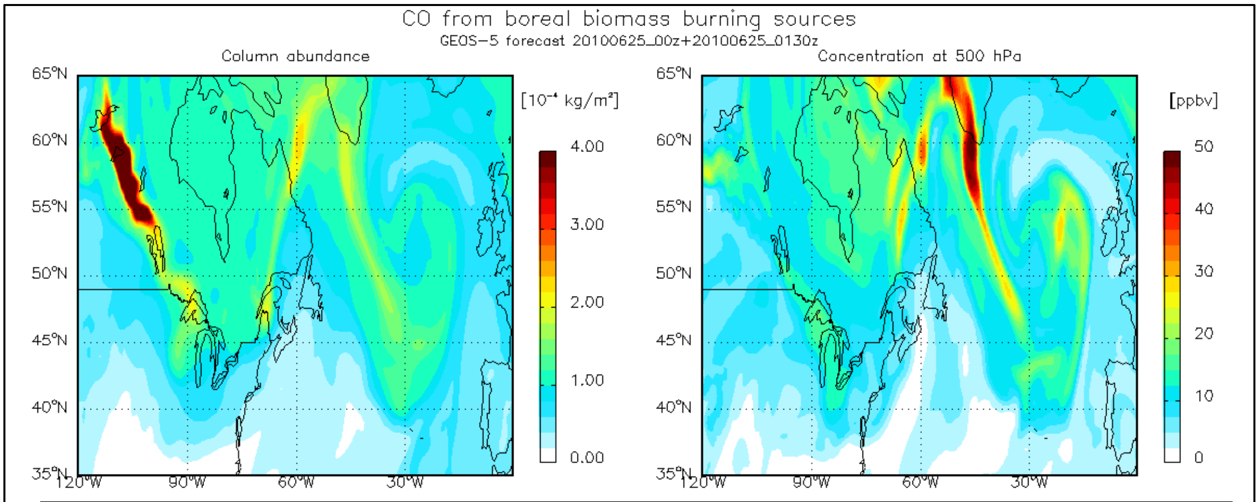

Figure 4.4: Maps of carbon monoxide, CO, released from Canadian forest fires, June 26, 2010. Smog Blog.

July 4, 2010: White pines cast needles infected by fungi.

July 10, 2010: Air quality improves, Smog Blog reports. The first BORTAS flights show a "Casper the Friendly Ghost" cloud of smoke over Canada moving southeast. The cloud of smoke is 1-3 kilometers high and "will not be expected to affect surface air quality until it mixes down further enroute."

August 3, 2010: Smoke comes not only from Canadian wild fires but from peat fires in Russia. Smog Blog mentions the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite, CALIPSO, a satellite which samples the contents of the troposphere and found on July 29, 2010 that smoke can circle the globe.

August and September 2010: Fung, if present, form blister- like damage on 2010 needles.

September 1 &2, 2010: Temperatures in the 90s, clear skies, cause moderate (code yellow) and unhealthy for sensitive groups (code orange) ozone in New Hampshire and throughout

New England. No large fires are reported but aerosols of "unknown origin and composition" are circulating in the region, Smog Blog reports.

Second flush maple leaves on Bald Mountain develop classic ozone chlorosis, Figure 4.5.

Using satellite images from two satellites, CALIPSO and the Moderate Resolution Imaging Spectroradiometer (MODIS), The Smog Blog reports that Michael Fromm of the U.S. Naval Research Laboratory (NRL) in Monterey, CA, can track smoke moving 12 kilometers high, the first evidence that smoke from wild fires can move into the stratosphere. : "Few things have the power to send aerosol particles that high into the atmosphere. Until a decade ago, most scientists thought that only a volcano could do so." Smog Blog says.

Figure 4.5: Sugar maple leaf with chlorosis between veins, following ozone event in September 2010. Photo by Carlson.

The NRL models and CALIPSO profiles of atmospheric aerosols opened new avenues for research by many scientists, including Emily Fischer, an atmospheric chemist who studied at UNH and is now at Harvard. Fischer is using these technologies to build global models of PAN. Wild fires produce large amounts of PAN and, as NRL proved, the fires can send it into the stratosphere where cold temperatures preserve it for long distance transport, Fisher told us on December 7, 2012.

September 24, 2010: A code yellow ozone day, Smog Blog reports.

October 11, 2010: Code yellow ozone.

November 21, 2010: Smog Blog delivers an outstanding lesson on the cause of wintertime ozone events. Although temperatures are cold and photochemistry is reduced by the lower angle of the sun, the troposphere is compressed in winter. Stagnant air is concentrated and can travel horizontally from sources such as Midwest electric generating plants.

November 23, 2010: Code yellow ozone, Smog Blog reports.

The first indication of trouble among the Forest Watch pines might have been from Lyme NH when students sent in samples of 2010 needles on November 23, 2010. We scanned some second year needles from Tree 1369, a hearty tree that stands in an open field.

Notice that the REIPs of the second year needles are very low, 719.3 on the North side and 711.6 on the South side, in Figure 4.6. Needles on both sides are experiencing water stress, particularly on the North side, as the TM5/4 ratios show: 0.764 and 0.625. The NIR 3/1 is alarming. Needles on the North side have an index of 1.023, a reading that indicates the needles are dead. Needles on the South side show beginning senescence with NIR3/1 ratios of 0.933.

Lyme	1369N1	1369N2	1369S1	1369S2
REIP	723.9	719.3	723.9	711.6
NDVI	0.829	0.818	0.831	0.798
TM54	0.497	0.764	0.483	0.625
NIR31	0.842	1.023	0.832	0.933

Figure 4.6: Indices of VIRIS scans of Lyme School trees, November 23, 2010.

Lyme's first year needles appear to be fine but needles that opened in 2009 and grew through the 2009-2010 school year, the summer of 2010 and into fall 2010 had experienced some kind of severe stress. White pines normally retain second, third and even a few fourth year needles. Older needles should be robust with high REIPs, no water stress and no signs of premature senescence.

December 10, 2010: High levels of NO_2 over New England, The Smog Blog reports.

December 12, 2010: High levels of sulfate over New England, The Smog Blog reports.

December 17 & 18: High levels of sulfate, The Smog Blog reports.

December 30 & 31, 2010: Code orange ozone over New England. The EPA, Region 1, reports that in 2010 New England experienced 24 days in which ozone levels exceeded the 75 parts per billion (ppb) limit.

January 20, 2011: Moderate code yellow levels of particulate matter 2.5 are reported (Figure 4.7). Smog Blog explains that nitrogen dioxide reacts with the hydroxyl free radical ($OH^{\cdot}$) to form nitric acid (HNO_3). Nitric acid may form nitrate, return to nitrogen dioxide or, as it frequently does in winter, react with ammonia to form ammonium nitrate (NH_4NO_3). "Cold temperatures and higher humidity strongly favors the formation of fine NH_4NO_3 aerosol particles ….," Smog Blog explained.

Early February 2011: High levels of NO_2 recorded on numerous days over New England.

March 2011: High NO_2 over northeast.

April and May 2011: Fungi, if present, produce fruiting bodies on 2010 needles.

May 26, 2011: Smog Blog reports "bad air" due to smoke from wild fires in Canada, Mexico and Central America.

May 31, 2011: Code orange ozone in Northeast; wild fires in Canada.

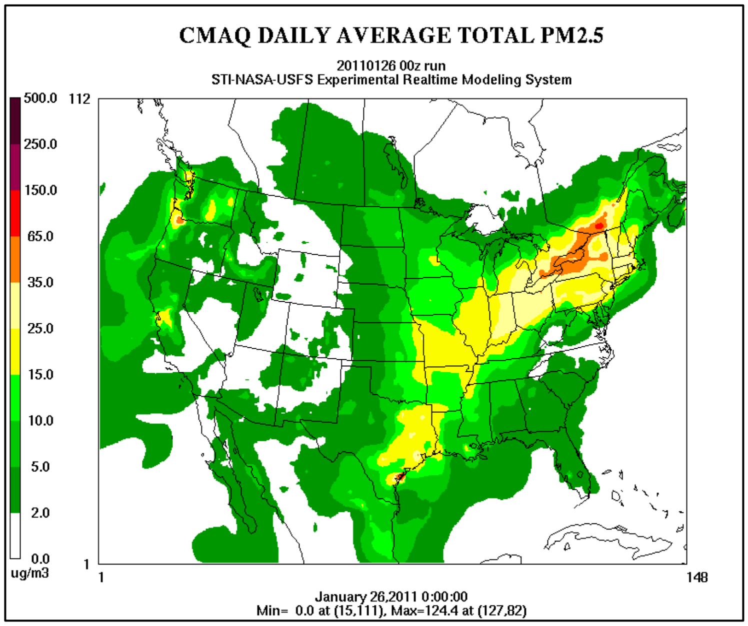

Figure 4.7: Particulate matter over the eastern seaboard, January 26, 2011.

Early June 2011: *White pines release pollen and open 2011 needles. These are the new "first-year needles" discussed in this report. The 2010 needles are now "second-year needles." Remaining 2009 needles are "third-year needles". Fungal spores infect emerging 2011 needles.*

June 1, 2011: Smog Blog reports haze, smoke and ozone over New England.

June 8, 2011: Air "unhealthy" with code orange NO_2 and code red ozone over New England. Wild fires burn over 200,000 acres in Arizona.

June 9, 2011: High ozone over East coast.

June 30, 2011: Wild fires in Canada, high PM 2.5 levels and high ozone over New England.

July 1&2, 2011: Rising ozone levels. *Infected 2009 and 2010 needles are cast.*

July 7, 2011: Ozone builds to a code orange 124 ppb in the afternoon over Baltimore as seen in Figure 4.8, a bar graph familiar to Forest Watch students.

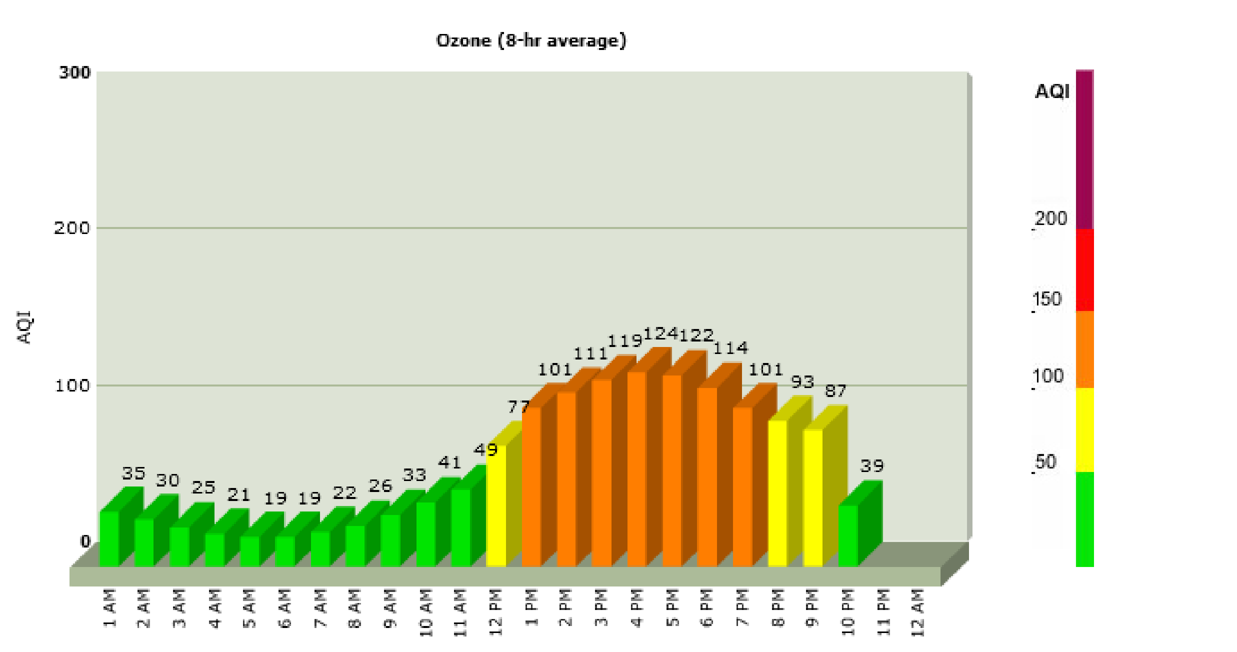

Figure 4.8: Ozone builds to code orange levels on a hot sunny day in Baltimore, July 7, 2011 (Smog Blog).

July 19, 20, 21, 2011: High ozone and smoke are profiled in a lidar image of the troposphere, Figure 4.9.

July 29, 2011: Code orange ozone.

August 1 & 2, 2011: Code yellow ozone, due to fires in Canada.

August 20, 2011: Smoke from the Great Dismal Swamp, North Carolina, causes unhealthy ozone in northeast.

August 28, 2011: Hurricane Irene floods New Hampshire and Vermont with 5 inches of rain and high winds.

September 8, 2011: Smog Blog

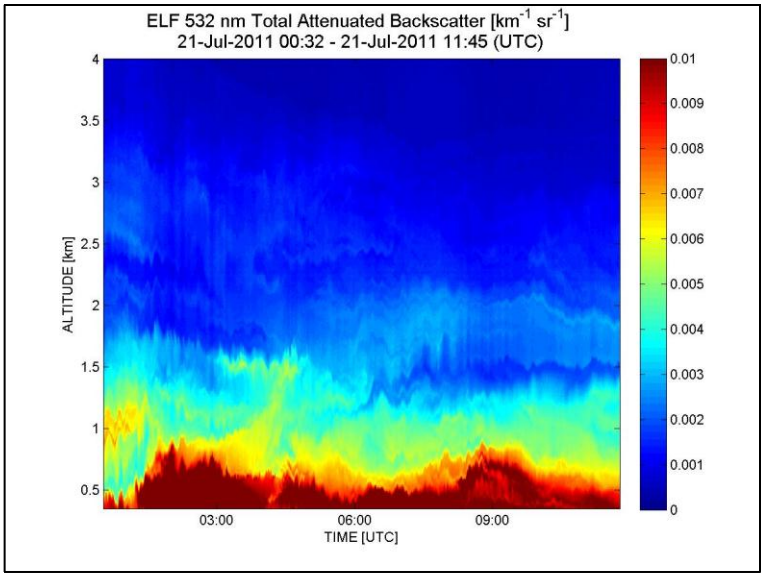

Figure 4.9: A lidar image of the troposphere at UMBC shows high levels of smog and particulates trapped close to the ground, July 21, 2011, Smog Blog.

publishes a photograph of Texas as seen by astronauts aboard the International Space Station. The photograph clearly shows a smoke plume rising from a fire in Bear Creek, Texas. Such images now allow researchers to track smoke plumes visually.

October 29, 2011: Snowstorm over New England.

October 31, 2011: Code orange PM2.5 and ozone in New Hampshire and Massachusetts is caused by a temperature inversion, warm polluted air compressed by upper level cold air onto very cold snowy ground, Figure 4.10.

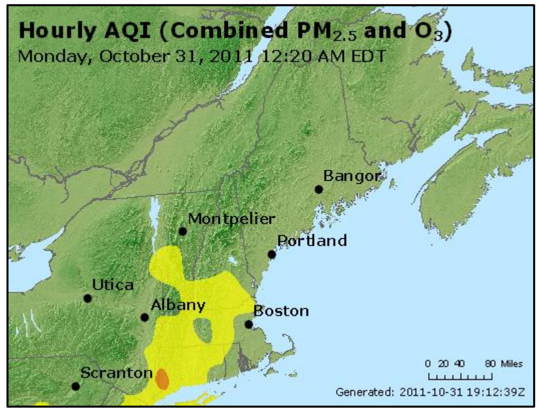

Figure 4.10: AIRNOW image of PM2.5 and O3, October 31, 2011 (Smog Blog).

November 3 & 4, 2011: Poor air quality continues in the Northeast. Smog Blog's Daniel Orozco quotes from a paper by Anabela Carvalho *et al*, 2010. The paper discusses the increase in forest wild fires and its impacts on air quality, human health and plant health. The paper notes that such pollution and the incidence of wild fires are projected to increase with climate change. Carvalho estimates that her region in Portugal will see a 500% increase in wildfires by 2050.

November 7 & 8, 2011: Sulfates cause a code orange and yellow air quality rating over the northeast, Figure 4.11. While ozone and smoke are minimal, sulfate levels are high across the region.

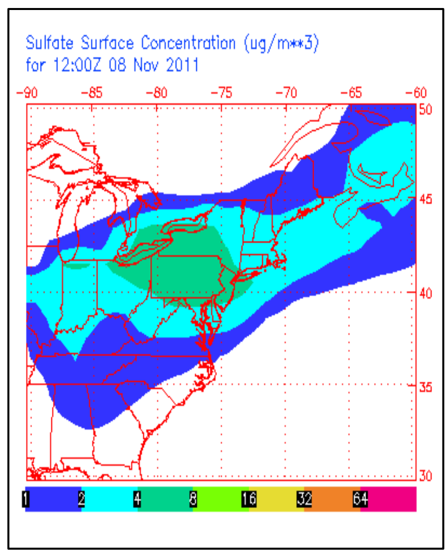

Figure 4.11: Sulfate cloud over New England and east coast, November 8, 2011.

November 9, 2011. Elevated NO_2 and PM2.5 are measured over the northeast. Particulates identified as sulfates cause poor air quality in New England, particularly in Burlington, VT.

December 1, 2011: Smog Blog announces a report by Vitali Fioletov of Environment Canada which used the Ozone Monitoring Instrument (OMI) aboard NASA's Aura satellite. The study finds that sulfur dioxide levels over the Appalachians, near coal-fired power plants, have dropped significantly between 2005 and 2010. The 2005 Clean Air Interstate Rule is credited with prompting many utilities to install desulfurization devices and other sulfur controls.

December 2, 2011: Code yellow ozone.

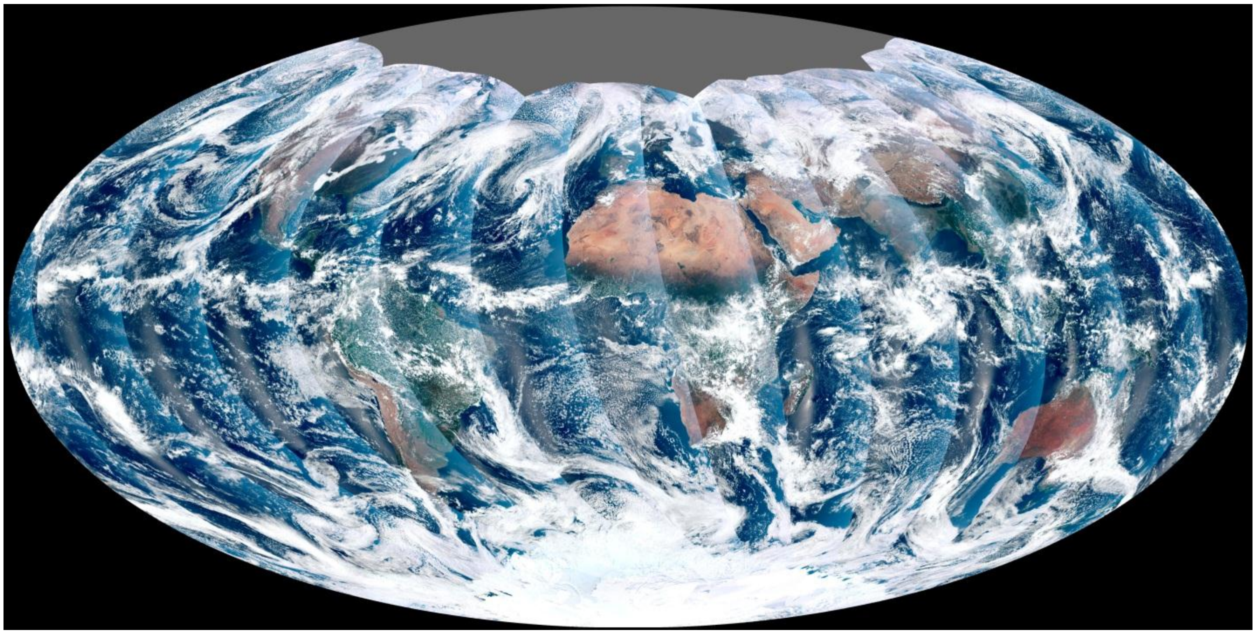

Figure 4.12: VIIRS first portrait of Earth. From Earth Observatory as published by Smog Blog, December 15, 2011.

December 12 & 13, 2011: Ozone and high PM2.5 event over New England and the mid-Atlantic

December 15, 2011: Smog Blog publishes the first complete view of the globe as seen at 824 km (512 miles) produced by the Visible Infrared Imager Radiometer Suite (VIIRS) on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project, Figure 4.12. High sulfate levels are measured over the northeast, Smog Blog also reports

December 19, 2011: Weather maps produced by Plymouth State University are published by Smog Blog to help explain code yellow PM2.5 levels over the mid-Atlantic and Northeast. Poor air conditions continue through the rest of the month, including a high sulfate day on December 19, Figure 4.13.

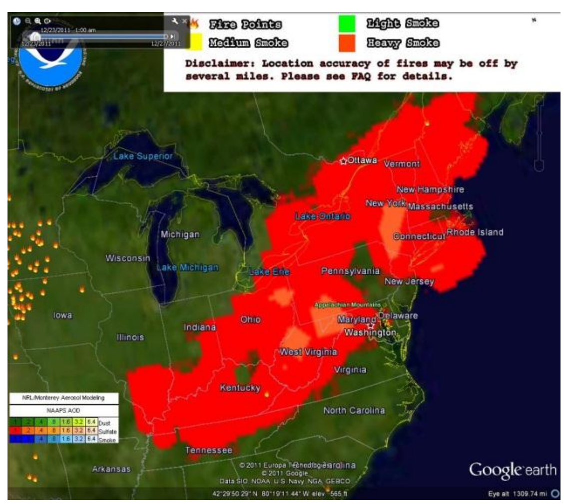

Figure 4.13: High sulfates over the Appalachian Mountains and New England, December 19, 2011. Smog Blog.

December 30, 2011. As of this date, wildfires have burned 8.7 million acres of land with extensive burning in Texas. Unusual spring *wildfires burned 3.2 million acres of land in March, April and May, the NCDC reports. Large fires in New Mexico and Arizona burned for weeks in June and July. The year ranks third in wildfires in the last 12 years (NCDC 2011).*

The EPA Region 1 reports 16 days in New England when ozone levels exceeded 75 ppb for 8 hours or more.

January 2, 2012: Smog Blog reports that air over the East is clear at last.

Notice this period—October 31, 2011, to January 2, 2012, has day after day of ozone, NO_2 and/or SO_4. In the 1980s, numerous studies reported that co-occurrences of these pollutants were rare in nature. Experiments with deliberate exposure of plants found that white pines showed water stress and chlorotic lesions when exposed to low levels of all three pollutants for 4 hours a day for 35 consecutive days (Yang et al., 1983as reviewed by Kotchmar et al., 1993). Low levels were defined as 0.05 to 0.1 ppm of each of the pollutants. These measurements are at or below current EPA air quality standards—0.075 ppm for ozone, 0.075 ppm for SO_2, and 0.001 ppm for NO_2. Damage to plants depends on time, concentration and mix, the 1980s researchers found (Kotchmar et al., 1993). According to these Smog Blog reports, white pines may have been exposed to a mix of O_3, NO_2 and SO_4 simultaneously over some 60 days. Each of the notifications of poor air quality signaled a day when a particular pollutant exceeded current standards, all higher than the damage level described for co-occurrence damage. The EPA reports in its 2011 Annual Report that an air quality monitor in Pembroke, NH, recorded SO2 levels at 0.263 ppm for one hour.

January 7, 2012: Ozone event, probably caused by smoke from fires in Southeast and Midwest, Smog Blog reports.

January 11, 2012: High PM2.5 with winter formation of ammonium nitrate.

January 31, 2012: High sulfates in northeast, attributed to fires in the Southeast.

February 10 & 11, 2012: Code orange and high NO_2 over Northeast.

February 16, 2012: High sulfates over mid-Atlantic and Northeast.

February 27 & 29, 2012: High ozone and PM2.5 over Northeast.

March 6, 2012: Smoke from Southeast and Great Lakes fires spreads into Northeast.

March 12, 2012: Unusual warming, high PM2.5 levels.

	2010	2011A	2011B
REIP	725.74	715.43	713.19
NDVI	0.819	0.829	0.8169
TM54	0.5437	0.5673	0.5459
NIR31	0.8732	0.8554	0.8715

Figure 4.14: Means of VIRIS indices from St. Johnsbury School, St. Johnsbury, VT compare spring 2010 needles with 2011A, taken in February 2012 of 2011 needles, and 2011B taken in March 2012.

March 18, 2012: St. Johnsbury School sends Forest Watch a second batch of samples. The first set of needles, sent in mid-February, showed REIPs averaging 715, an alarmingly low index of chlorophyll for first year needles. Concerned that something in shipment or our handling of the needles may have damaged them, we asked for a second sampling. Otto Wurzburg and his students sent a second set from the same trees. The VIRIS scans were worse: the mean REIP was 713.9. Four of the 10 samples showed initial or full water stress and initial senescence. The same trees, in 2010, had a mean REIP of 725.74, as shown in Figure 4.14.

March 19, 2012: Temperatures reach 93^{o} F in Orford, NH. Maple sap stops running. Ozone code yellow in New England.

March 28, 2012: Smoke from fires in Midwest and Southeast bring dust and particulates, high sulfates to New England and mid-Atlantic.

March 30, 2012: UMBC's lidar shows very high PM2.5 pressed close to the surface as winds bring smoke from Midwest fires into the mid-Atlantic.

April1 15, 2012: Moderate ozone and PM2.5 with sulfates

.

April 16-20, 2012: Record heat, red flag fire warnings, code yellow ozone and PM2.5.

Forest Watch visits Gilmanton School, Gilmanton, NH, and teacher Mary Fougere and her students in 7th grade science. We sample trees from a new site and visit large older trees in the old site. First year needles appear vibrant. These needles have been growing for 10 months, since they opened in June 2011.

Second year needles were much different.

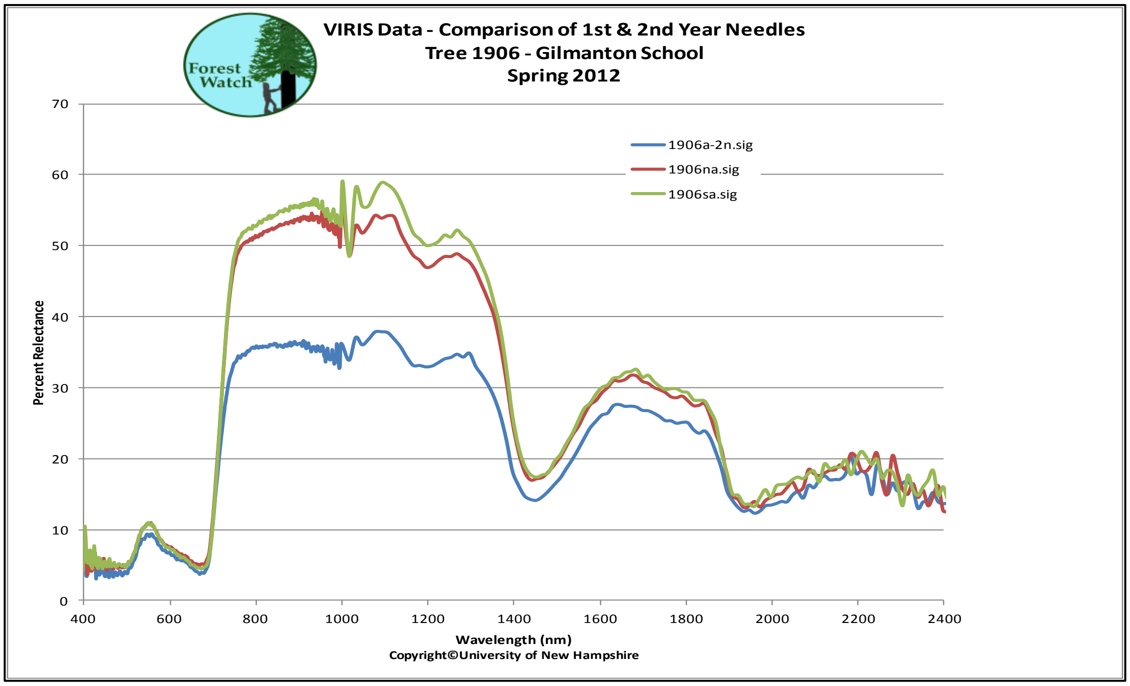

Figure 4.15: VIRIS scan of 1st year needles, North and South, and 2nd year needles from one Gilmanton School white pine, Tree 1906, April 2012.

Gilmanton 2010 needles, Sampled in 2nd year, April 16, 2012.							
	1906-2Yr	1907-2Yr	1908-2Yr	1909-2Yr.	1910-2Yr	Oldsite-2	Mean
REIP	705.4	719.3	720.8	719.3	714.6	719.3	716.45
NDVI	0.774	0.815	0.838	0.836	0.827	0.8	0.815
TM54	0.726	0.633	0.625	0.547	0.558	0.692	0.63
NIR31	0.941	0.94	0.955	0.888	0.907	0.941	0.929

Figure 4.16: Two-year-old needles on both young new trees and one older tree sampled show low REIPs, water stress in the TM5/4 index and oncoming senescence in high NIR 3/1 ratios.

The scan shown here in Figure 4.15 illustrates the extreme difference in reflectance exhibited by first and second year needles. Second-year needles from Gilmanton's Tree 1906 have much lower reflectance in the Near Infrared and the three peaks of the NIR plateau are flat, an indication of aging cells. Four of six trees show water stress in the TM5/4 ratio and early senescence in the NIR3/1. These needles had a mean REIP of 716.45, Figure 4.16.

April and May 2012: Fungi, if present, produce fruiting bodies.

April 21, 2012: Smog Blog publishes a model of Asian dust crossing the Pacific into the American Midwest, Figure 4.17. The model is produced by the Navy Aerosol Analysis Prediction System (NAAPS) which has also produced the many modeled maps of sulfates shown in this report.

May 3, 2012: Sulfates over New England.

May 9, 2012: Sulfates over New England
.

May 13, 2012: Code yellow and orange ozone.

May 14, 2012: A wildfire breaks out in Hewlett Gulch, CO. Dr. Anthony Prenni, Colorado State University, Fort Collins, and Bret Schechtel, National Park Service, Fort Collins, use lidar to measure components of smoke. Ammonia, NH_3, increases 20-30% over normal levels and is a major ingredient in the smoke. Carbon monoxide, CO, usually at 30-200 parts per billion (ppb) jumps to 3000-4000 ppb. NO_x compounds, normally 5 ppb, increase to 25-30 ppb (Prenni, personal communication, AGU, San Francisco, 2012).

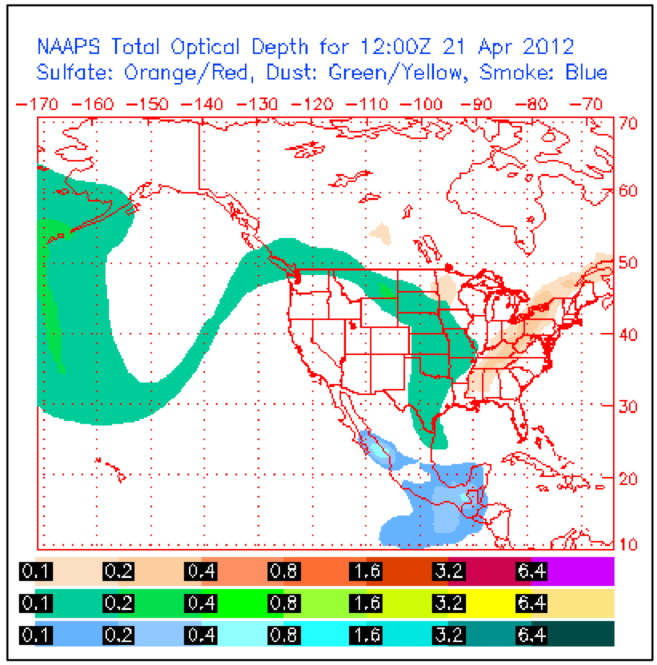

Figure 4.17: NAAPS model of dust from Asia shows dust and particulates arriving in Midwest and spreading northeast, April 21, 2012 (Smog Blog).

May 28, 2012: Smoke from the Baldy-Whitewater fire in New Mexico, burning 82,000 acres of forest, is tracked to the eastern seaboard. Other fires burn along the Mississippi in dry agricultural lands. Poor air quality is measured from New Mexico to Maine, Figure 4.18.

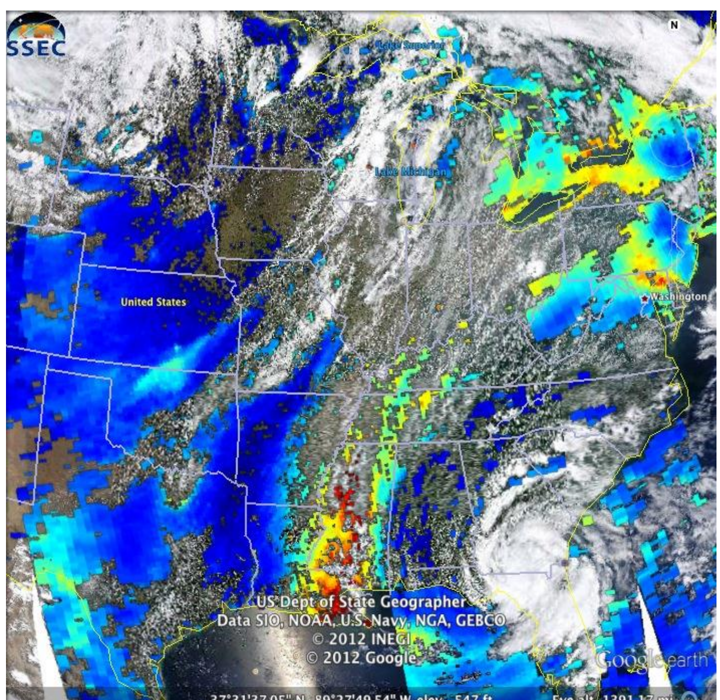

Figure 4.18: Smoke across most of the lower 48 on May 28, 2012 is mapped by the Department of State Geographer using data from numerous satellite sources. (Smog Blog).

Early June 2012: The 2012 needles open. The 2011 needles are now second-year needles.

July 4th: Dr. Munck finds this the typical date for needle cast if fungi are present.

Fall 2012: Needle cast continues to alarm white pine growers and observers. Dr. Rock's Monitoring Forest Health students examine pines in Vermont and New Hampshire.

- *Nathan Fallon, UNH undergraduate, finds low REIPs and other evidence of stress in white pines in the Green Mountain Forest. Pines at 2000 feet elevation show greater damage than pines at 1500 and 1000 feet. High elevation needles were coated in a black sooty substance.*
- *Wesley Niebling, UNH undergraduate, compares pines infected with Caliciopsis pinea Peck, a fungus which causes cankers on the bark and cambium of the tree. VIRIS scans showed slight differences but both infected trees and uninfected trees had high REIPs, no water stress and no senescence.*

Wildfires continue. By October, more than 9 million acres in Colorado, the Northwest and the Mississippi Valley have burned making the year the second worst fire year since 1990 (NCDC 2012).

November 30, 2012: Sarah Thorne and her students at Prospect Mountain High School, Barnstead, NH, send in 20 samples from 10 trees. Of the first year needles, 5 REIPs showed a moderate lack of chlorophyll. Eleven of 20 showed initial water stress in the TM5/4 and 5 showed full water stress. Two samples of first year needles showed advanced senescence.

We scanned 10 samples of second year needles. Six of the 10 showed initial loss of chlorophyll with REIPs under 720. Nine of the ten showed severe water stress and senescence, Figure 4.19, below.

	21927n	21928n	21929n	21929s	21930s	21931s	21933s	21934n	21935n	21935s		Averages
REIP	716.2	716.2	727	722.4	722.4	716.2	716.2	719.3	716.2	728.5		720.06
NDVI	0.809	0.8	0.812	0.813	0.815	0.785	0.802	0.771	0.775	0.827		0.8009
TM54	0.782	0.695	0.724	0.761	0.713	0.832	0.756	0.718	0.862	0.599		0.7442
NIR31	1.063	0.975	0.993	0.989	0.981	0.996	1.013	0.989	1.046	0.944		0.9989

Figure 4.19: Fall Mountain High School spectral indices of second year needles.

Photographed at 15-40x magnification, Prospect Mountain second year needles presented a variety of damage. A few needles as in Figure 4.20-A, show classic ozone damage with pale yellow chlorosis. A few needles showed fungal damage as described by Munck, 4.20B. Many needles showed a deep orange discoloration that looked like blistering of the needle cuticle, 4.20C and 4.20D. Such damage could be caused by acid.

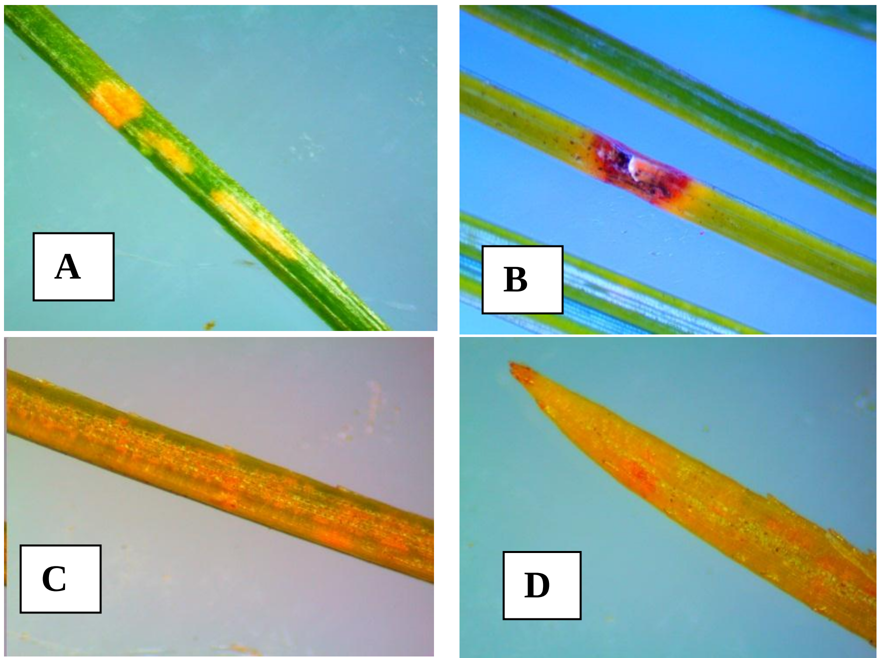

Figure 4.20. Chlorotic mottle in A is typical of ozone damage. Fungal wound in B. Orange blistering in C and D was widespread on these second year needles from Prospect Mountain.

We measured 10 needles selected from second year stems for length and percent of damage by length. Needles were tallied for the presence of tip necrosis, chlorosis and fungi. In Table 4.21, below, all sets had both tip necrosis and chlorotic mottling or blistering. Not all sets showed fungal infection.

Assessment of 10 needles, second years, Prospect Mountain High School, November 2012										
	1927N	1928N	1929N	1929S	1930S	1931S	1933S	1934N	1935N	1935S
Avg. Lengt	89	85	73	73	73	79	83	70	95	80
% Damage	12.5	15.3	15.8	19.8	3.7	51.8	17.5	65.1	43	9.9
# with										
TipNec.	6	7	9	6	10	6	8	10	10	10
Chlorosis	7	5	6	4	5	10	4	10	10	6
Fungi	3	1	0	2	0	6	3	0	1	1

December 31, 2012. The EPA, Region 1, reports that during 2012, ozone levels exceeded the 75 ppb 8-hour limit on 29 occasions.

January 2013. The NCDC reported that in 2012, January through October, wildfires burned more than 9 million acres, 1.5 times the 10 year average. A wildfire report for the entire year was not yet complete for this essay. The year will rank first or second for number of wildfires in the decade.

Conclusion

Forest Watch white pines appear to be stressed by atmospheric pollutants carried into the Northeast from wildfires. These pollutants might include nitric or sulfuric acid fogs and oxidants including ozone and PAN.

Water stress might be associated with leakage of cells caused by oxidants or acid clouds. Early senescence might be caused by cell damage. If the pines are repeatedly stressed by air pollutants which disrupt photosynthesis, the pines may be producing less sugar. Less sugar may reduce the production of protective phenolic compounds which the pine needs to ward off fungal infection.

Forest Watch schools are ideally situated to help research this possibility.

Schools could sample white pines early in the school year, gathering enough needles to monitor both first and second year needles. Using The Smog Blog, Forest Watch and its school partners could learn when poor air quality days are projected and when they occur. Following the event, students could sample needles again, documenting whether significant damage occurred and what type of damage is found. See suggested protocols in Chapter 8.

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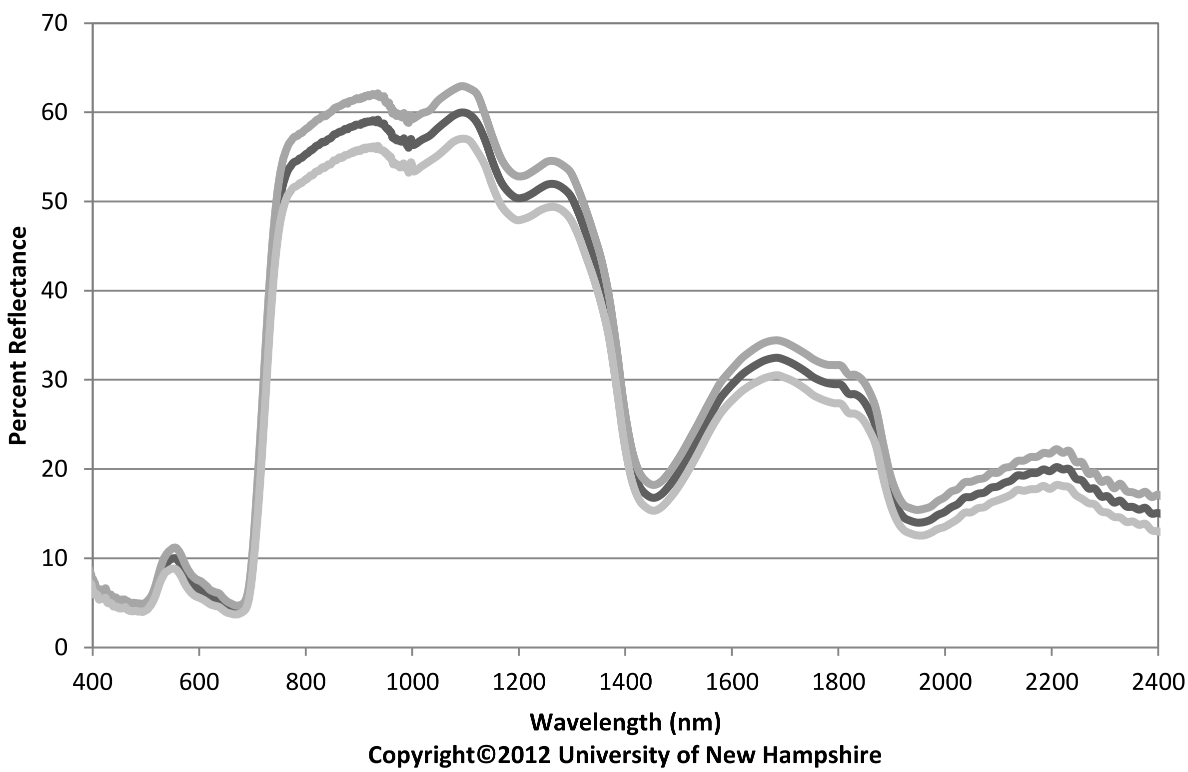
Chapter Five
Spectral Measures of 2011 Needles

Reading Light

White pine needles absorb 90 to 95% of all visible light that reaches them. Pigments within chloroplasts, called chlorophylls and carotenoids, use light to capture energy which needles and broad leaves use to make sugar. The foliage reflects infrared light in varying amount depending on cell structure, water content and the length of light waves. Long waves of light are not energetic enough to make sugar. How much light is absorbed or reflected along the spectrum of visible and infrared light tells a story of the white pine needle's health.

Over the past thirty-five years, Forest Watch scientists and other plant physiologists have deciphered the messages contained in a plant's spectral reflectance properties. "Reading light," (Figure 5.1) we can learn how much chlorophyll the needles contain, whether the needles contain adequate amounts of water, and how healthy the needle mesophyll cells are. Those messages of reflectance and absorption give us a clear picture of a white pine's health.

Figure 5.1: Reflectance - All Trees 2011
Means & Standard Deviation (+ and -)



Each year Forest Watch schools provide our labs at UNH with a supply of fresh needles from their white pine trees for spectral measurements. When they collect samples for their own classroom and laboratory study, Forest Watch teachers and their students carefully collect a duplicate set of needles, store them in labeled Ziploc bags and ship them overnight to UNH. Usually, we select from these needle samples only first-year needles (in this case, 2011 needles).

At UNH, the white pine samples are scanned using a spectrometer called the Visible InfraRed Intelligent Spectrophotometer (VIRIS). The VIRIS measures the reflectance and absorption properties of the white pine needle samples, providing 585 spectral bands of data to work with, ranging from 400 to 2500 nanometers, nm (Figure 5.2). Areas on this spectrum are named for the bands of light measured by the Thematic Mapper (TM), an instrument which orbits Earth aboard Landsat 500 miles high. The light which the Thematic Mapper captures is a reflectance from the forest canopy. Information in those captured images of forest reflectance is the same information we capture from foliage samples in the Forest Watch laboratory using the VIRIS.

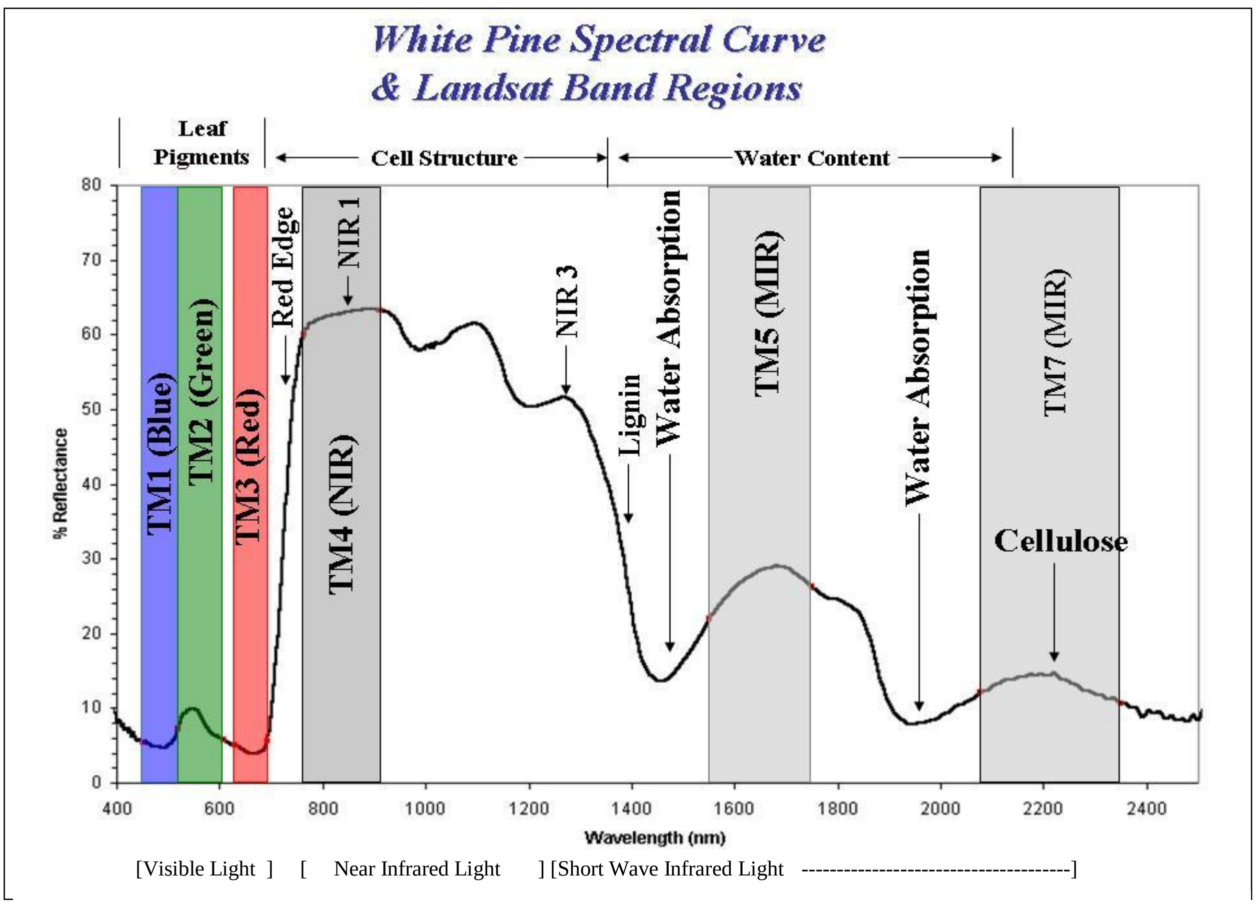


Figure 5.2:shows visible light, near infrared and short wave infrared light. TM bands are identified by number as they are in Landsat imagery sets as well as by the information they provide as to plant conditions.

On the left side of the spectrum, visible light shown in Figure 5.2, bands of blue, green and red light indicate how much light our needles are absorbing and using for photosynthesis. At the long wavelength edge of the red band, the red edge reflectance soars into the near infrared zone, a high plateau with three peaks, NIR 1, NIR 2, and NIR 3. Farther to the right, infrared light is absorbed by water in the needles at two valleys in the short wave infrared light region.

How do we "read" the light in such a spectrum? Notice the words "Red Edge" just at the interface of the red band, TM3, and the TM4 (Figure 5.2). The red edge inflection point (REIP) is the first derivative, the tipping point, on the steep slope between absorption in TM 3 and reflectance in TM4. With the VIRIS, we can detect to within a nanometer of light where that point, the REIP, is. Higher REIP numbers indicate rich chlorophyll in a deep broad well of red visible light absorption. This is the part of the spectrum in which chlorophyll a and chlorophyll b absorb most efficiently. Lower REIPs indicate less chlorophyll in stressed or aging leaves or needles.

Figure 5.2 shows the three peaks of the NIR plateau (NIR1, NIR2 and NIR3). A ratio of NIR 3 over NIR1, the percent of reflectance for each peak, gives scientists an accurate measure of the cellular maturity of needles—how many cells, cell walls and water they contain compared to the amount of intracellular space. Lower ratios indicate young vigorously growing needles. High ratios over 0.90 indicate aging, damaged or senescing needles.

A third message from the light reflectance measurements tells us how much water is in the needles. It is a ratio between the little plateau in the short wave infrared zone, TM 5, and TM 4, in the NIR. Again, lower ratios indicate that a plant cells are flush with water. Ratios of percentages of 60% or more indicate water stress and a plant that will have trouble photosynthesizing.

Dr. Rock and a number of other plant pathologists, biogeochemists, and photosynthesis experts have spent their careers learning to decipher these mysteries of reflected and absorbed light. Look back at Figure 5.1. Dr. Rock would see a fairly deep, rounded red chlorophyll well in the red band, TM3, showing that most Forest Watch trees have plenty of chlorophyll for healthy levels of photosynthesis this past year. Compare Figure 5.1 to Figure 5.2. Look at the slope of the NIR1. On the sample, Figure 5.2, the plateau has a very square angle on the left side. Notice that on Figure 5.1, the slope of the angle is more gradual, a suggestion that perhaps the chlorophyll is there but it may not be working as fully as a healthy white pine needs.

Reflectance Indices	
All Needles from 63 trees, 2011	
Red Edge Inflection Point (REIP)	723.8
TM Band 5/TM Band 4 Ratio (TM5/4)	54.5
Near Infrared Band 3/Band1 Ratio (NIR3/1)	87.5

Table 5.1: VIRIS indices for white pine needles, 2011.

Precise readings from the VIRIS give numerical accuracy to those interpretations. Table 5.1 shows the three major indices of reflectance and plant health which we use in Forest Watch (there are 81 different indices). The 68 trees monitored in the past year average REIPS of 723.7 nm. This agrees with other average REIPs measured in the last decade, a sign of abundant chlorophyll. But remember that sloped shoulder on the NIR—is the chlorophyll working?

The average TM5/4 ratio, for the first time in 20 years is 54.5, an indication that the white pines are 5% dryer than usual. NIR 3/1 ratios are also higher than at any time since 1993, at 87.5 %, a warning that needles are aging prematurely.

How do scientists know they are reading the VIRIS correctly? The indices are painstakingly compared with other measures to look for correlations. NIR 3/1 ratios can be correlated with photographs of needles—do needles look young and vigorous or are they thin and old looking. NIR 3/1 can also be correlated with estimations of their specific leaf area—a ratio of leaf mass and leaf size.

Chlorophyll extractions should correlate with the REIP values for needles sampled**.** In the early 1990s, in studies of red spruce, Dr. Rock and his graduate student David Moss, now a professor of education at the University of Connecticut, identified a strong correlation between chlorophyll and the REIP, as Figure 5.3 shows. As the Red Edge Inflection Point rises, moving to longer

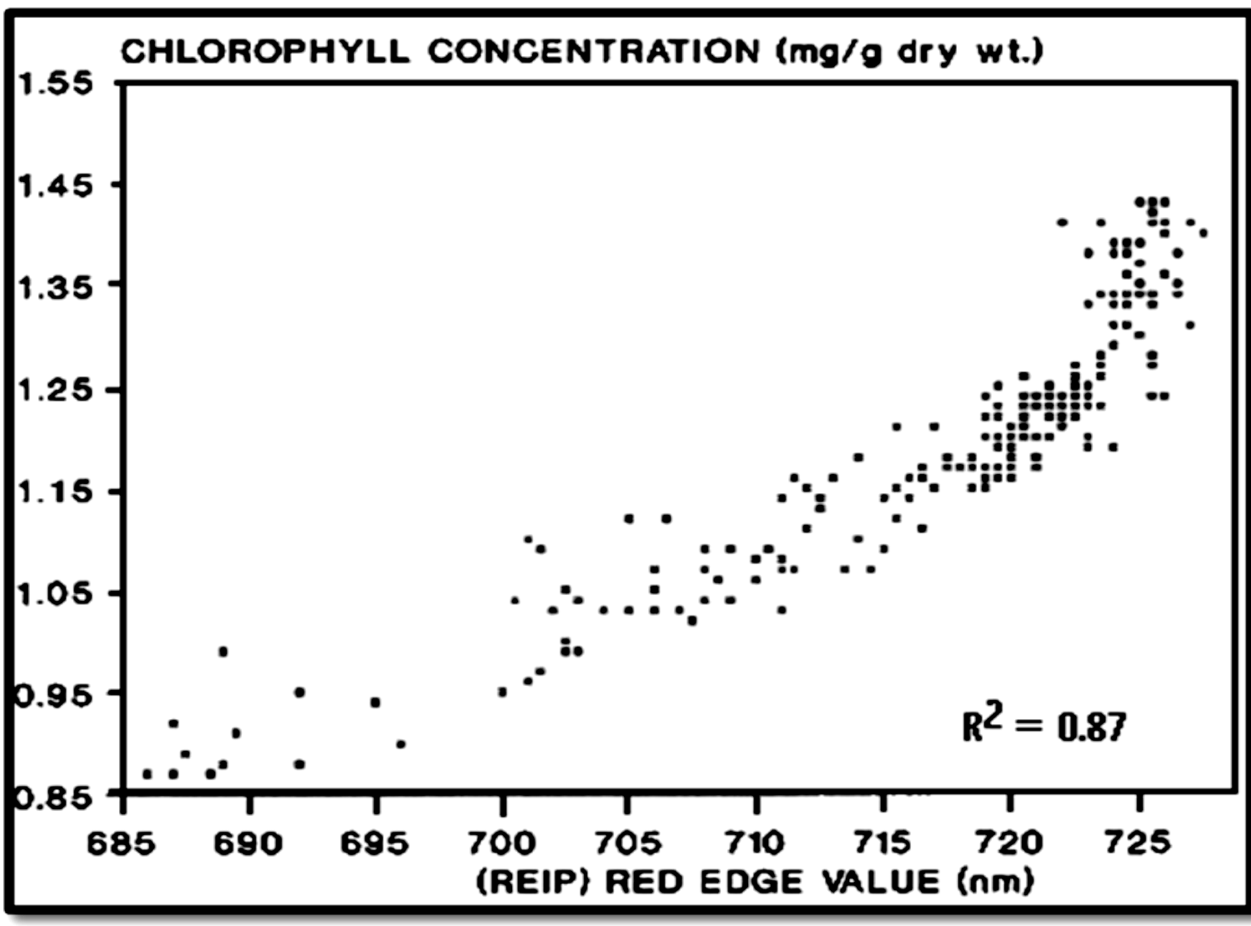


Figure 5.3: A positive correlation between chlorophyll and REIP (Moss & Rock, 1991.)

wavelengths in the spectrum of light, Moss and Rock found more chlorophyll in the spruce samples. The r2 value of 0.87 means that 87% of the data points exhibit this correlation.

We will explore this year's findings in more detail.

Table 5.2: REIP Summary by State
2011 Needles - Fall and Spring Samplings

		Avg. REIP	Std. Dev.	# Trees
State: CT				
RHAM High School		727.14	3.31	10
Tolland High School		724.12	4.3	5
	State Average	723.0	1.53	
State: ME				
Morse High School		725.58	1.27	5
	State Average	725.4	1.68	
State: MA				
Hanson Middle School		725.9	3.22	5
Springfield Central School		727.4	3.4	5
	State Average	726..5	3.12	
State: NH				
Community School		724.2	1.89	5
Gilmanton Middle School		723.1	4.67	8
Lyme School		725.6	3.56	5
Monadnock Regional High School		723.38	3.08	5
Salem High School		721.3	3.26	5
Sant Bani School		722.1	6.25	5
	State Average	723.7	2.74	
State: VT				
St. Johnsbury School		713.2	3.18	5
	State Average	713.2	2.29	
New England Regional Average		**723.8**	**2.52**	
Number of Trees				**68**

In Table 5.2, schools in Connecticut, Massachusetts and Maine all have RIEPs above this year's average. What's pulling down the average? One school in Vermont, St. Johnsbury School had white pines with a very low REIP. St. J's average pulls the entire group down. But the regionwide average still looks good. Let's look further.

Long-Term Spectral Analysis

For the first time since 1993, TM5/4 averages of 131 samples approach and meet initial water stress, Figure 5.4. Fourteen samples on 9 different trees showed full water stress of >0.60. Another 34 samples, 25% of the group, showed initial water stress.

This seems odd since 2011 was the 24th wettest summer in the last 144 years (NOAA 2012). Concord recorded 12.66 inches of rain in June, July and August. The 30-year average from 1980 to 2010 is 10.61 inches during the summer. How could our white pines be water stressed?

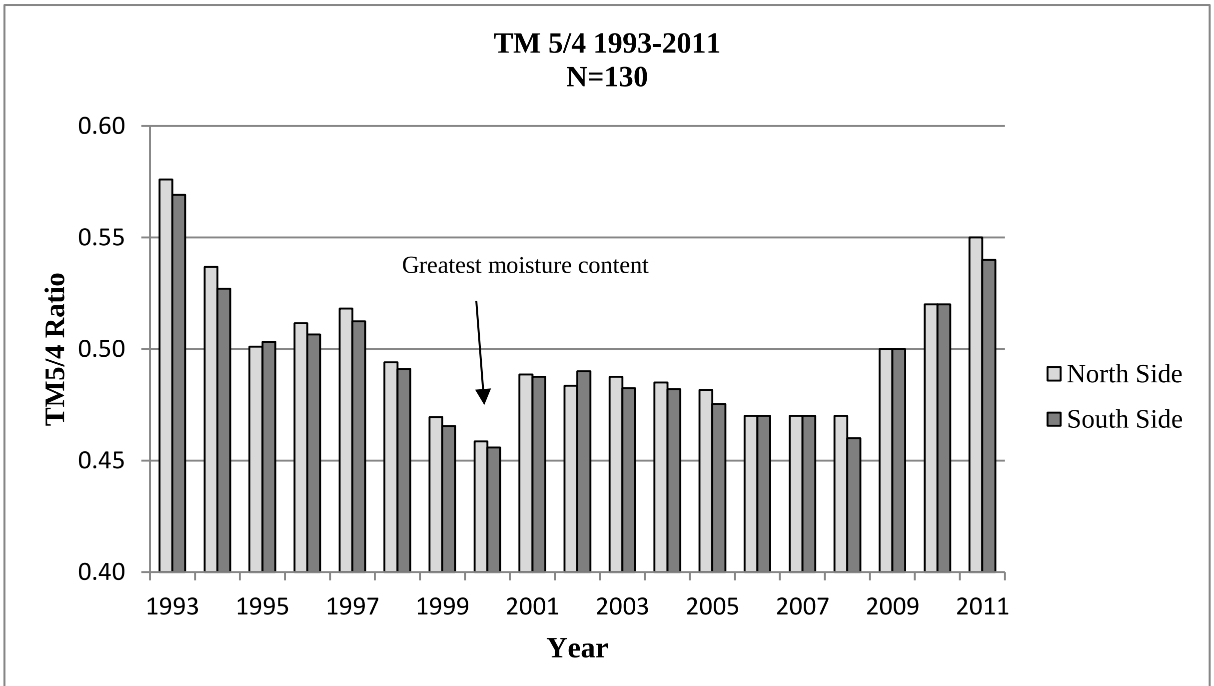


Figure 5.4: Water stress is apparent in the 2011 average TM5/4 ratio. At 0.55, the index is higher than at any time since 1993.

VIRIS indices of cellular maturity, as seen in the NIR3/1 ratio, also show unusual numbers, averages that indicate early senescence of cells in the 2011 needles, Figure 5.5.

Ten trees evidenced NIR3/1 ratios of >0.93, indicating senescing cell tissue, pulling the average higher than at any time since 1997. Again, what environmental factor or factors caused premature aging of first year needles?

Over the many years of Forest Watch, the Red Edge Inflection Point (REIP) has been our key measure of white pine health. Now, two other measures which were rather quiet seconds to the REIP are sounding an alarm.

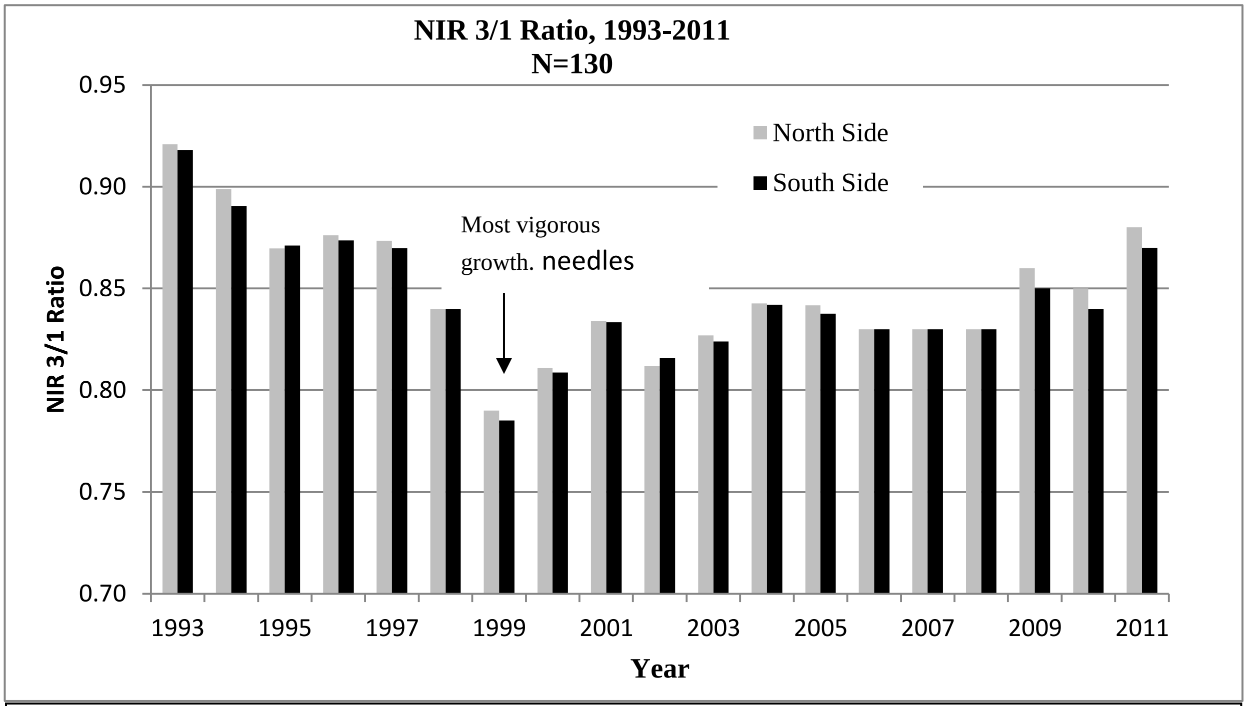


Figure 5.5: NIR 3/1 ratios are an indicator of cell maturity or senescence. 2011 first year needles show unusually high NIR3/1 ratios.

Meanwhile, the vaunted REIPs look normal, Figure 5.6. The average REIP in 2011 was 723.68, a level that is almost exactly the same as other REIPs in the last decade, an index we have considered proof of abundant chlorophyll and healthy photosynthetic machinery. The conflict

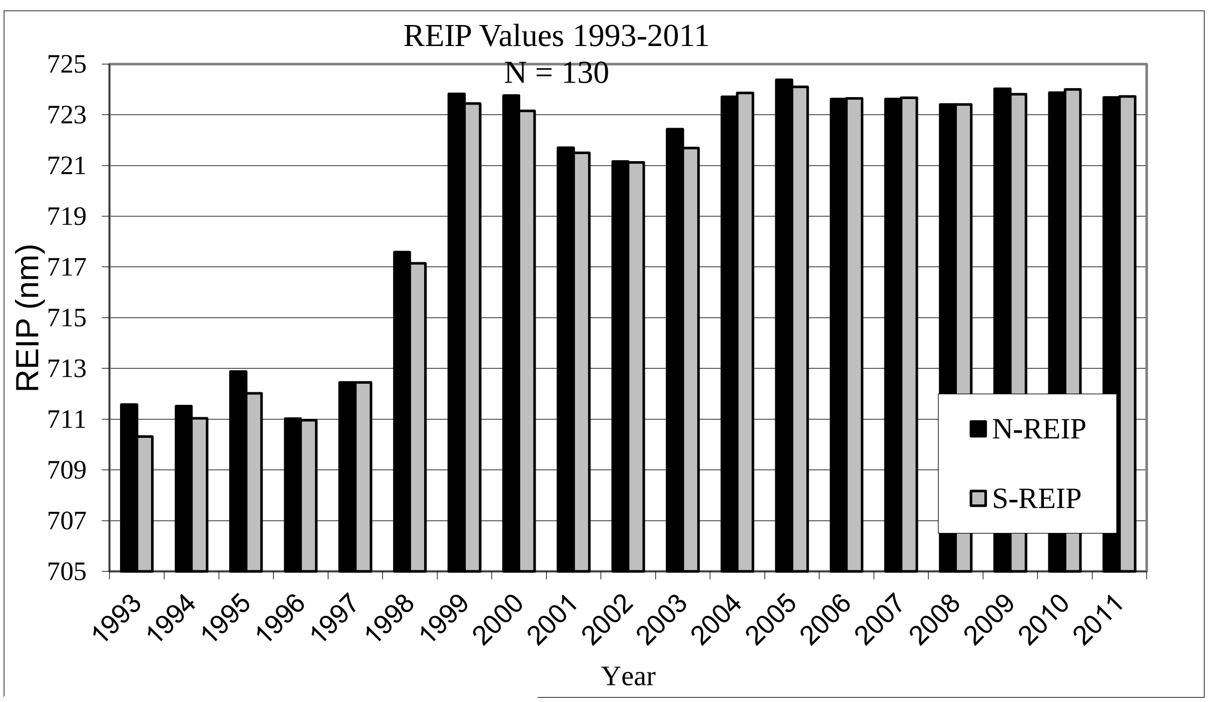


Figure 5.6: REIPs 1993-2001.

between abundant chlorophyll and water stress in the TM5/4 and early senescence in the NIR3/1 would indicate that although chloroplasts were present, perhaps they were not functioning properly.

A closer look at the REIP data may hold a clue. While the average REIP in 2011 is similar to other recent averages, the standard deviation from that mean is not. Over the past decade, in every year but 2003, when conditions were unusually dry and ozone levels rose, in the other years when ozone was low, REIP averages varied little; the standard deviation plus or minus was only 3.5 nm. But in 2003 when trees were stressed and in the early years of Forest Watch, before Clean Air Act controls reduced ozone, the standard deviation was 5.5 or 5.9 nm. In 2011, the standard deviation of REIPs was 5.09. We illustrate this difference in Figure 5.7. It would appear that in stressful years, there is wider variation in REIPs. In low-stress, healthy years, all trees across New England are similar with little variation.

What is stressing the pines? What could cause water stress and early senescence? What would cause wider variability in chlorophyll abundance? A closer look at rainfall from June 2011 through June 2012 may hold some clues. As noted earlier, the summer brought above average total rainfall, 12.66 inches over a 30-year norm of 10.61. The entire 13-month period appears rainy, with a total of 51.84 inches June 2011 through June 2012, the period when 2011 needles are first year needles. That is 17% more than the 30-year average, 1980-2010.

But the record shows unusual dry periods in the rain pattern and exceptionally heavy rains. Figure 5.8 shows rainfall in June, July and August 2011 with most of the record rainfall occurring in just three major storms. The chart of daily rainfall shows a long dry period in late June and July.

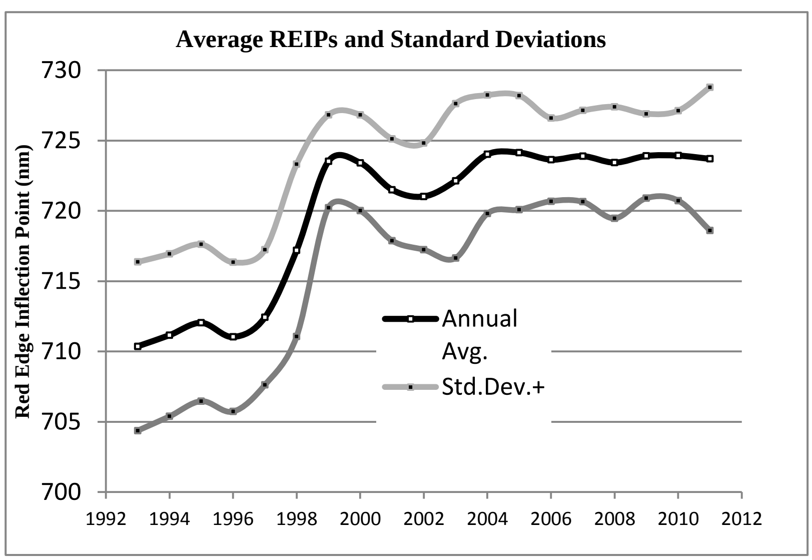


Figure 5.7: Average REIPs and standard deviations + and – show wider variation or greater deviation in stressful years.

August and September 2011 produced rain at more than twice normal amounts with five rainstorms each dumping more than an inch of rain on Concord. July 2011 and February, March and April in 2012 were exceptionally dry, with rainfall half its normal levels in three of these months. Nearly one quarter of all the rain in the 13 month period fell in five storms that brought more than 2 inches each to the area. The 30-year average shows only 9 rain storms per year of more than an inch of

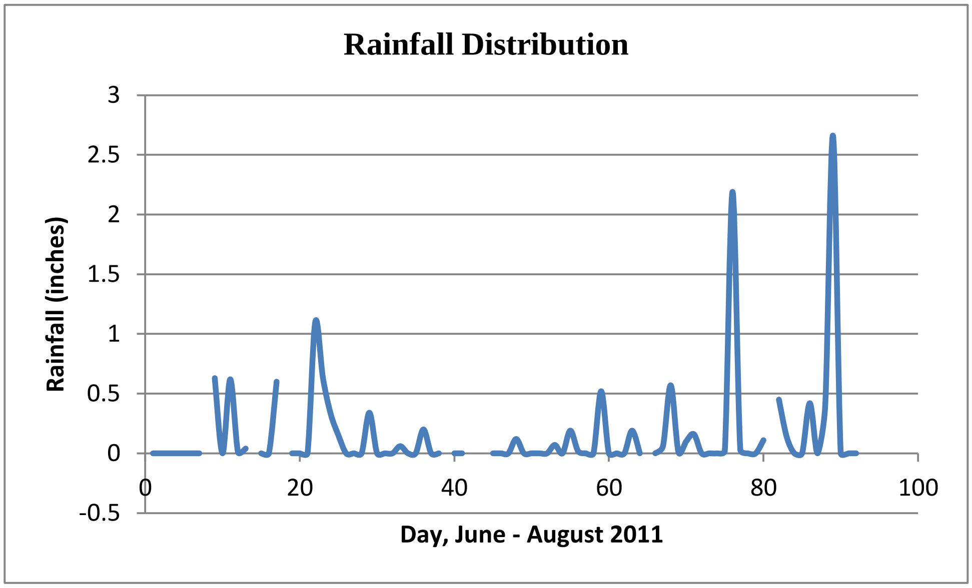


Figure 5.8: Rainfall was unevenly distributed in summer 2011.

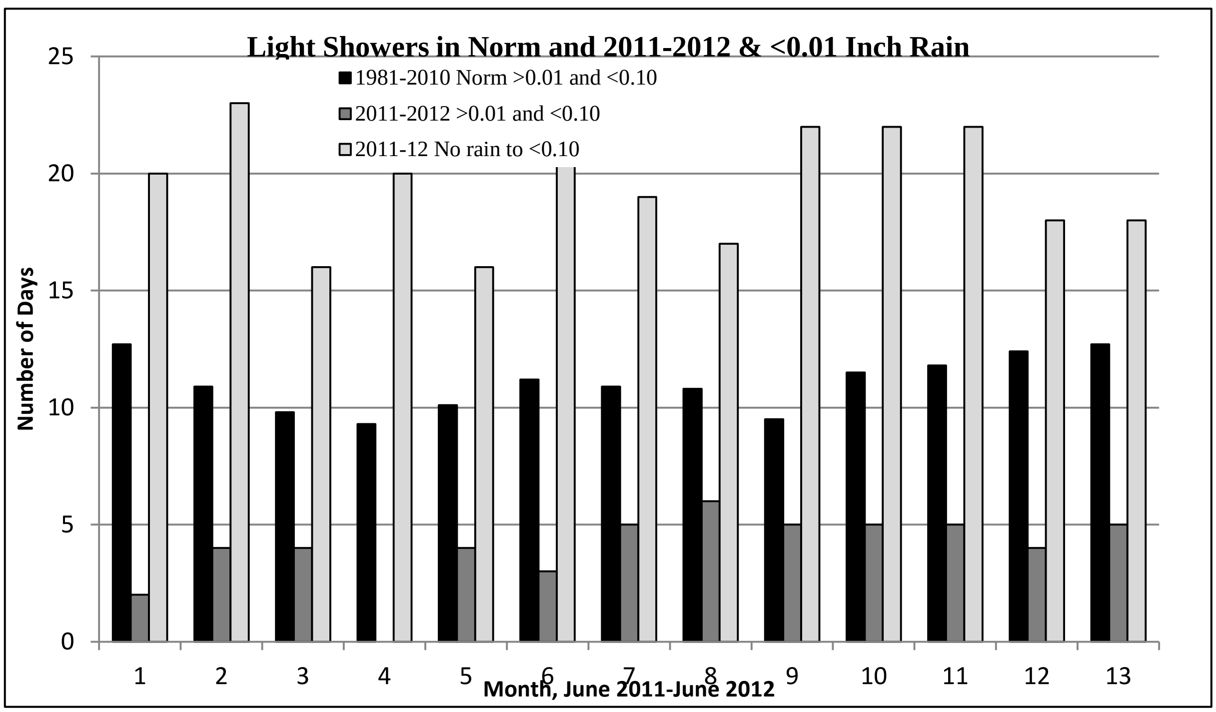


Figure 5.9: Rain in 2011-2012 rarely fell as gentle showers. Black columns show the 30-year norm of the number of days when rainfall is measureable but less than 0.1 inch. About 10 days each month see these light showers, as the norm. The grey bars show the number of days when light showers occurred in 2011-2012. There were half as many such showers as usual. The light grey bars show the number of days each month when rainfall was zero or less than 0.01 inch.

rain, not the 15 we saw in the 2011-2012 period.

Dry periods are also different from the norm. Gentle showers historically bathe the New England landscape about one day in three, according to the norm. As Figure 5.9 shows, light rains of between 0.01 inch and 0.10 inch occurred only 2, 4 or 5 times a month in the 2011-2012 period, not the usual 9 to 12 times. Worse, there were 17 to 23 days each month with no rain or less than 0.01, one one-hundredth of an inch. The white pines withstood dry stretches of 8, 12, and 20 days without any rain. Changes such as these in precipitation patterns are projected to be part of the new “climate weirding,” a term coined by Hunter Lovins, Rocky Mountain Institute (Friedman 2012).

Temperatures may have also played a role in the pine’s stress. Daytime average highs were fairly normal in June 2011 and 2012 and in August 2011 but July 2011 was 3^{o}F hotter than normal with 24 days over 80^{o} F including 9 days of 90^{o}F and one day of 100^{o}F. Hotter still was the winter. November, December of 2011 and February of 2012 were 6 degrees hotter than normal. Average temperatures in March were 9^{o}F warmer than normal, including 5 days of 80^{o}F or more, temperatures which are well remembered by New England sugarmakers whose sap runs stopped on March 19.

The U.S. Forest Service Climate Change Atlas projects that *Pinus strobus* may lose 10 to 27 percent of its range depending on which climate model is used to project change this century. Rising temperatures, particularly July temperatures, but also the spread between summer and winter temperatures, are key factors in the USFS model (Prasad et al., 2007-ongoing).

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Moss, D.M., and B.N.Rock. 1991. Analysis of red edge spectral characteristics and total chlorophyll values for red spruce (*Picea rubens*) branch segments from Mt. Moosilauke, NH, USA, Conference Proceedings of the 11th Annual International Geoscience and Remote Sensing Symposium, Helsinki, Finland.

Prasad, A. M., L. R. Iverson., S. Matthews., M. Peters. 2007-ongoing. A Climate Change Atlas for 134 Forest Tree Species of the Eastern United States [database]. http://www.nrs.fs.fed.us/atlas/tree, Northern Research Station, USDA Forest Service, Delaware, Ohio, http://www.nrs.fs.fed.us/atlas/tree/

Chapter Six
Forest Watch Biometric Data Analysis

Biometrics are measures of the biological features of the white pine: tree height, diameter at breast height, needle length and symptoms of disease or environmental damage on the needles. Trees are growing living organisms. They respond to growing conditions, weather, soil and site conditions, human activities, animal and insect browsing, and atmospheric chemistry.
Forest Watch teachers and students use very simple tools to measure their white pines, to collect and record data. Carefully following the same protocols, schools all across New England make keen and accurate measures. Together, these data build a highly accurate picture of white pine health.

The Forest Watch Data Book examines the data just for 2011 and it compares this year's biometrics with measures from past years.

Histograms of 2011 Tree Size

Each year we create histograms of the data. At a glance, histograms display the "frequency" of how data is distributed. In our first look at histograms, we compare Forest Watch measurements of diameter at breast height (DBH) taken in the 2011-2012 school year with those taken the year before. What a difference!

Histograms are a great way to introduce students to statistics and to the mathematics of analysis. Before students learn the definitions of histogram and its terminology, they can see with their own eyes how different our selection of trees this year is compared with last year.

Figure 6.1A: DBH in 2011

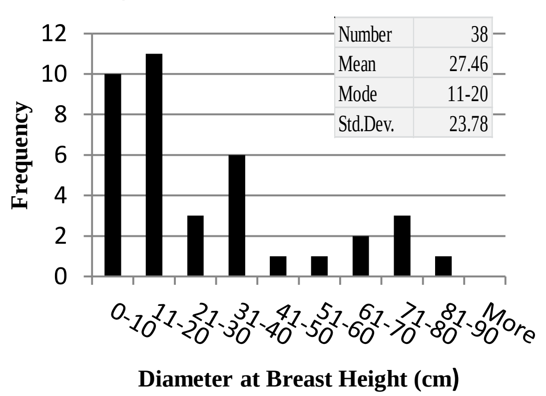
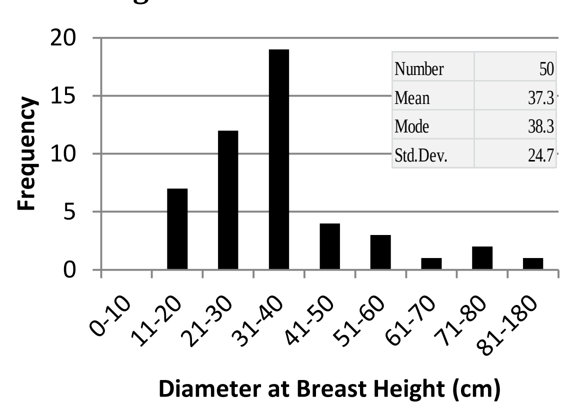


Figure 6.1B: DBH in 2010



Ask students what they see. There are lots of trees with small DBH in 2011, a greater frequency in the 10 to 20 cm group. In 2010, more trees were between 30 and 40 cm in size. Last year, our Data Book discussed the age of Forest Watch trees. Many trees had been in our program--measured, studied and beloved by students-- for over 20 years. Those trees were getting too tall for students to sample.

This year, histograms of DBH and other tree measurements show that many schools are sampling younger new trees. Where are the trees at Gilmanton School? Or the trees at RHAM? Students can make histograms of the five or ten trees at their school. How do they compare on a histogram for dbh?

Once students become familiar with the concept of distribution and frequency, they can use histograms to examine other analytical tools. Forest Watch histograms include several:

The *Number* or N = is the number of samples in each chart. As students look at various Forest Watch histograms, they will find different numbers. N for DBH this year is 38, the number of trees. N for number of needles which students across New England measures is 7,787! What is a good number to have in a statistical study? What is the minimum we need for an accurate picture? Can a number be too big to really matter? Young scientists, especially those who are planning to conduct their own experiments might want to answer these questions. Generally, in Forest Watch, we advise students to have at least 6 or 6 large things, like trees, in any study. And we recommend they count at least 30 needles to get an accurate look at needle anatomy and health.

Mean is the average, the total measurements divided by the number. *Mode* is the most common number in *discrete* data sets. In *continuous* measurements, such as most Forest Watch data, the mode is the place on the histogram where most values cluster.   How is this different from mean? Sometimes the mean and the mode are closely aligned. But other studies will find a wide difference. Why? Histograms offer students good examples that might have real meaning for them.

Notice that in 2010, the mean DBH was 37.3 cm and the mode, if we ask Excel to calculate one, was close to the mean at 38.3 cm. This may be a little bit confusing. If our numbers were discrete, the mode calculation would simply tell us that there are more trees of 38.3 cm in size than there are trees of any other unique DBH. But we are analyzing continuous groups of numbers. Our eyes tell us that most trees in 2010 were between 31 and 40 cm in diameter at breast height. This is a *Modal Class.*

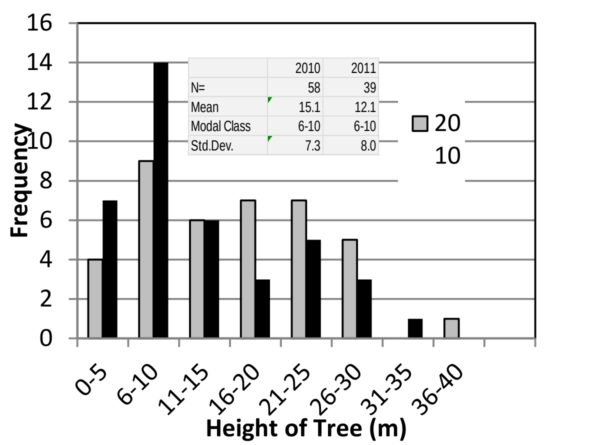
This year, the mean DBH is 27.4 cm but look at the mode; the main cluster of trees is in the 11-20 cm group.   There are lots more small trees this year. But the average of all trees' DBH is increased by a few old trees, like those giants at Monadnock Regional or Sant Bani. Some trees are wide and some trees are slender. Both small young trees and large older trees and their differences can be described in one histogram.

Another statistical tool, St. Dev., *standard deviation,* tells us how tightly all the measurements are clustered around the mean in the set of data. In some histograms, standard deviations are very small. In others, a wide standard deviation will be found. How much do the trees in this set of numbers differ from one another? Notice that the 2010 histogram produces almost the same standard deviation as we see in 2011. Forest Watch schools study lots of trees of very different size. As students learn to design their own experiments, they might discuss how their choice of subjects will affect standard deviation. Should all trees be the same? What features or factors in an experiment must be the same and which might be different, deliberately so?

We congratulate both those Forest Watch schools who are venturing to monitor new trees and those who have figured out how to continue monitoring long-term older trees. There are interesting benefits to each choice. Students who watch the same trees over many many years can see how differences in annual growth and health are evened out over time by a species that is evolved to live here for 200 years or more. New trees offer other study options. At Lyme School, Skip Pendleton and his students are considering how to manage their new young trees on an adjoining conservation parcel of land. In a thicket of young pines, students might hypothesize and then measure which of the young stems will become dominant over their neighbors and, by measuring canopy closure and other variables, learn why.

Histograms of other tree measurements show the same transition from old trees to young trees in Forest Watch school yards. Tree height, as described in Figure 6.2, has changed in one year from a mean of 15.1 m to 12.1. Notice that the modal class is the same: most trees studied by most schools cluster in the 6 to 10 meter range. As the histogram shows with simple clarity, there are more shorter trees in 2011 that students can study, measure and sample.

Figure 6.2: Tree Height 2011



The shape and structure of Forest Watch white pines is determined not only by a tree's height but by the size or depth of its crown. Last year we discussed how the crowns of many of our trees were growing smaller, in comparison to tree height. Crowded into dense unmanaged stands, many of our pines were losing shaded lower branches. Students and teachers were reaching higher and higher to sample needles. Forest Watch students need to see the classic shape of a white pine and they need deep canopies so they can reach needles in the middle of those canopies. Figure 6.3 illustrates these features of a white pine. Selecting trees or growing them from saplings requires planning and long-term management of trees. That involves cooperation with school administrators, school yard maintenance managers and neighboring landowners or conservation groups.

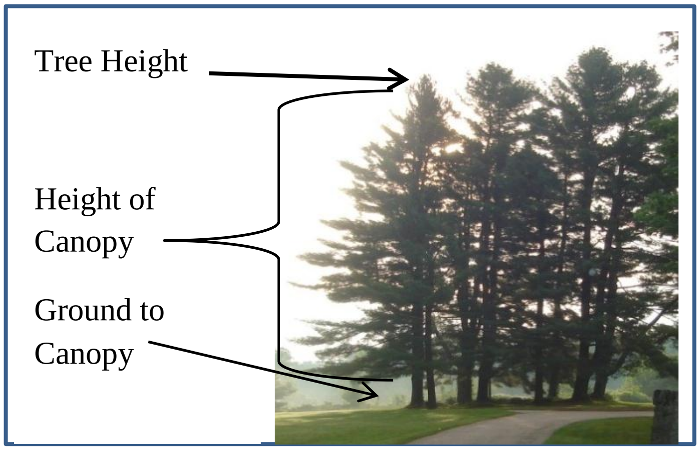


Figure 6.3: Classic white pines allow students to see, draw, photograph and understand the shape of a pine, its swooping arms and round-top triangular shape. Ideal trees have deep canopies with branches close to the ground, giving students ample opportunity to sample needles in the mid-canopy. (Photo by Carlson).

A graph of this year's Forest Watch tree measurements aligns tree height with canopy height, Figure 6.4. The first should be just a bit taller than the second. A third bar for each tree shows the difference, the distance from the ground to the lower branches of a tree's canopy.

During the 2011-2012 school year, we visited and talked with almost every Forest Watch teacher debating this issue. As the graph shows, two schools, Sant Bani and Monadnock Region chose to stick with their beloved old trees. In Sant Bani's case, this is an easy choice—these original Forest Watch trees stand in open spaces where canopies are large and the distance from ground to canopy is low. But in Monadnock Regional's case, Gerry Babonis and our UNH team were torn. These trees, an elegant stand of pines right outside Gerry's classroom, are the pride of Monadnock Regional, a handy study site and a beautiful entry way to the school's playing fields. But as the trees in this lovely park have grown, they have crowded one another, shrinking their canopies to very small tops high above the ground, out of reach of Gerry and his students.

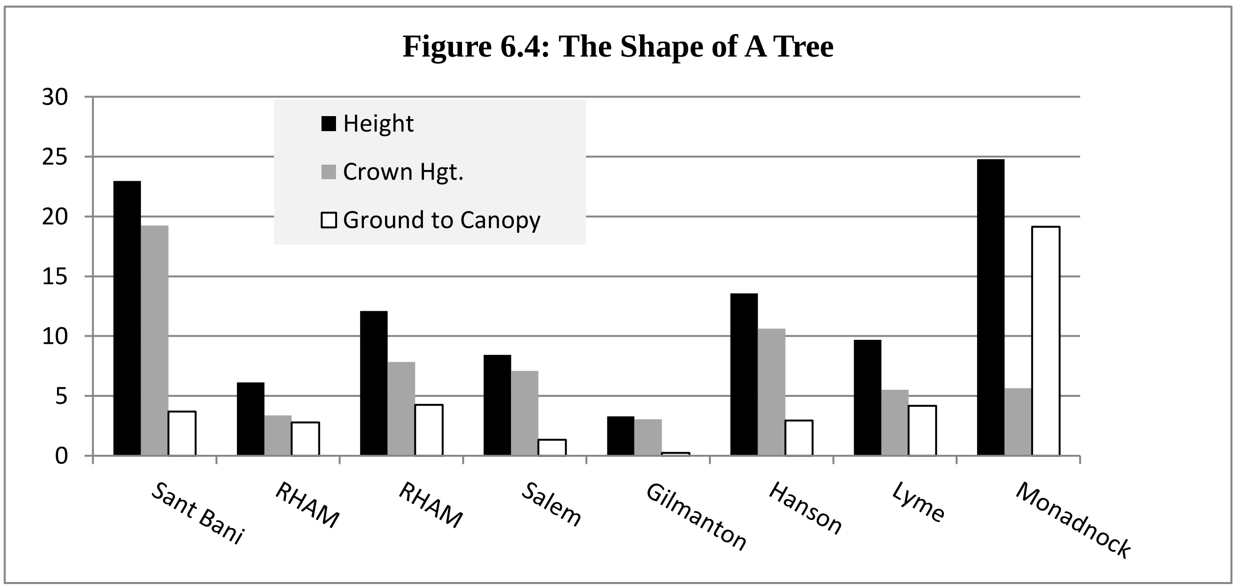


Figure 6.4: Tree height, canopy height and ground-to-canopy height are graphed side by side to show the average shape of eight Forest Watch schools' trees.

Gerry and his students have room on their campus to study other options. In fact a small clearcut at the far end of the playing fields offers young pine sprouts. The area is large enough so that students could divide it in half, managing one section with selective thinning and letting the trees self-select in the other half. How does forest succession work? Such a site is an ideal place to explore succession. But Monadnock might also do some creative tree sampling, calling in a student's parent who owns a bucket truck? Their old trees provide students with many years of interesting data for comparison. Now, as we consider the impact of needle cast on the pines, coring these big old trees might show dramatic change in annual growth rings.

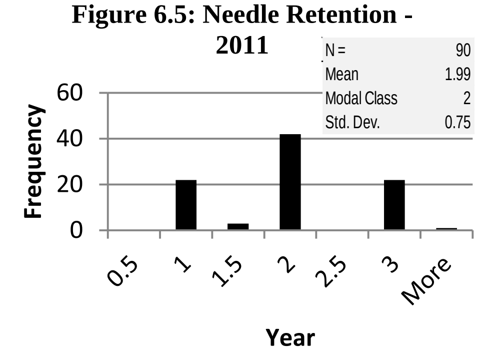
Many other Forest Watch teachers had the same difficult decision. As the chart shows, Gilmanton and Lyme, for instance, took the plunge and chose new trees. Their old trees still remain fond friends on the school grounds. But they have selected new trees with deep canopies and accessible needles.

We encourage Forest Watch teachers to talk about such conundrums with your students. What better opportunity for problem solving, experimental design, land use planning and consideration of benefits versus costs. There is no right answer. But getting to the answer can provide exciting lessons in critical thinking for your students.

Histograms Graphed from Student Measurements of Needles

Collecting, observing and measuring biological samples are steps in a long and tedious process. Forest Watch students and teachers collected, bagged, labeled and shipped 116 samples of fresh pine needles in the 2011-2012 school year. In their classrooms, students measured and examined 7,787 needles, measuring the length of each one, examining each for chlorotic mottle and tip necrosis. For each set of needles, students then made calculations about their size and the symptomology common to ozone damage. Some massed their needles and later calculated water content. Some entered their data and then analyzed it using Excel or other statistical methods. These studies provide a rich body of data about white pine health.

Figure 6.5: Needle Retention - 2011



The histogram of Needle Retention is a bit different this year. In the past, we've asked students to give us discrete counts of needle retention. Whether a twig held 10 second year needles or 110 second year needles, the count was 2, two years of retention. No differentiation was made between a twig with just 10 needles on its two-year-old stem or one that held a dense 110 needles. As we will discuss later in this chapter, we would like schools to begin providing us with continuous counts of needle retention. This is a much harder and more time consuming count but we believe it will give us a much more accurate picture of pine health. The histogram here shows just a few needles Forest Watch counted in our lab. Rather than just three bars, a continuous count would give us six or seven bars, a much more discerning perspective on the pines.

Water content in 2011 shows a range of percentages with a mean at 61.66 percent. The modal class, marked by the highest line shows a frequency of 17 trees at or near that percentage. This histogram also is a fine illustration of how students might use standard deviation to test their accuracy. Notice that in this study, the standard deviation is 14.7. That means that water content might vary from a low of 61.66 – 14.7 or 36.8 percent or a high of 66.2 percent. What is going on in our histogram? We have 3 measurements below 36 percent and we have 2 and possibly more over 66.2 percent. Why do we have so many high percentages in the 66-70%.

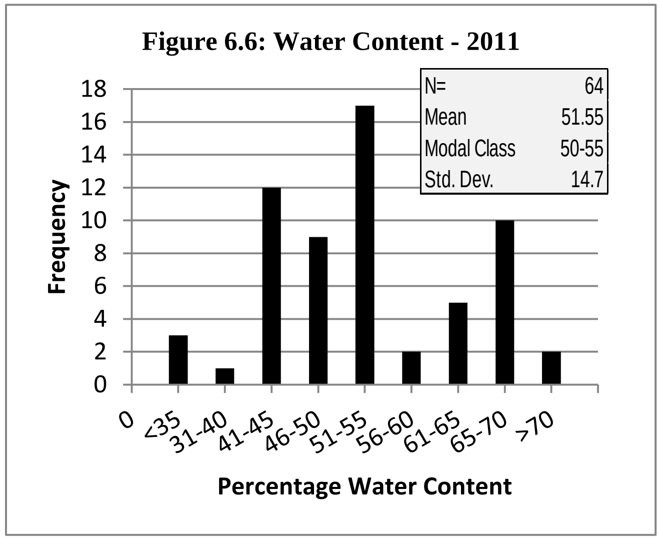


Figure 6.6: Water Content - 2011

Looking back at old Forest Watch Data Books, we find a study done by Mike Gagnon in 2007-2008. Mike tried two different methods of drying needles and calculating water content. He found that white pine needles, coated in thick cuticles, need about two weeks of drying to get a full measure of water content. That might explain the counts which lie outside or below the standard deviation. What would account for the high number of wetter than usual counts? Ask students to examine their methods. Were students weighing needles that were wet from plastic bags that contained damp paper towels? An initial measurement of wet weight may require students to pat dry their needles before they mass them.

The next histogram, Figure 6.7, Average Needle Length, shows a very nice bell curve, excepting a little dip in the 76 to 80 mm bar.

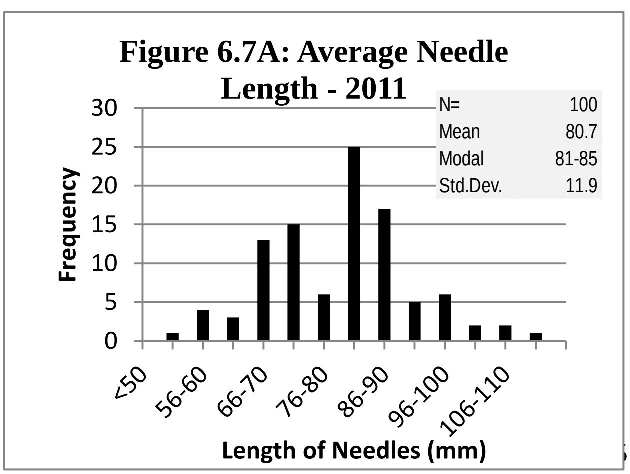


Figure 6.7A: Average Needle Length - 2011

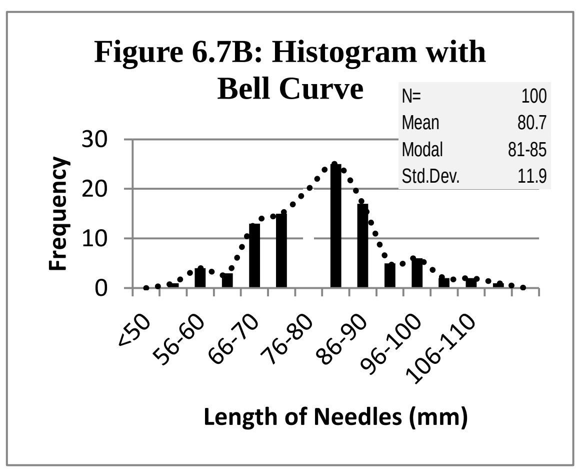


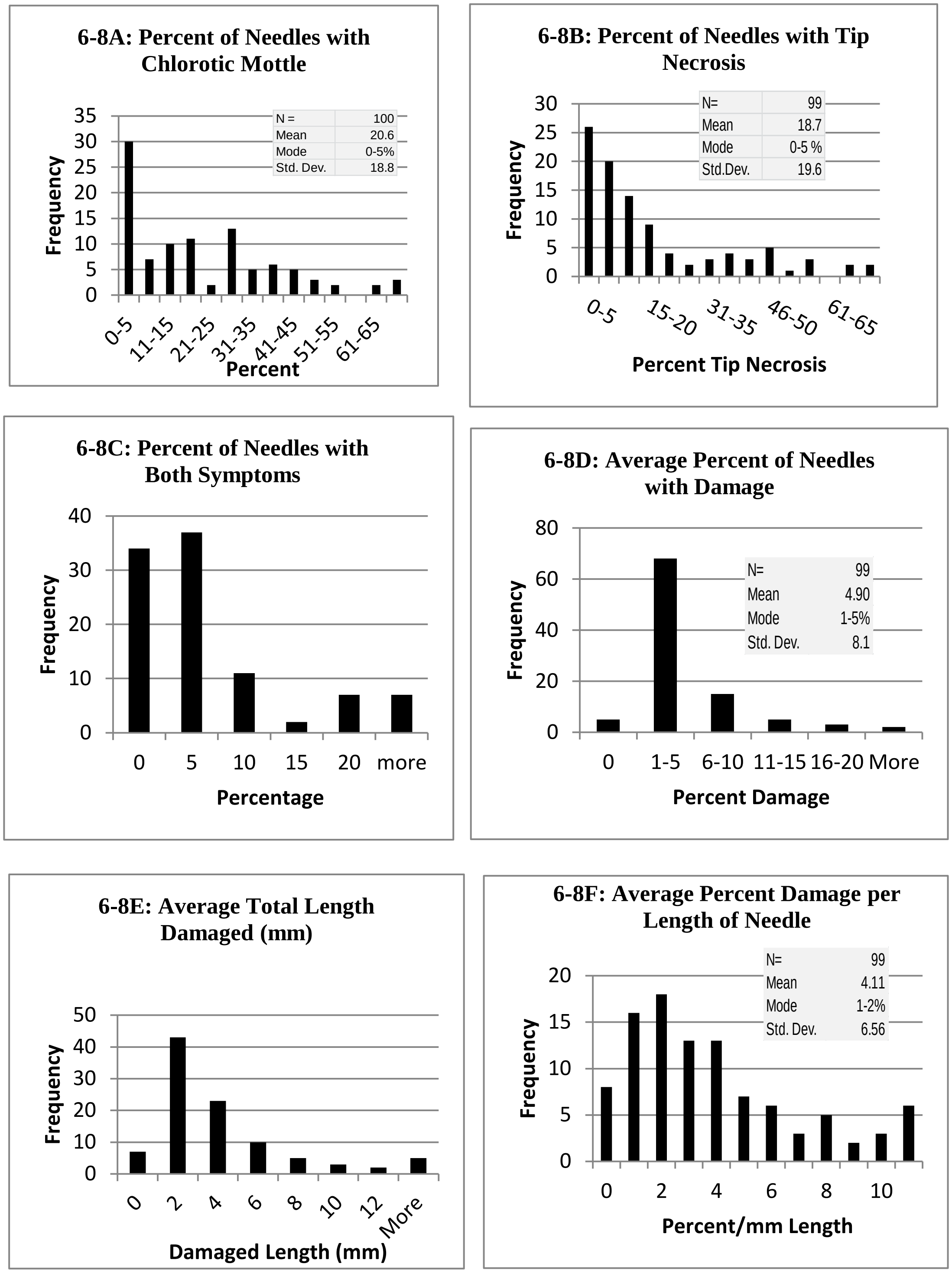
Figure 6.7B: Histogram with Bell Curve

Needle length offers a good opportunity to discuss such curves and to think about them with fresh perspective. Most needles lie in the middle of the curve. But are these needles the healthiest? Can students find a benefit for needles that are longer than usual, way out on the edge of the bell curve? Longer needles might have had better growing conditions. With longer length, they will contain more chloroplasts and can conduct more photosynthesis. They might produce more sugar and more wood. What about the trees that have short needles? Can students think of any advantage a white pine might have if it produced short needles? In a dry year, would conservation carry an advantage? What if a pine were busy making cones and seeds? A low measurement is not necessarily a sign of poor needle health.

Other Histograms

Forest Watch students, working in teams or individually, carefully examine 10 or 20 or 30 needles. They do quick counts of how many of these needles have tip necrosis, how many have chlorotic mottle and how many have both types of damage.

Students then measure the damaged areas and record the length of needle which is damaged. From that measurement, students calculate averages. We encourage Forest Watch teachers to study the following histograms with their students. Why do we ask for so many different types of analyses? What do they tell us about the white pine's health and how damage from ozone occurs? Is one analysis more telling than another? How?



Figures 6-8: Some histograms show a bell-shaped curve, such as Needle Length shows in Figure 6.7A and B. This indicates that most white pine needles really do average 80.7 mm in length. Other histograms such as Percent Chlorotic Mottle, 6-8A, show a falling frequency from lots of needles with little or no damage to a wide spectrum of damage percentages. This may indicate different amounts of ozone in different regions. It also graphically shows white pines are very healthy and most have little damage.

Long-Term Biometric Analysis

The big news for Forest Watch schools is how needle retention has changed. Last year, for the first time in 22 years, average needle retention dropped to below two years. This year, the number has improved a bit but still is below an average of two years, Figure 6.9. Trees have lost all third year needles and many second year needles. What impact will the loss of two-thirds of the photosynthetic machinery have on the white pine?

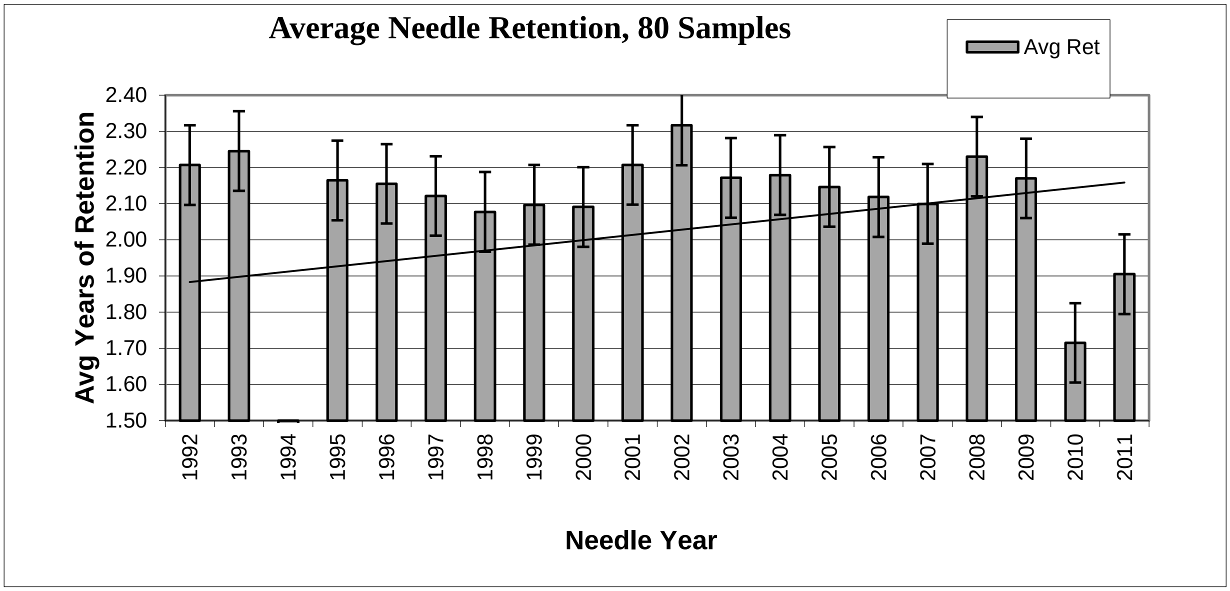


Figure 6-9: Average needle retention of trees in 2011 was 1.905.

In Lyme, NH, along the Connecticut River, Skip Pendleton and students at the Lyme School counted only one year of needles on their trees in 2011-2012. Similar counts were seen in St. Johnsbury School and at Sant Bani in Sanbornton, NH. All of these schools lie in the northwestern reach of our Forest Watch community. That average is offset by rich arrays of one, two and three year needles on the RHAM High School needles in central Connecticut.

Why are needles in northern New England losing their needles when we would expect ozone damage to be higher along the I-93 corridor near RHAM?

The needle retention problem also points up a possible flaw in our methodology. Presently, the Forest Watch Protocols simply ask students to note how many years of needles are present. It makes no difference whether a twig holds 6 second-year needles or 60. The student would record 2 as the number of years of needle retention.

Experimenting, we tried a different method which could provide more detail. Needles grow in fascicles or bundles of needles, 6 needles in 1 fascicle. When needles fall off, the base of the fascicle, a pedicel, remains on the twig as a tiny circular scar. If we count pedicels from bud scar to bud scar, we could estimate the total number of fascicles and needles which the twig should contain. We could then count remaining needles to calculate what actual percentage of second or third year needles remain on the twig.

Figure 6.10: Experimenting with new needle retention protocol. St. Johnsbury School's tree 1551, 5-10A, clearly has no 2nd year needles. But 1553S has a few, a very few. Should Figure 5-10B be counted as a tree which retains 2nd year needles? In Figure 5-10C, we cut the 2nd year stem from the 1st year tip and the old 3rd year twig. We removed all 2nd year needles to make a careful count. In Figure 5-10D, we marked each pedicel with a red marker so we could make an accurate count.

We experimented with St. Johnsbury School needles. As Figure6-10A shows, Tree 1661 had no 2nd or 3rd year needles. But Tree 1663S, Figure 6-10B, had a few 2nd year needles. Tree 1662S had more, Figure 6-10C. Counting pedicels, Figure 6-10D, multiplying by 6, we can calculate how many needles the trees had when the 2nd year needles were first produced. A careful count of remaining needles allows us to calculate that 1663S retains only 7% of its 2nd year needles. Tree 1662S retains 66%.

Figure 6-11. Morse High School's Tree 1742 retains three years of needles.

If we use this protocol, students could report that Tree 1661 retains only 1st year needles. Tree 1662 retains 1.66 years of needles. Tree 1663 retains 1.07 years of needles.

The same procedure could be used to give an accurate count of a tree such as Morse High School's Tree 1742's 3rd year needles, Figure 6-11.

Needle Anatomy

Needle length of 2011 needles averaged 80 mm, the longest length in 22 years, Figure 6-12. Thanks to the 160 sixth graders at Hanson Middle School, Hanson, MA, we have a very high number of needles, 7,787 in all, giving us a high degree of accuracy on this count. First year needles averaged 63.77 percent water on north side needles and 62.06 percent on south side needles in 2011. Over the past 22 years, both north and

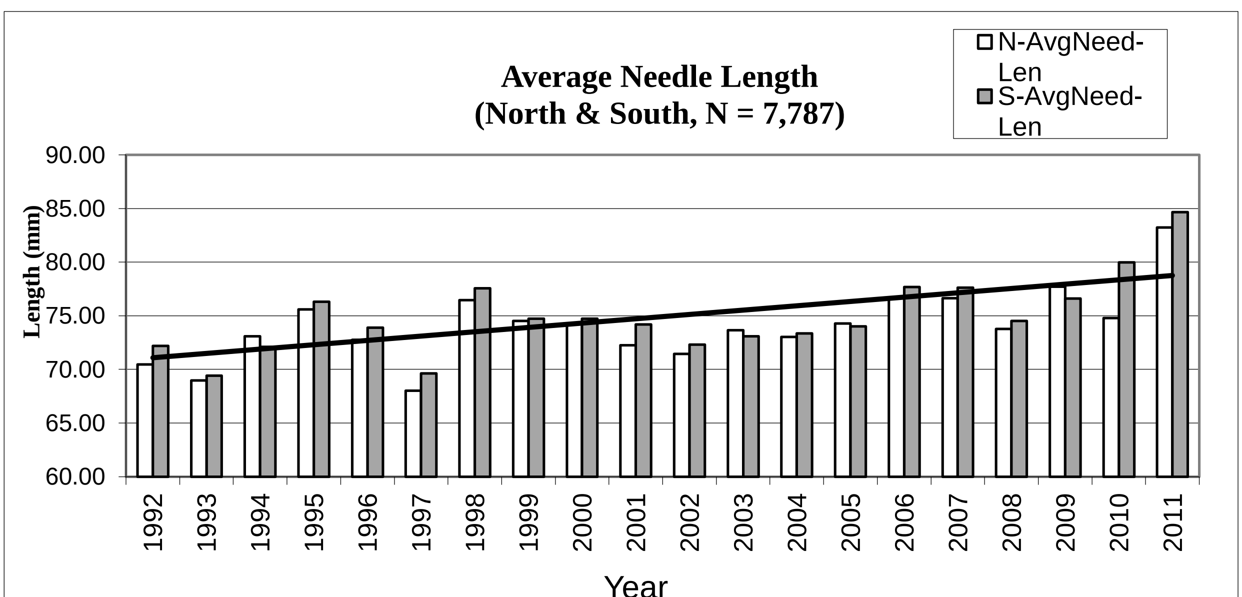


Figure 6-12: Average needle length of 6,887needles was 84 mm, the longest lengths in 22 years.

south side needles have averaged 63 percent water content. As Figure 6-13 shows, this year's needles are close to that long-term average.

Needle length and water content of needles may correlate, or they may not. Needles develop early in the summer. Soils moistened by spring rains and ample June rainfall are the driving factors in needle length. Students might compare spring and early summer rainfalls with their needle lengths to see why some years produce longer needles than others. Abundant rainfall in other periods of the growing season has little effect on needle length since the needle reaches its maximum length by July. Students might hypothesize, for example, that 2009 must have been a dry year. Precipitation records available on the NOAA National Climatic Data Center. The three-month average for 2009's summer will show it to be a record summer for heavy rains and foggy weather. So why were needles so short that year?

Students who study their white pines in June might experiment with water content and needle length. Daily measurements of rainfall might be compared with the growth in young new needles. Young saplings might be watered or not watered to see how needle growth correlates with soil water content. Students might also make thin sections of needles to learn whether they can "see" differences in cell structure of short needles versus long needles, of wet needles versus dryer needles. Students might also experiment with their methods of measuring needle water content. How many hours, days or weeks does it take to fully measure the water content of a waxy pine needle?

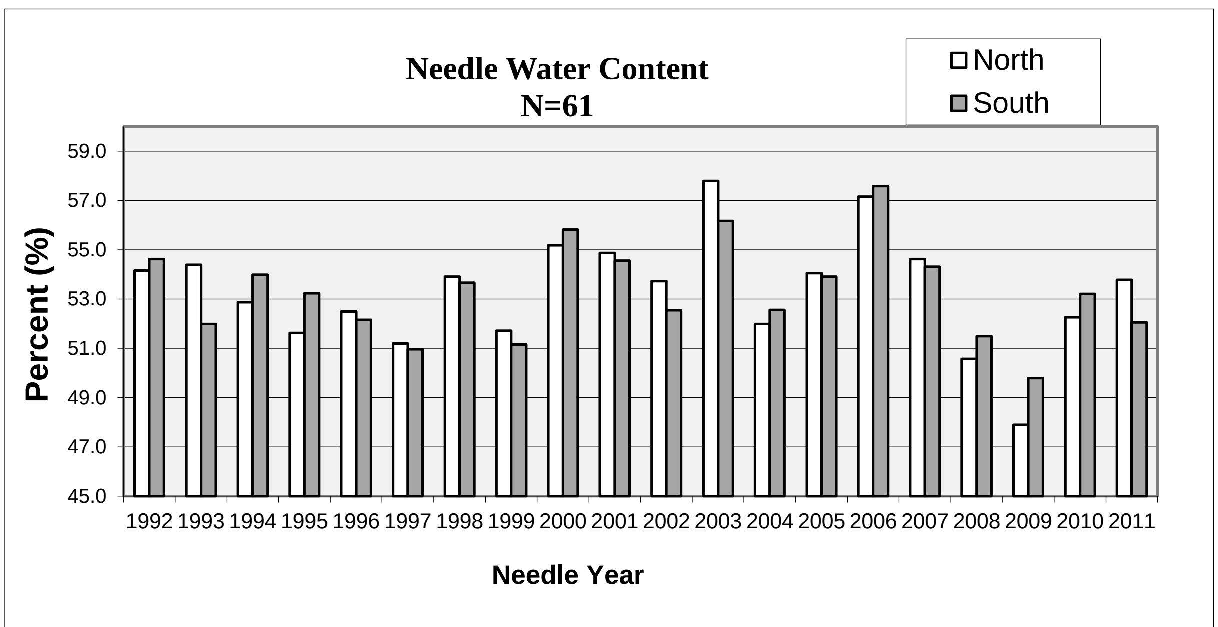


Figure 6-13: Water content was 53 and 52% for N and S side trees. This measurement, very easy to do on classroom countertops or in an oven, is a test Forest Watch hopes more schools will try.

Needle Condition

First-year needles in 2011 are in better condition than ever before, according to our student measurements of tip necrosis and chlorotic mottle. Needles average just 18% chlorotic mottle, half the amount of yellowing caused by ozone which students have seen in past years, Figure 6-14 shows. As Figure 6-16 shows, only 16% of needles showed tip necrosis this year.

These findings are rather odd considering the high loss of 2nd and 3rd year needles trees in much of the region are showing. Was there less ozone in the months between June 2011 and June 2012 when these needles were measured? See Chapter 2 on the year's ozone exceedance data. The reduction in damage certainly mirrors the reduction in nitrogen dioxide discussed there. It is also possible that the trees, stressed by unknown air pollutants and by numerous fungal infections on their older needles, concentrated protective phenolics on the tender young first year needles.

The chart is even more dramatic in Figure 6-16 which shows the percentage of needles which exhibit both symptoms. For the first time, this calculation falls below 6%. This is a heartening picture of white pine health.

As these 2011 needles headed into their second year, in June 2012, these long-term graphs seem to indicate that the pines are in good health, in better condition than our needles in any past year.

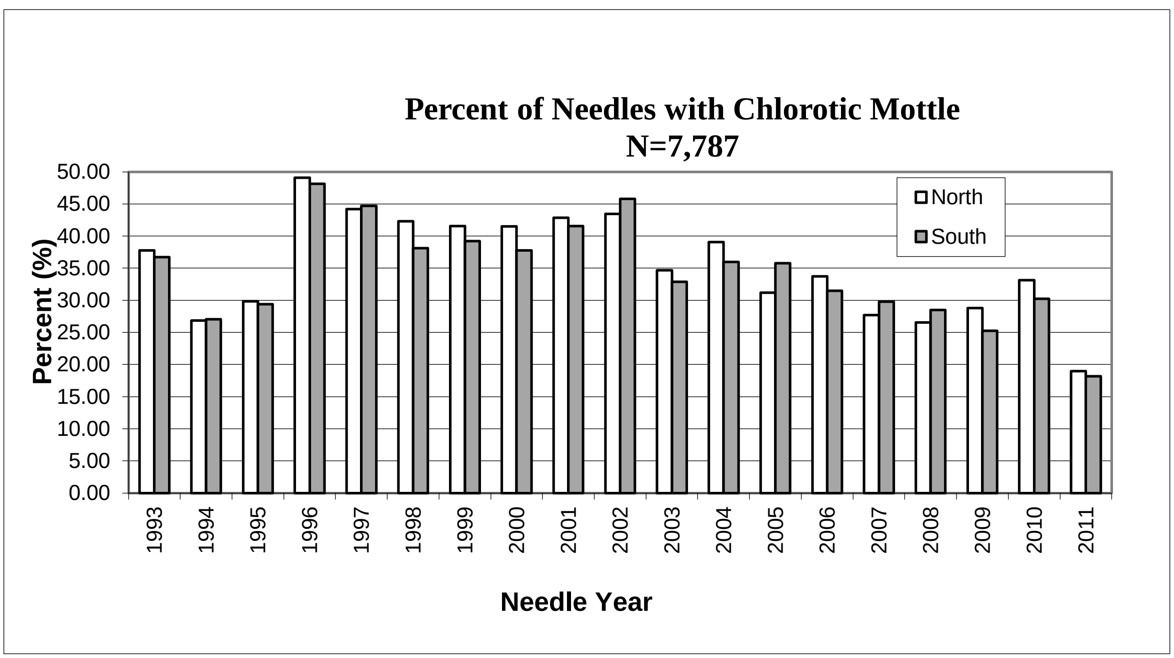


Figure 6-14: 2011 needles average 18.9 and 18.2% chlorotic mottle.

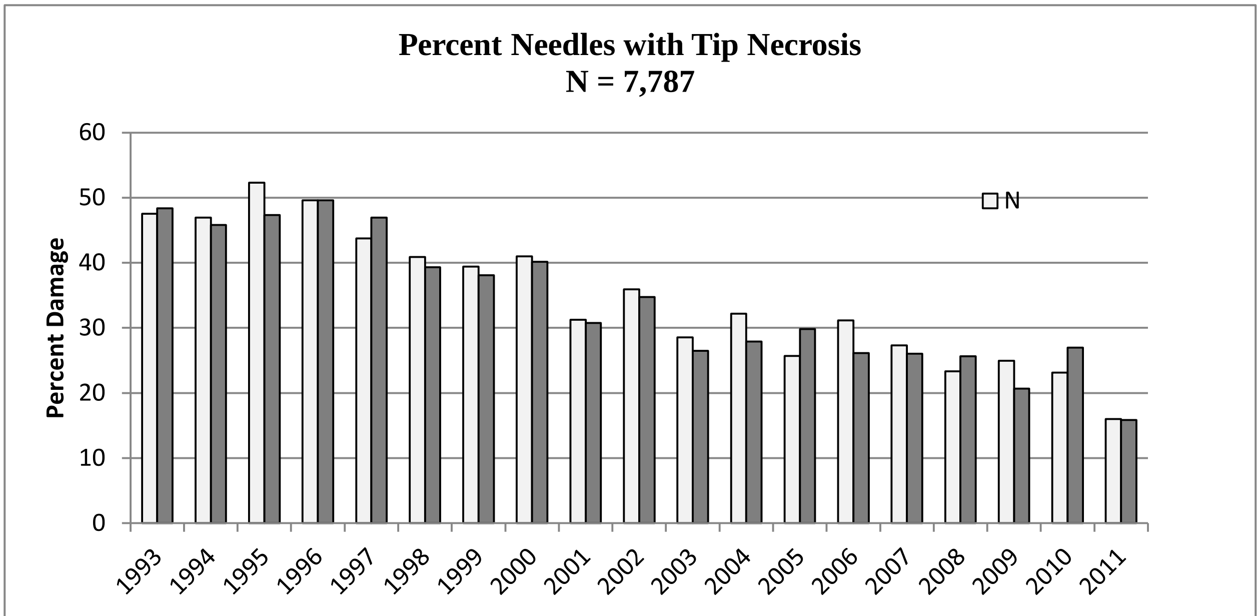


Figure 6-15: Needles averaged 10.4 percent tip necrosis in 2011.-2012.

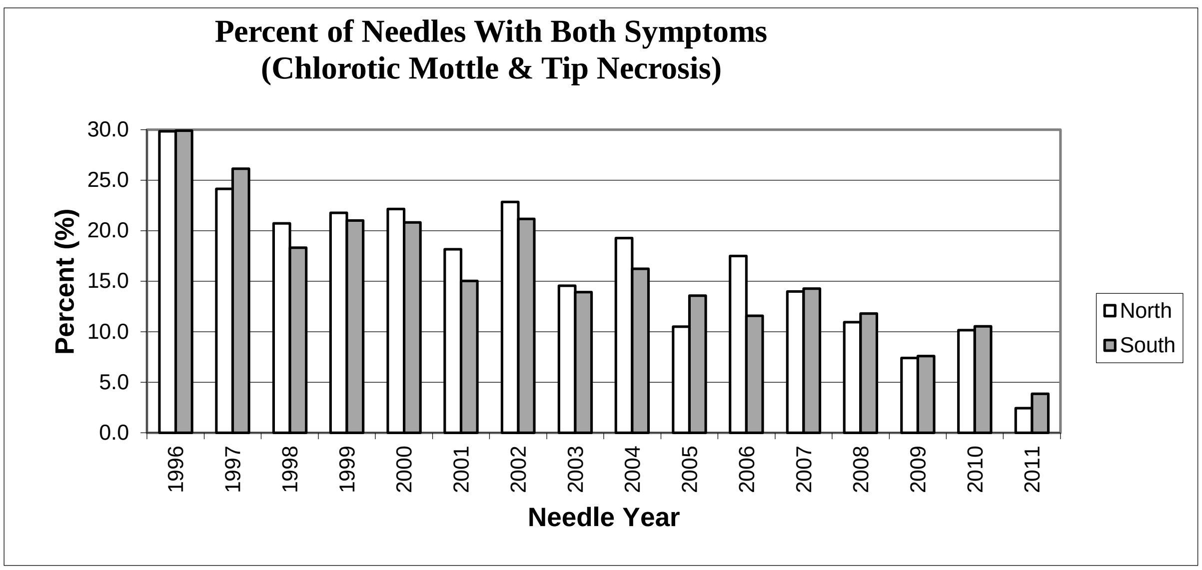


Figure 6-14:: The percent of needles exhibiting both types of damage falls below 5% for the first time in 22 years.

The averages presented in these charts covers a wide range of needle conditions. The RHAM High School trees which retain three years of needles have slightly shorter needles than the trees in Lyme but they show much less damage by length and by total percentage of damage. They have half the tip necrosis. Curiously both schools' trees have about the same percentage of chlorotic mottle.

Table 6.1: Comparison of needle condition.

School	Needle Retention	Needle Length	Damage By length	% Tip Necrosis	% Chlorotic Mottle	% Both Damage
RHAM, Hebron, CT	3	81.97 mm	1.84	7.46	6.74	2.08
Lyme, Lyme, NH	1	93.3	4.81	14.1	6.0	0.6

Again our data in these charts and graphs seems to contradict the extensive damage we saw more recently on 2012 first year needles. Each year's weather and stresses are different. Yet the tree's health or stress is cumulative. If conditions have been more stressful in 2012, perhaps the good condition we see in these 2011 will help the trees be resilient.

We have learned from our study of highly stress sugar maple leaves that trees can respond to stress by increasing protection of remaining foliage. It is possible that the northern pines in Vermont and New Hampshire are protecting the first year needles, even while they lose their second and third-year needles.

Such a mystery is clear evidence that we need more Forest Watch study!

Chapter Seven
Biometric and VIRIS Data
2011 Needles

The following pages present data gleaned from samples submitted to UNH and measurements made and analyzed by students.

Spectral curves show mean reflectances with standard deviations (+and) of each school's samples, as calculated by the Visible Infrared Intelligent Spectrophotometer (VIRIS). Reflectance is measured by a GER 2600 and processed with Pro-VIRIS, a software developed by Forest Watch.

Biometrics are recorded on Excel and summarized here. Forest Watch maintains all data submitted since 1992. As the charts show, Forest Watch students engage in precise measurements, careful recording of data, and numerous mathematical calculations and summations as they prepare biometric reports.

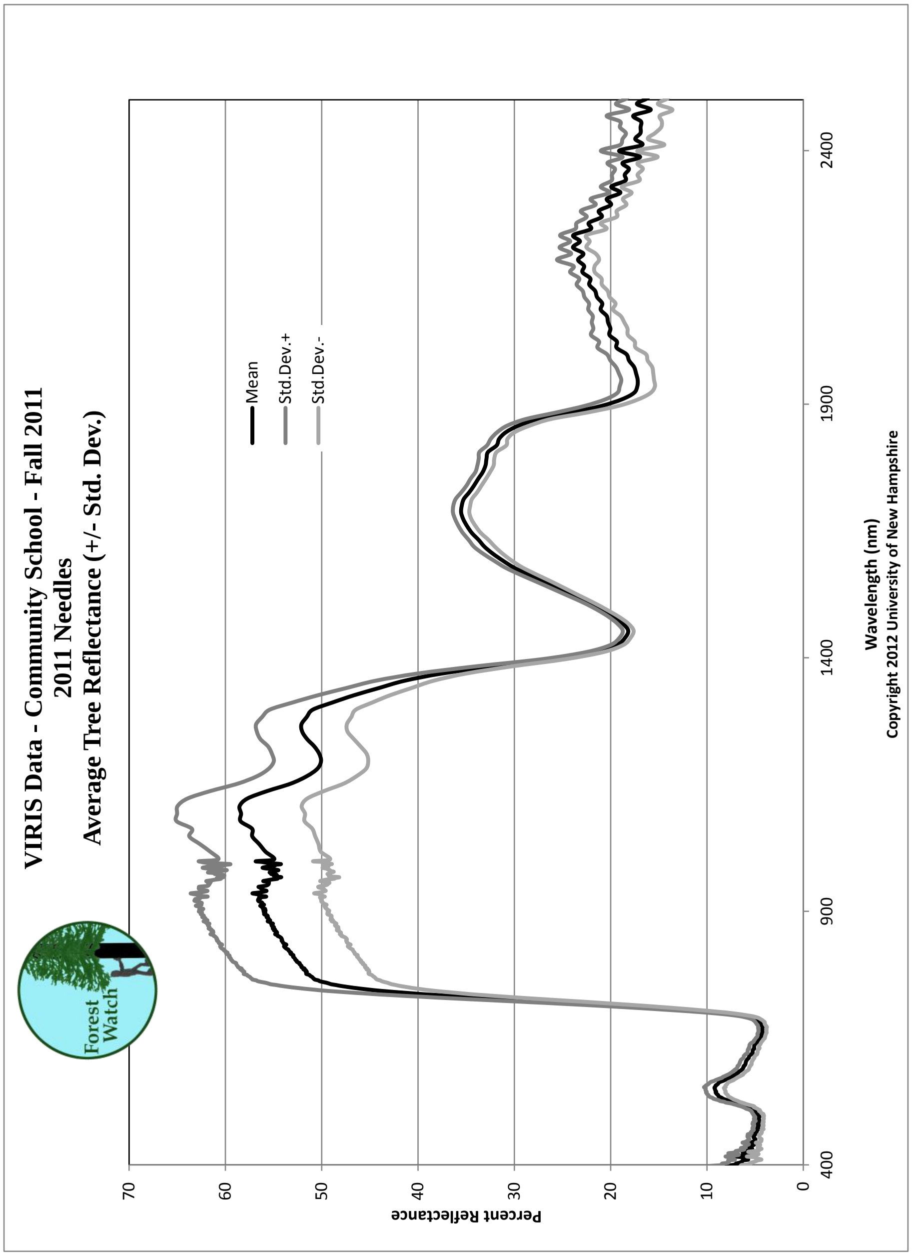
In addition to the following charts and graphs, each school receives an Excel file containing all data from spectral scans, graphs of each tree's reflectance and explanations of spectral indices.

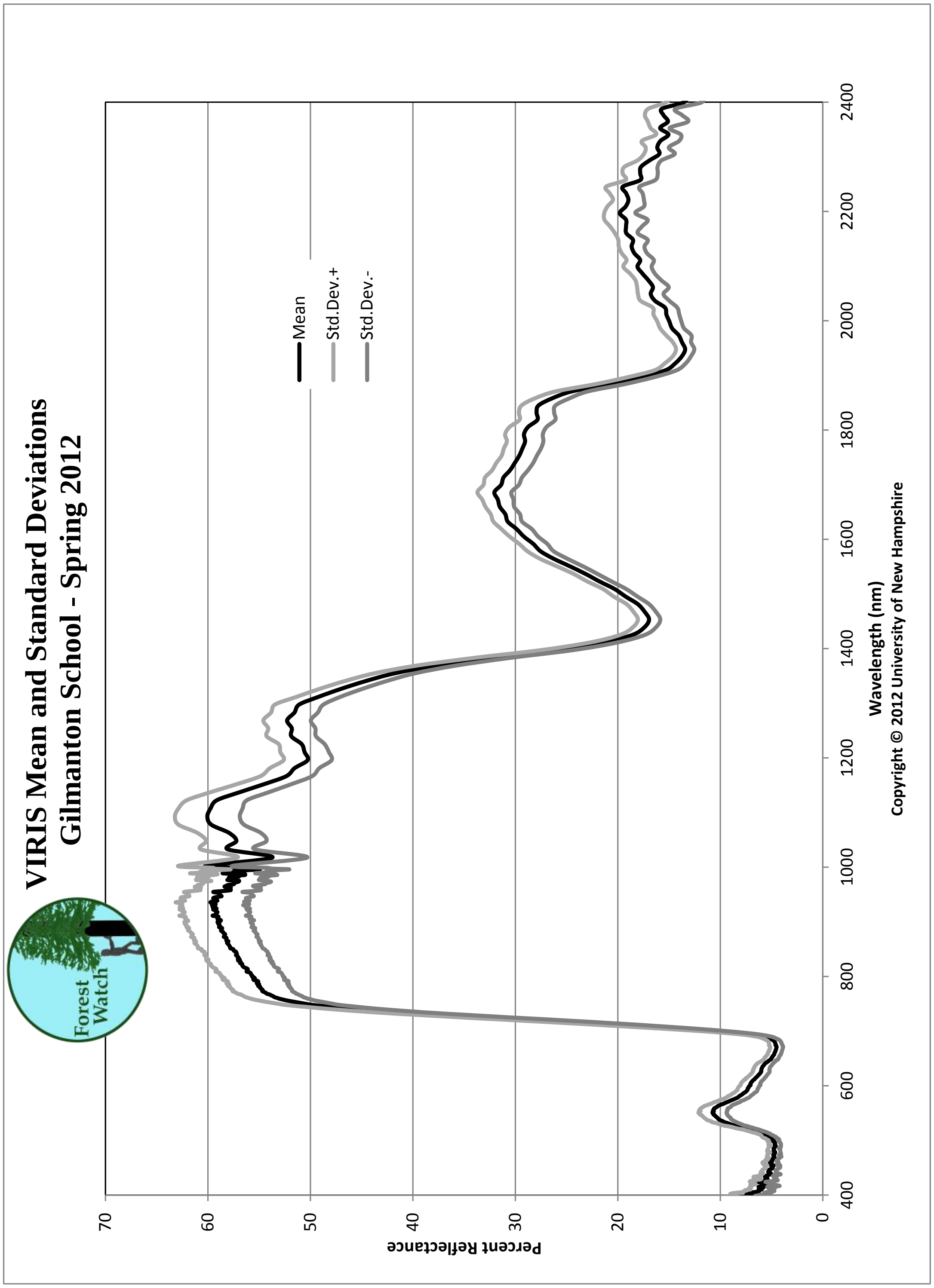
As these charts show, each school adapts Forest Watch to their curricula. Some do a complete array of field and laboratory measurements. Others incorporate collection of samples in other ecology activities.

Students in many schools use their own data and UNH spectral reports to build hypotheses and make comparisons of data which might explain change in white pine health, tree to tree and year to year, school to school or state to state. Students build posters which display their studies and findings. On May 31, 2013, Forest Watch will display these student research projects in the third Forest Watch Student Convention. Please join us.

Community School, South Tamworth, NH
Spectral Data from Samples Submitted by Kathy Flaccus

Index	1031N	1031S	1032N	1032S	1033N	1033S	1034N	1035N	1035S
REIP	727	725.4	723.9	727	723.9	723.9	720.8	723.9	722.4
NDVI	0.83	0.837	0.849	0.858	0.835	0.841	0.845	0.847	0.838
TM54	0.681	0.674	0.584	0.557	0.696	0.741	0.538	0.579	0.581
NIR31	0.981	0.978	0.894	0.907	0.984	0.953	0.886	0.91	0.896

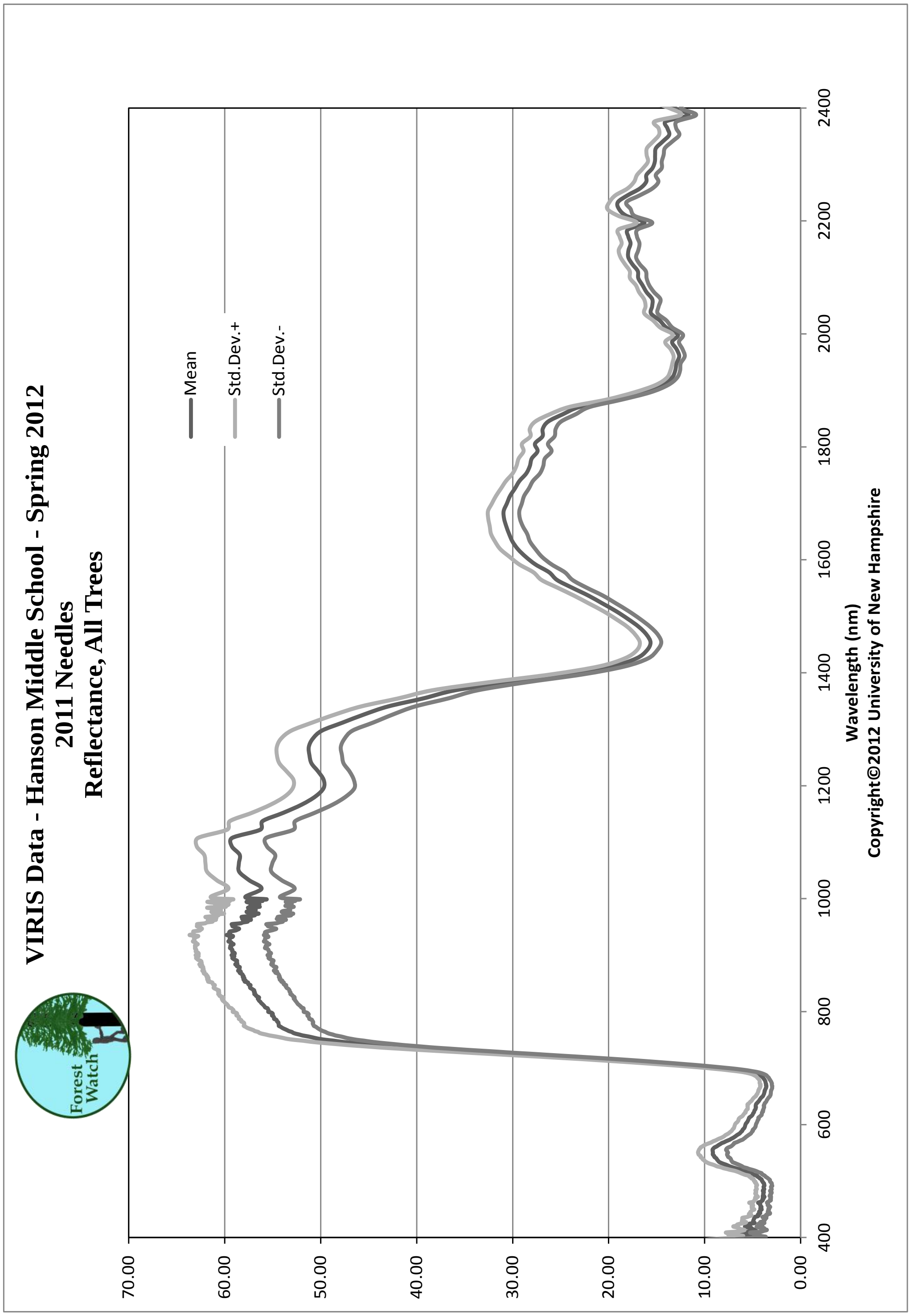




	First Year Needles										Old Site behind ball field		
Index	1906n	1906s	1907n	1907s	1908n	1908s	1909n	1909s	1910n	1910s	old1	old2	old3
REIP	719.3	723.9	725.4	731.6	719.3	723.9	723.9	723.9	719.3	719.3	723.9	731.6	714.6
NDVI	0.808	0.827	0.85	0.857	0.789	0.845	0.845	0.85	0.851	0.842	0.826	0.84	0.847
TM54	0.568	0.562	0.512	0.493	0.566	0.518	0.493	0.483	0.514	0.539	0.576	0.487	0.548
NIR31	0.902	0.925	0.885	0.845	0.922	0.875	0.86	0.83	0.874	0.884	0.951	0.841	0.912

Gilmanton School
Biometric and Spectral Data

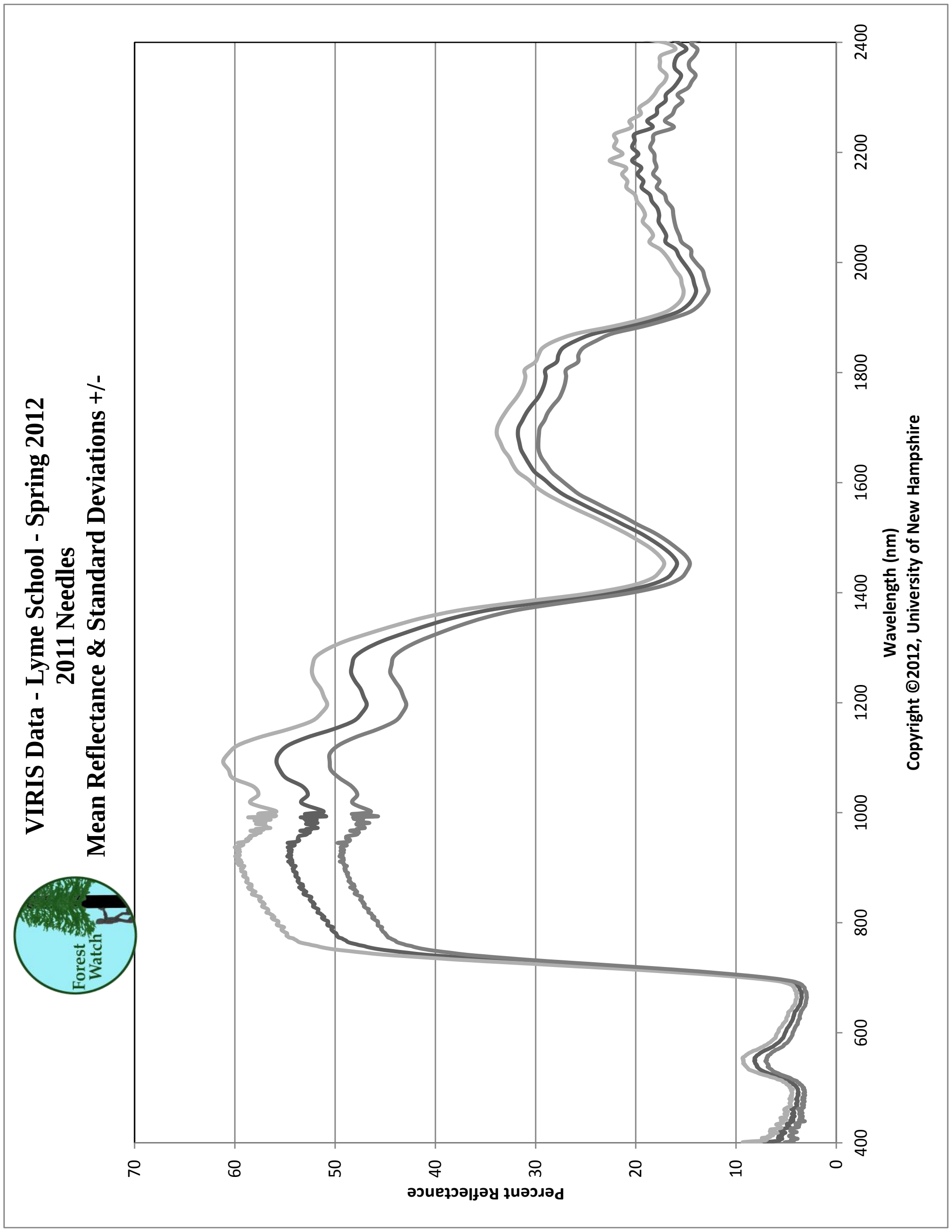
NeedleYear	2011	CollectionDate	4/16/2012		
Submitted By	Mary	Fougere			
TreeNumber	**1906**	**1907**	**1908**	**1909**	**1910**
DBH (cm)	5.3	7.1	11.1	4.1	3.5
CrownHeight (m)	2.7	3.1	4.8	2.2	2.4
TreeHeight (m)	2.8	3.4	5.3	2.4	2.5
N-Coll-Ht (m)	1.6	1.8	1.7	0.9	1.3
S-Coll-Ht (m)	1.4	1.3	2.5	1.2	1.1
N-Fas-Len (mm)	8.7	7.1	8.5	7.1	6.3
S-Fas-Len (mm)	6.4	6.4	9.2	5	5.2
N-Need-Ret (year)	2	2	2	2	2
S-Need-Ret (year)	2	2	2	2	2
N-Water (%)	50	50	54.2	63.3	53.3
S-Water (%)	53	51.8	54.8	51.8	52.2
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	68	53	86	72	67
S-AvgNeed-Len (mm)	67	66	88	56	66
N-PerTipNec	37	37	47	23	50
S-PerTipNec	3	47	47	23	57
N-PerChlMot	17	17	30	33	10
S-PerChlMot	0	30	20	20	20
N-AvgTotDamg-Len	5.4	1.2	5.2	4.1	3
S-AvgTotDamg-Len	0.4	3.6	1.8	3.3	1.6
N-PerNeedBothSymp	16.7	3.3	20	10	3.3
S-PerNeedBothSymp	0	26.7	20	10	13.3
N-AvgPerDamage	6.7	2.3	6.5	6.2	4.3
S-AvgPerDamage	-0.9	5.8	2.1	6.5	2.5
N-avg%Damage by Len.	7.90	2.30	6.00	5.70	4.50
S-avg%Damage by Len.	0.6	5.5	2	5.9	2.4



Index	1661N	1661S	1662N	1662S	1663N	1663S	1664N	1664S	1665N	1665S
REIP	722.4	730.1	722.4	731.6	722.4	727	722.4	727	727	727
NDVI	0.838	0.867	0.874	0.865	0.856	0.868	0.889	0.87	0.867	0.889
TM54	0.505	0.475	0.489	0.49	0.514	0.531	0.549	0.545	0.513	0.507
NIR31	0.849	0.815	0.846	0.858	0.882	0.857	0.88	0.905	0.873	0.848

Hanson Middle School
Biometric and Spectral Data

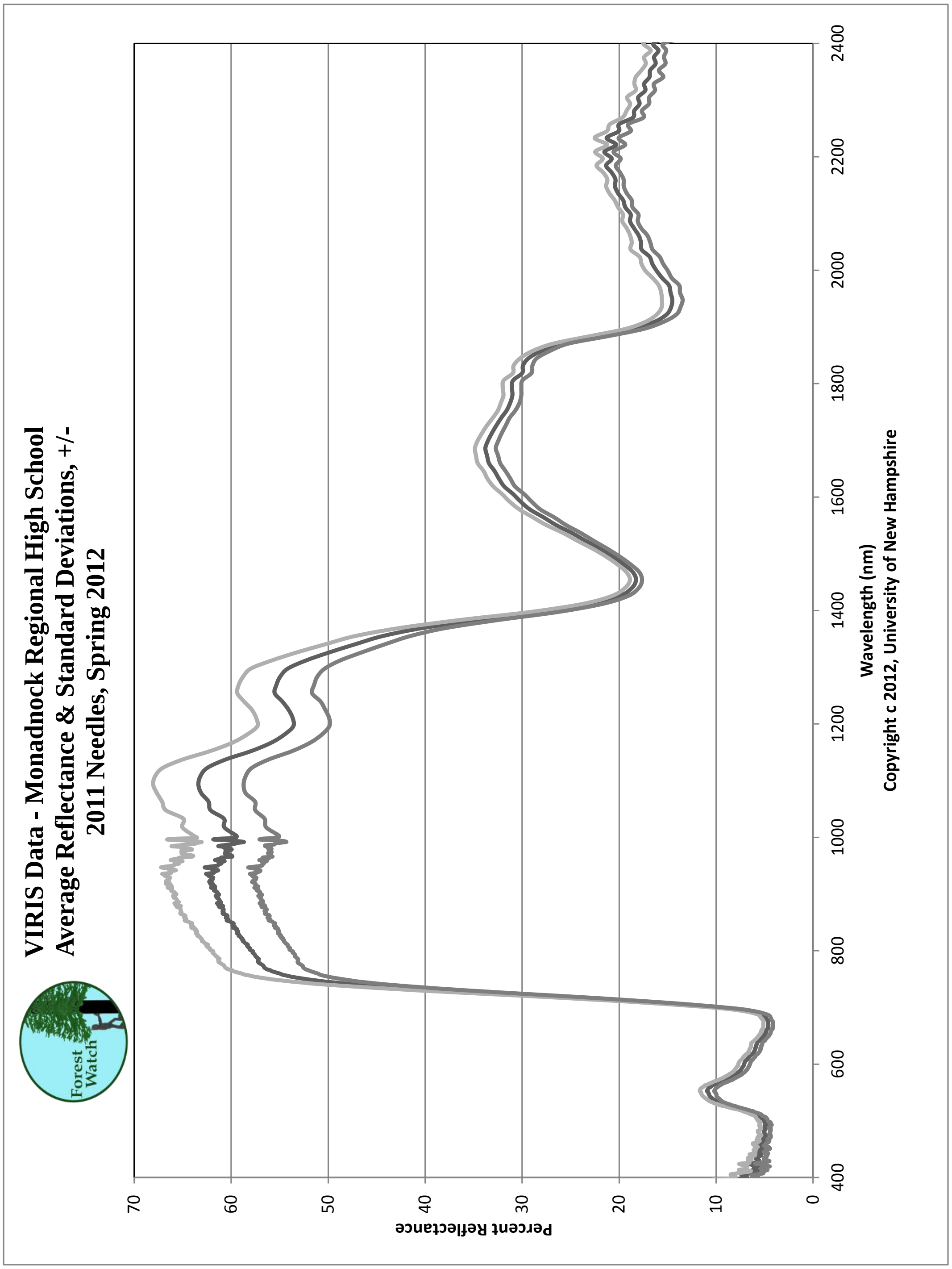
NeedleYear	2011	SubmittedBy Wes Blauss			
CollectionDate	5/25/2012				
TreeNumber	**1661**	**1662**	**1663**	**1664**	**1664**
DBH(cm)	30.9	32.5	26.8	31.2	35.6
CrownHeight (m)	9.5	13.9	8.7	10.1	10.9
TreeHeight (m)	12.3	16.1	10.6	11.7	17.1
N-Coll-Ht (m)	3	7	5	5	7
S-Coll-Ht (m)	3	7	5	5	7
N-Fas-Len (mm)	81	94	67	54	88
S-Fas-Len (mm)	84	92	71	47	79
N-Need-Ret (year)	1	2	2	2	2
S-Need-Ret (year)	2	2	1	2	2
N-NumNeedles	312	945	450	720	310
S-NumNeedles	254	678	600	596	245
N-AvgNeed-Len (mm)	82	87	74	84	88
S-AvgNeed-Len (mm)	88	83	68	56	93
N-PerTipNec	11	9	6	8	8
S-PerTipNec	9	12	6	6	6
N-PerChlMot	40	29	50	33	41
S-PerChlMot	33	44	26	40	53
N-AvgTotDamg-Len	4	1	2	1	4
S-AvgTotDamg-Len	1	2	1	1	2
N-PerNeedBothSymp	5	2	7	3	3
S-PerNeedBothSymp	1	5	2	3	2
N-AvgPerDamage	5	1	3	1	5
S-AvgPerDamage	1	3	1	2	2
N-avg%Damage by Len.	4.9	1.1	2.7	1.2	4.5
S-avg%Damage by Len.	1.1	2.4	1.5	1.8	2.2



Index	1901N	1901S	1902N	1902S	1903N	1903S	1904N	1904S	1905N	1905S
REIP	730.1	723.9	720.8	722.4	727	730.1	720.8	723.9	730.1	727
NDVI	0.881	0.883	0.863	0.853	0.856	0.875	0.855	0.865	0.866	0.856
TM54	0.596	0.592	0.56	0.646	0.604	0.519	0.517	0.57	0.578	0.577
NIR31	0.888	0.915	0.849	0.948	0.907	0.862	0.867	0.88	0.884	0.897

Lyme School
Biometric and Spectral Data

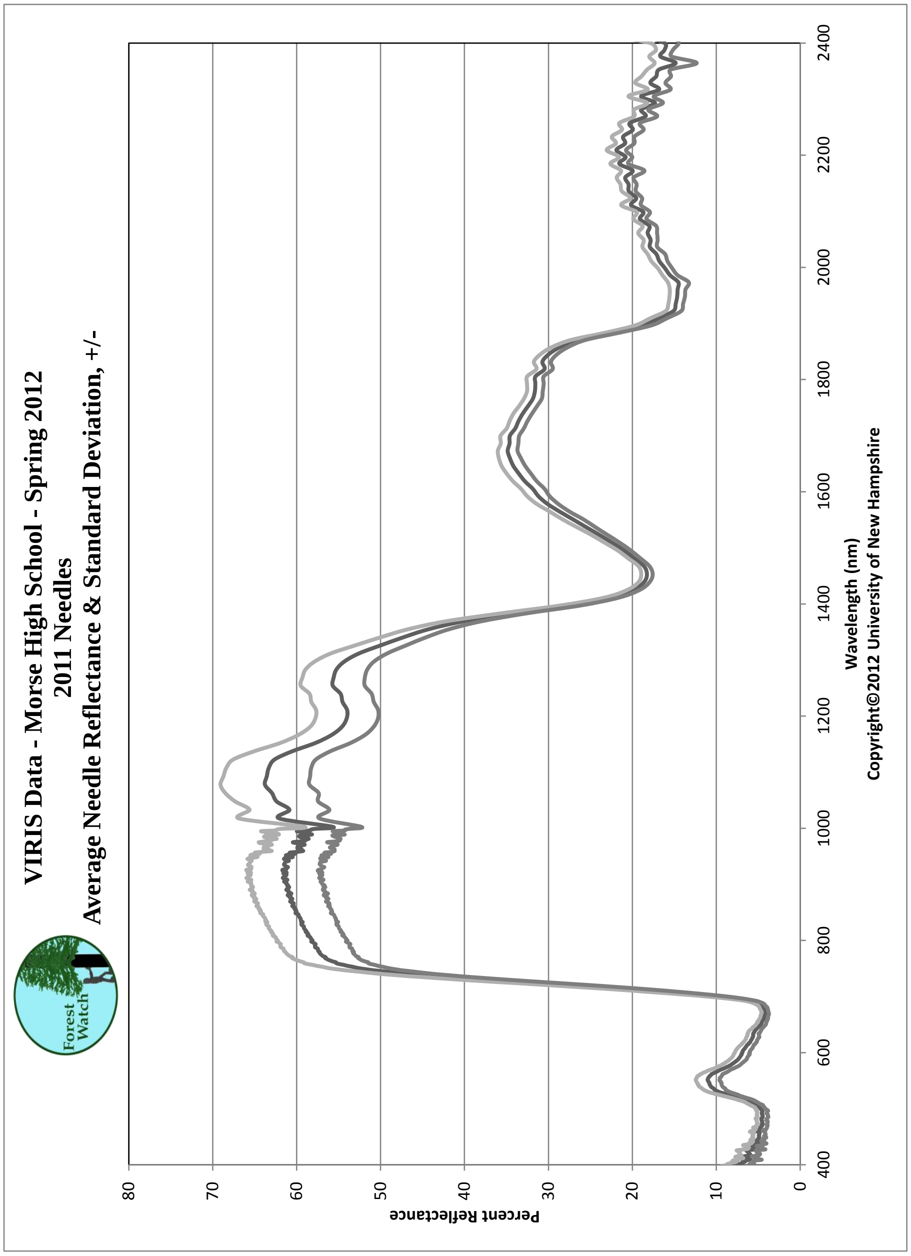
Needle Year: 2011	Submitted by Skip Pendleton				
CollectionDate	Spring 2012				
TreeNumber	**1901**	**1902**	**1903**	**1904**	**1905**
DBH (cm)	6.1	17.3	3.2	9.6	15.9
CrownHeight (m)	5	15.5	2.3	8.6	14.8
TreeHeight (m)	4.9	6.6	4.5	5.8	8
N-Coll-Ht (m)	4.4	4	3.1	4.3	4.4
S-Coll-Ht (m)	4.4	4.4	3.1	4.4	4.4
N-Fas-Len (mm)	92.3	75.3	93	113	96
S-Fas-Len (mm)	106	80	93	84.5	99
N-Need-Ret (year)	1	1	1	1	1
S-Need-Ret (year	1	1	1	1	1
N-NumNeedles	26	30	30	26	18
S-NumNeedles	30	30	27	30	30
N-AvgNeed-Len (mm)	92	75	93	113	96
S-AvgNeed-Len (mm)	106	81	93	85	99
N-PerTipNec	12	17	10	31	17
S-PerTipNec	3	13	11	10	17
N-PerChlMot	4	0	0	27	0
S-PerChlMot	3	10	0	3	13
N-AvgTotDamg-Len	4.7	6	1.5	8.7	4
S-AvgTotDamg-Len	2.3	11.5	1.5	3.4	4.5
N-PerNeedBothSymp	0	0	0	0	0
S-PerNeedBothSymp	0	0	0	3	3
N-AvgPerDamage	5	8	1.5	8	5
S-AvgPerDamage	2	12.5	1.6	4	4
N-avg%Damage by Len.	5.11	8.00	1.61	7.70	4.17
S-avg%Damage by Len.	2.17	14.20	1.61	4.00	4.55



Index	1266n	1266s	1267n	1267s	1268n	1268s	1269n	1269s	1270n	1270s
REIP	723.9	722.4	722.4	723.9	719.3	722.4	723.1	719.3	730.1	727
NDVI	0.852	0.835	0.84	0.846	0.819	0.843	0.845	0.844	0.84	0.852
TM54	0.505	0.553	0.511	0.591	0.524	0.511	0.56	0.526	0.528	0.556
NIR31	0.87	0.846	0.891	0.92	0.907	0.894	0.937	0.898	0.907	0.908

Monadnock Regional High School
Biometric and Spectral Data

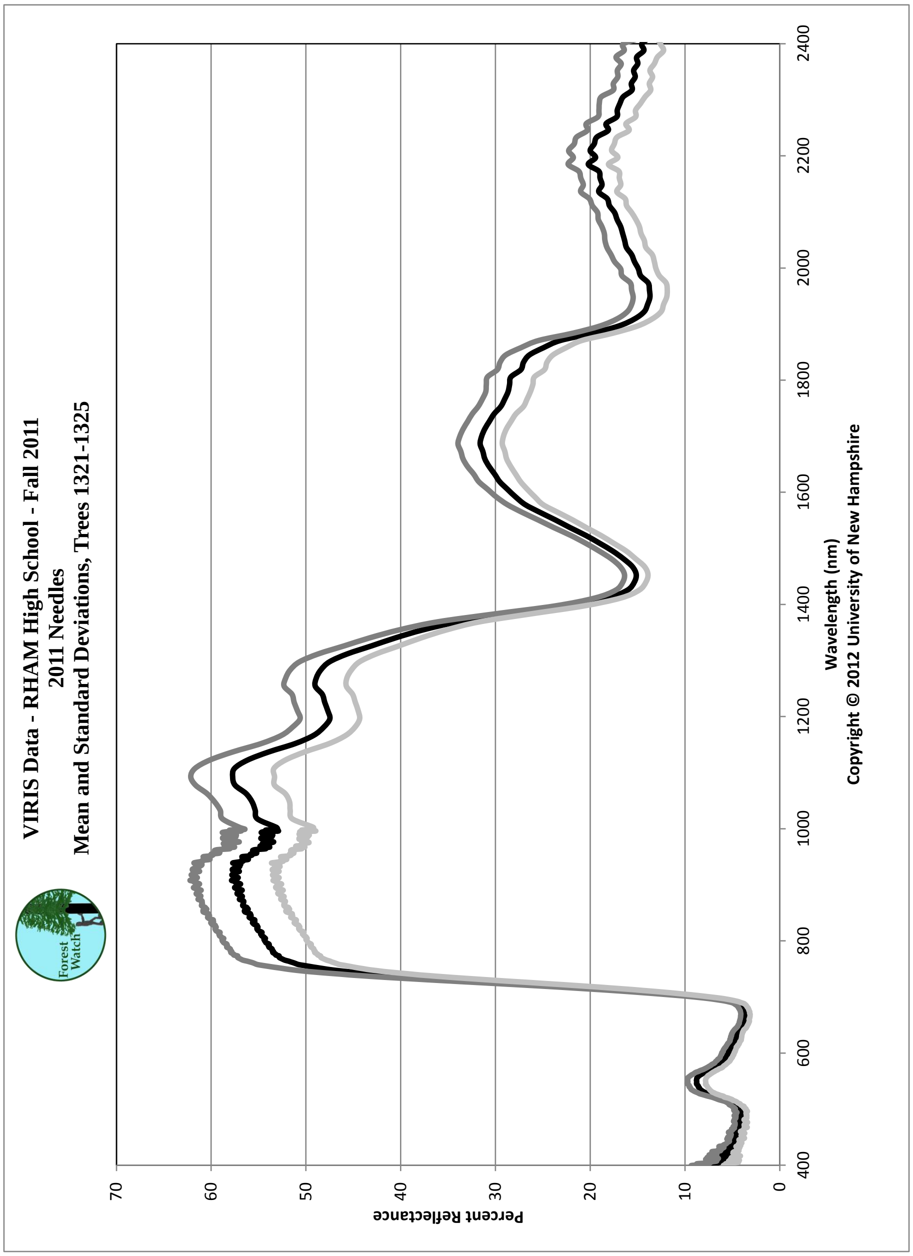
NeedleYear	**2011**	SubmittedBy	Gerry	Babonis	
CollectionDate	4/25/2012				
TreeNumber	**1266**	**1267**	**1268**	**1269**	**1270**
DBH	76.4	66.2			89.2
CrownHeight	3.60	7.50	6.80		2.30
TreeHeight	30.25	26.9	24.2		27.8
N-Coll-Ht (m)	10.50	10.50	10.50	10.50	10.50
S-Coll-Ht (m)	10.50	10.50	10.50	10.50	10.50
N-Fas-Len (mm)	79	73	76	70	75
S-Fas-Len (mm)	89	66	77	75	87
N-Need-Ret (year)	2	3	1	2	3
S-Need-Ret (year)	2	2	2	2	3
N-Water (%)	47.6	43.8	43.8	49	41.7
S-Water (%)	47.02	45	47	46.5	42.8
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	73	72.2	79.4	75	66
S-AvgNeed-Len (mm)	83	72.6	71	86	79.5
N-PerTipNec	70	6	36.6	56	70
S-PerTipNec	56	25	86.7		13.3
N-PerChlMot	47	20	26.6	26	70
S-PerChlMot	66	7.1	63.3		40
N-AvgTotDamg-Len	3.5	1.9	0.8	4.4	30
S-AvgTotDamg-Len	3	1	3		2
N-PerNeedBothSymp	33.3	0	16.6	16	70
S-PerNeedBothSymp	43		53.3		6.6
N-AvgPerDamage	4.1	2.6	1	6.5	70
S-AvgPerDamage	4.7	10.3	4.4		1.6
N-avg%Damage by Length	**4.79**	**2.63**	**1.01**	**5.87**	**45.45**
S-avg%Damage by Length	**3.61**	**1.38**	**4.23**	**0.00**	**2.52**



Index	1741N	1741S	1742N	1742S	1743N	1743S	1744N	1744S	1745N	1745S
REIP	725.4	725.4	725.4	727	722.4	725.4	725.4	725.4	727	727
NDVI	0.835	0.848	0.856	0.852	0.841	0.835	0.855	0.858	0.864	0.879
TM54	0.585	0.551	0.543	0.546	0.601	0.518	0.573	0.548	0.534	0.525
NIR31	0.907	0.902	0.907	0.912	0.903	0.866	0.915	0.882	0.912	0.909

Morse High School
Spectral Data

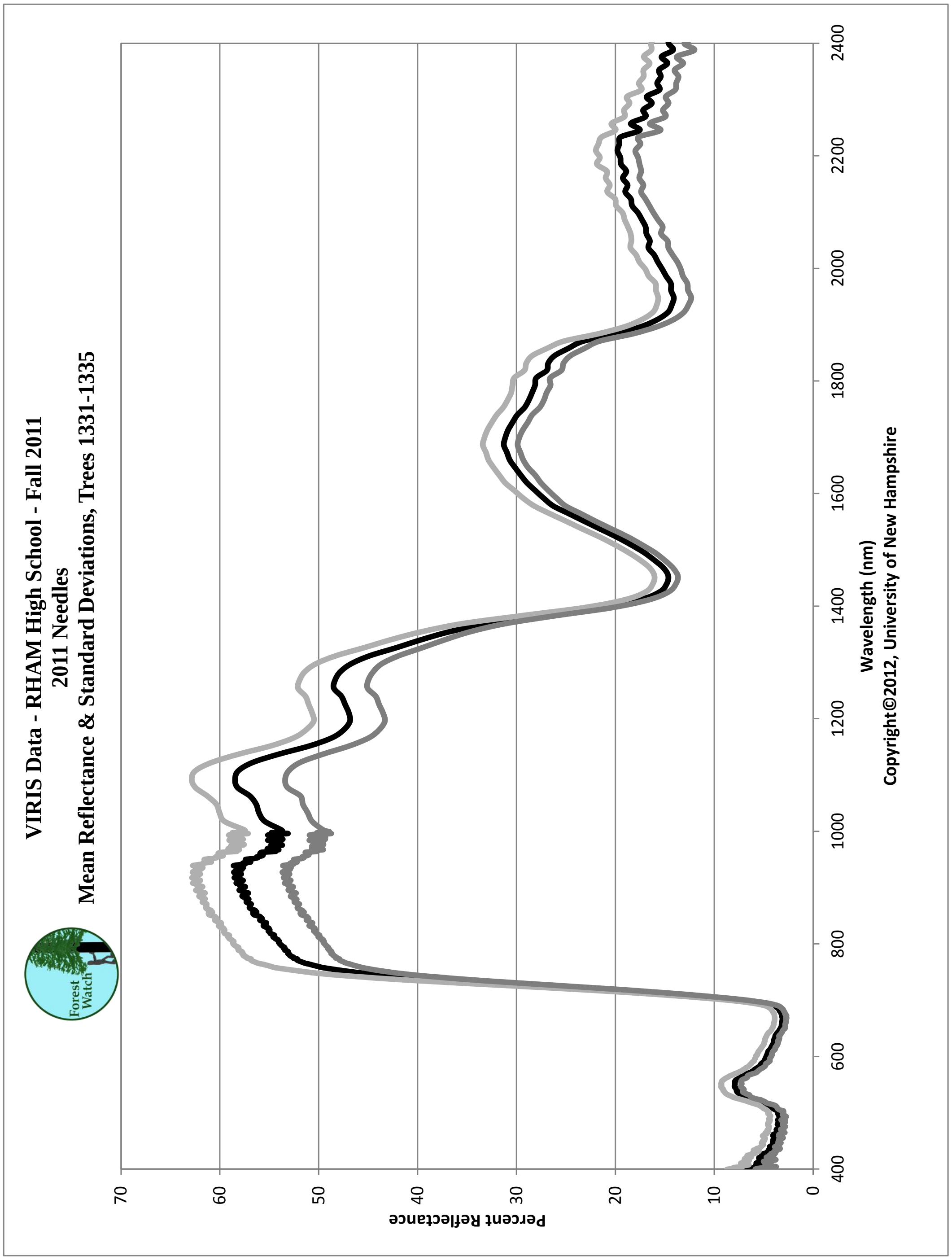
Needle Year	2011				
Collection Date	6/4/2012				
Submitted by	Carolyn	Nichols			
Tree Number	**1741**	**1742**	**1743**	**1744**	**1745**
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	83.2	105	58.6	72.9	67.7
S-AvgNeed-Len (mm)	87.5	85	82.4	98.2	74.7
N-PerTipNec	0.5	27	0	2	33
S-PerTipNec	0	14	30	80	3
N-PerChlMot	0	27	0.2	6.6	77
S-PerChlMot	0.2	12	30	36.7	63
N-AvgTotDamg-Len	0.4	2.8	0.5	1.6	20.6
S-AvgTotDamg-Len	0.2	7.3	3.8	2.2	9.7
N-PerNeedBothSymp	0	3	0	0	33
S-PerNeedBothSymp	0	16	16.7	33	3
N-AvgPerDamage	0.5	2.8	0.8	2.2	28.3
S-AvgPerDamage	0.2	9.2	4.6	2.5	13.5
N-avg%Damage by Len.	0.0	2.7	1.0	2.0	30.0
S-avg%Damage by Len.	0.0	8.6	4.6	2.2	12.9



Index	1321n	1321s	1322n	1322s	1323n	1323s	1324n	1324s	1325n	1325s
REIP	719.3	727	730.1	728.5	728.5	723.9	728.5	728.5	725.4	727
NDVI	0.878	0.88	0.863	0.883	0.862	0.861	0.87	0.852	0.859	0.851
TM54	0.569	0.495	0.521	0.597	0.488	0.485	0.531	0.564	0.515	0.57
NIR31	0.855	0.832	0.812	0.869	0.833	0.841	0.844	0.85	0.83	0.871

RHAM High School
Biometric and Spectral Data, Trees 1321-1325

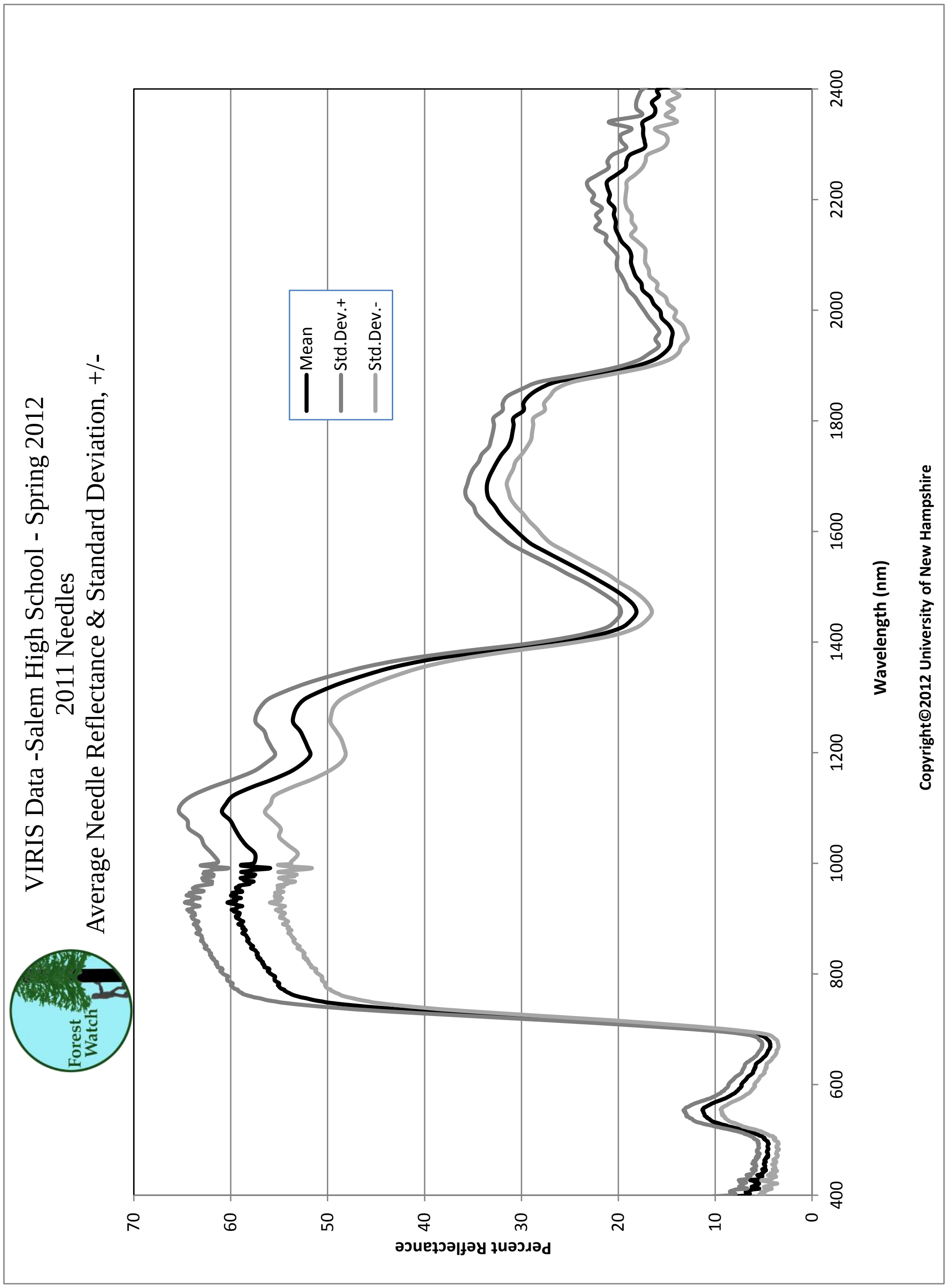
		Submitted by Frank Schmidt			
Needle Year	2011				
Collection Date	10/4/2011				
TreeNumber	**1321**	**1322**	**1323**	**1324**	**1325**
DBH (cm)	4.7	12.2	18.04	13.58	20.1
CrownHeight (m)	2	2.6	4.5	4.5	3.2
TreeHeight (m)	3.71	5.5	8.36	7.56	5.56
N-Coll-Ht (m)	3	3	4.5	4.8	3.2
S-Coll-Ht (m)	3	3	4.5	4.8	3.2
N-Fas-Len (mm)	68.9	65	107.4	59.5	93.3
S-Fas-Len (mm)	81.7	65	84.3	97.4	109.7
N-Need-Ret (year)	3	3	3	3	2
S-Need-Ret (year)	3	3	2	3	3
N-Water (%)	71	60	65.5	65.8	65.7
S-Water (%)	71	68.5	66.3	64.9	69.3
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	71	58	82	79	103
S-AvgNeed-Len (mm)	76	61	85	94	106
N-PerTipNec	13.3	3	10	13	3
S-PerTipNec	11.2	0	13	3	3
N-PerChlMot	3.3	3	20	3	2
S-PerChlMot	13.3	3	13	0	2
N-AvgTotDamg-Len	6.1	0	0.27	6	3.5
S-AvgTotDamg-Len	0.6	0	0.5	0	0
N-PerNeedBothSymp	3.3	0.6	0	0	3.3
S-PerNeedBothSymp	10	0	0	0	0
N-AvgPerDamage	1.7	1.7	2.7	5.5	2.2
S-AvgPerDamage	6.7	0	2.7	0	0.3
N-avg%Damage by Length	8.6	0	0	7.6	3.4
S-avg%Damage by Length	0.8	0	0.6	0	0



Index	1331n	1331s	1332n	1332s	1333n	1333s	1334n	1334s	1335n	1335s
REIP	728.5	733.2	728.5	728.5	720.8	728.5	727	730.1	728.5	722.4
NDVI	0.888	0.906	0.89	0.902	0.864	0.87	0.865	0.88	0.882	0.882
TM54	0.509	0.484	0.483	0.458	0.625	0.581	0.536	0.498	0.545	0.563
NIR31	0.831	0.802	0.796	0.803	0.863	0.826	0.846	0.813	0.87	0.856

RHAM High School
Biometric and Spectral Data, Trees 1331-1335

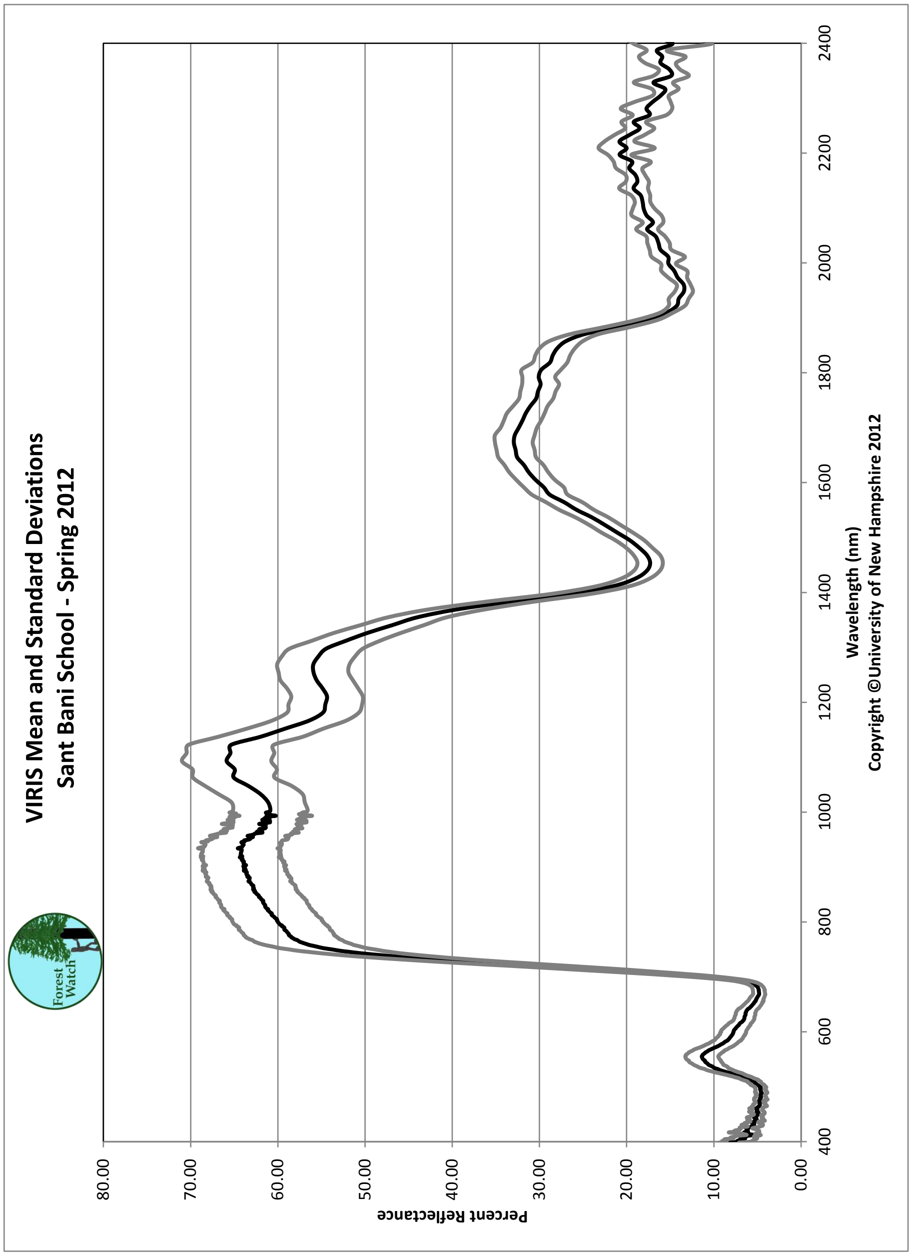
Needle Year	2011	Submitted by Frank Schmidt			
Collection Date	10/4/2011				
Tree Number	**1331**	**1332**	**1333**	**1334**	**1335**
DBH (cm)	16.03	6.6	26.64	38.22	30.2
CrownHeight (m)	6.2	3.4	8.7	10.2	10.7
TreeHeight (m)	8.84	6.86	13.67	16.25	14/89
N-Coll-Ht (m)	4.5	4	8	8	5.3
S-Coll-Ht (m)	4.5	4	8	8	5.3
N-Fas-Len (mm)	92.7	79.3	63.8	85	83.2
S-Fas-Len (mm)	78.1	74.7	80.5	83	87
N-Need-Ret (year)	3	3	4	3	3
S-Need-Ret (year)	3	3	3	3	3
N-Water (%)	68.1		64	61	70
S-Water (5)	64.3		66	60	70
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	84	89	88	82	77
S-AvgNeed-Len (mm)	96	90	73	88	76
N-PerTipNec	0	0.13	20	10	0
S-PerTipNec	3.3	0.13	20	10	13
N-PerChlMot	0	0.6	16	13	13
S-PerChlMot	6.6	0.4	17	3	2.6
N-AvgTotDamg-Len		2.1	1.4	0.02	1.8
S-AvgTotDamg-Len	1.6	0.02	5.9	2.2	3
N-PerNeedBothSymp	0	0.6	0	0	0
S-PerNeedBothSymp	3	0.1	6	0	6.6
N-AvgPerDamage		0.02	0.3	2	2.1
S-AvgPerDamage	1.6	0.01	3.3	2.5	4.2
N-avg%Damage by Length	0	2.4	1.6	0	2.3
Savg%Damage by Length	1.7	0	8.1	2.5	4



	1351N	1351S	1353N	1353S	1354N	1354S	1355N	1355S	1504N	1504S
REIP	725.4	720.8	719.3	722.4	719.3	723.9	719.3	717.7	717.7	727
NDVI	0.84	0.806	0.858	0.822	0.852	0.854	0.858	0.845	0.85	0.836
TM54	0.564	0.523	0.545	0.552	0.556	0.586	0.538	0.535	0.565	0.566
NIR31	0.925	0.85	0.894	0.875	0.876	0.918	0.904	0.899	0.948	0.943

Salem High School
Biometric and Spectral Data

NeedleYear	2011	Submitted	Norma	Bursaw	
CollectionDate	5/7/2011				
TreeNumber	**1351**	**1353**	**1354**	**1355**	**1504**
CrownHeight (m)	6.1	6.6	7.9	8.5	6.3
Tree Height (m)	7.7	7.3	9.2	10.1	7.8
N-Coll-Ht (m)	5.9	4.6	4.7	5.4	5.4
S-Coll-Ht (m)	5.6	4.8	4.7	4.6	5.4
N-Fas-Len (mm)	7.7	7.1	8	6.8	7.3
S-Fas-Len (mm)	8.7	7	9.4	7.7	7.3
N-Need-Ret (year)	3	2	2	2	2
S-Need-Ret (year)	2	2	2	2	2
N-Water (%)	42	43	47	37	44
S-Water (%)	42	52	44	45	45
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	64	64	88	68	69
S-AvgNeed-Len (mm)	84	67	97	70	70
N-PerTipNec	3	3	10	43	0
S-PerTipNec	7	3	7	13	13
N-PerChlMot	50	50	63	20	37
S-PerChlMot	27	53	40	30	60
N-AvgTotDamg-Len	1	1	1	1	5
S-AvgTotDamg-Len	3	1	6	1	4
N-PerNeedBothSymp	0	0	7	13	0
S-PerNeedBothSymp	0	0	3	7	10
N-AvgPerDamage	1	1	2	1	7
S-AvgPerDamage	4	2	6	1	6
N-avg%Damage by Len	1.6	1.6	1.1	1.5	7.4
S-avg%Damage by Len	3.6	1.5	6.2	1.4	5.7

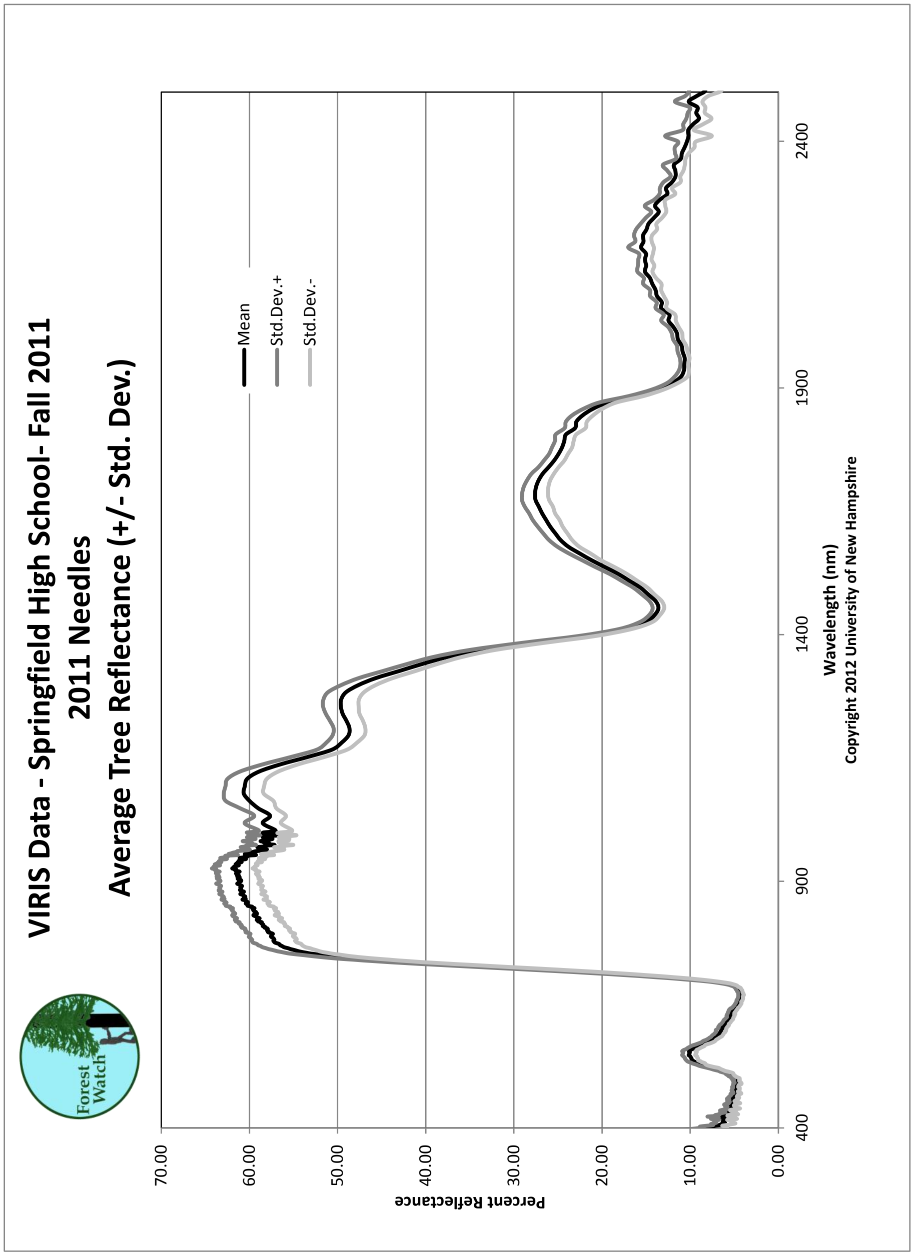


Index	96N	96S	97N	97S	98N	98S	99S	99W	100S	100W
REIP	727	727	730.1	716.2	722.4	706.9	722.4	720.8	725.4	722.4
NDVI	0.865	0.825	0.841	0.836	0.836	0.809	0.862	0.815	0.86	0.824
TM54	0.505	0.543	0.518	0.505	0.48	0.479	0.472	0.518	0.514	0.511
NIR31	0.853	0.9	0.896	0.845	0.851	0.852	0.857	0.875	0.887	0.879

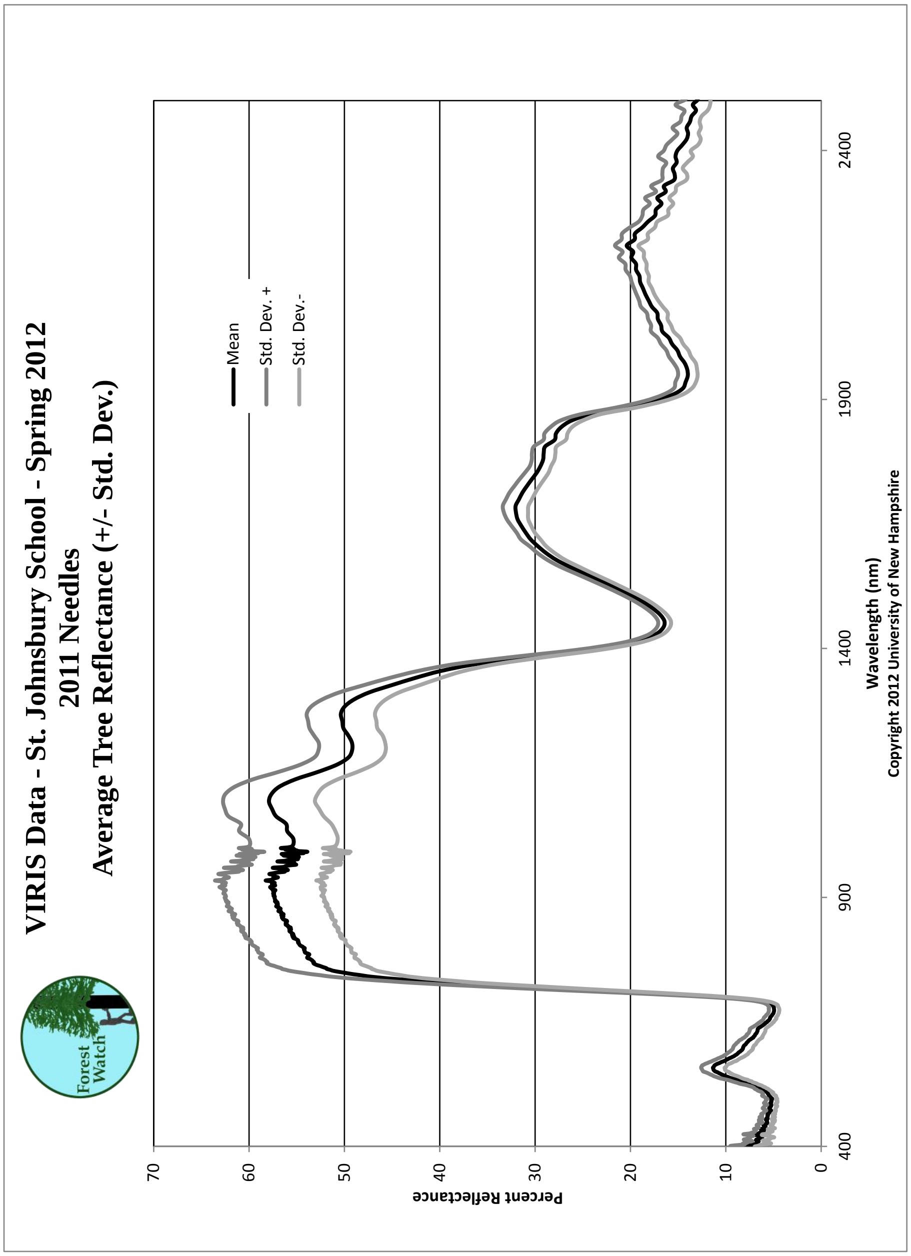
Sant Bani School
Biometric and Spectral Data

Needle Year	2011	Collection Date	6/1/2012		
Submitted by	Robert	Schongalla			
Tree #	96	97	98	99	100
Elevation: 850'	Canopy	65.00%	Ground	95.90%	
DBH (cm)	55.7	77.3	72.3	65.4	45.1
Crown Hgt (m)	18.3	18.2	19.3	22.8	17.7
TreeHeight (m)	21.8	21.2	22.8	26.8	22.2
N-Coll-Ht (m)	4.5	3.5	4.5	4	4.5
S-Coll-Ht (m)	3.5	3	3.5	4.5	5
N-Fas.Len (mm)	83	98	87	83	93
S-Fas.Len (mm)	78	90	85	88	90
N-Need-Ret (year)	2	2	2	1	3
S-Need-Ret (year)	1	2	2	1	2
N-Water (%)	51.8	54.1	51.6	53.5	49.8
S-Water (%)	51.8	52.2	52.2	52.3	52.4
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	82	84	84	89	82
S-AvgNeed-Len (mm)	75	83	82	82	100
N-PerTipNec	43	43	13	23	53
S-PerTipNec	33	37	20	20	50
N-PerChlMot	23	7	17	43	27
S-PerChlMot	23	27	3	7	13
N-AvgTotDamg-Len	1.8	14	8.6	2.9	11.1
S-AvgTotDamg-Len	14.8	8	4.8	6.2	19.5
N-PerNeedBothSymp	3	0	7	7	3
S-PerNeedBothSymp	3	3	0	0	13
N-AvgPerDamage	2.2	16.6	10.2	3.3	13.6
S-AvgPerDamage	19.8	9.6	5.8	7.5	19.6
N-avg%Damage by Len.	2.7	19.8	12.1	3.7	16.6
S-avg%Damage by Len.	26.4	11.6	7.1	9.1	19.6

Springfield High School, Springfield, MA
Spectral Data from Samples Submitted by Naomi Volain



Index	1736S	2071N	2071S	2072N	2072S	2073N	2073S	2076S
REIP	723.9	731.6	731.6	731.6	723.9	727	723.9	725.4
NDVI	0.843	0.85	0.863	0.865	0.842	0.852	0.86	0.852
TM54	0.441	0.422	0.419	0.432	0.448	0.441	0.431	0.454
NIR31	0.8	0.78	0.784	0.79	0.813	0.787	0.786	0.813

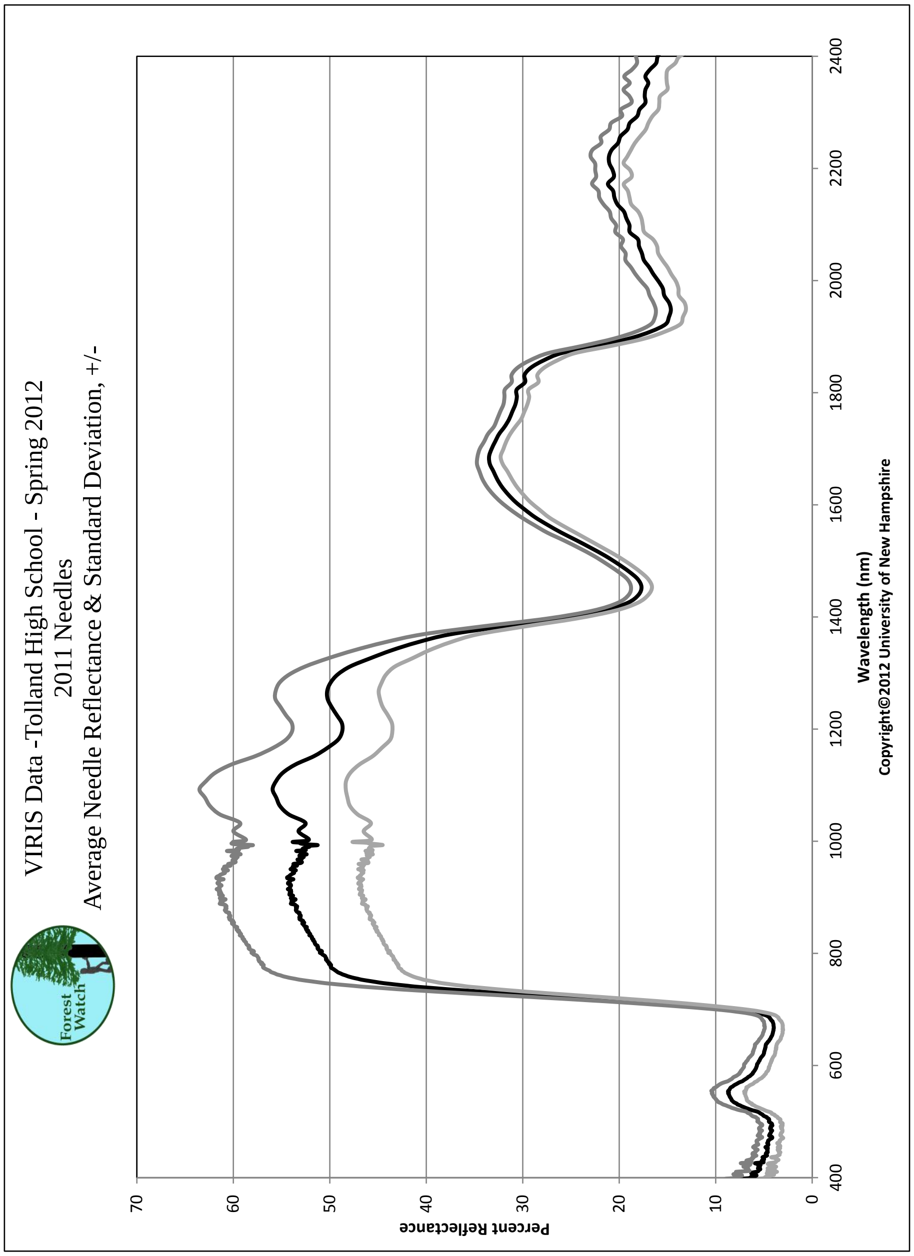


March 2012 readings										
	1806n	1806s	1807n	1807s	1808n	1808s	1809n	1809s	1810n	1810s
REIP	713.1	708.5	710	716.2	713.9	713.1	711.6	710	716.2	719.3
NDVI	0.816	0.82	0.81	0.828	0.817	0.816	0.784	0.825	0.808	0.845
TM54	0.529	0.538	0.571	0.559	0.635	0.6	0.533	0.512	0.498	0.484
NIR31	0.851	0.88	0.896	0.896	0.898	0.908	0.86	0.843	0.843	0.84

St. Johnsbury School, St. Johnsbury, VT
Biometric and Spectral Data

NeedleYear	2011				
CollectionDate	2/14/2012				
Submitted by	Otto	Wurzburg			
TreeNumber	**1551**	**1552**	**1553**	**1554**	**1555**
N-Coll-Ht (m)	9.2	9.2	9.2	9.2	9.2
S-Coll-Ht (m)	9.2	9.2	9.2	9.2	9.2
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len (mm)	73	84	84	82.5	89
S-AvgNeed-Len (mm)	71	88	83	85.5	88
N-PerTipNec	6	16	6	0	0
S-PerTipNec	3	10	20	0.2	3
N-PerChlMot	13	13	3	0	0
S-PerChlMot	0	16	13	0	3
N-AvgTotDamg-Len	3	3	0.5	0	0
S-AvgTotDamg-Len	0.2	0.8	7	0	0.4
N-PerNeedBothSymp	3	6	0.3	0	0
S-PerNeedBothSymp	0	0	0	0	2
N-AvgPerDamage	4	3	1	0	0
S-AvgPerDamage	1	1	8	1	0
N-avg%Damage by Len.	4.1	3.6	1.0	0.0	0.0
S-avg%Damage by Len.	0.0	1.0	8.4	0.0	1.0

Tolland School, Tolland, CT
Spectral Data from Samples Submitted by Fred Szezciul



Index	1751N	1751S	1752N	1752S	1753N	1753S	1754N	1754S	1755N	1755S
REIP	723.9	723.9	723.9	728.5	720	716.2	728.5	723.9	731.6	720.8
NDVI	0.822	0.825	0.867	0.876	0.811	0.847	0.855	0.849	0.861	0.851
TM54	0.52	0.513	0.607	0.594	0.764	0.653	0.609	0.669	0.645	0.559
NIR31	0.884	0.869	0.949	0.909	0.978	0.99	0.937	0.933	0.986	0.932