FOREST WATCH DATA BOOK 2010-2011

Published January 2012

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 (at or above 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.

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. 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 2010.

K-12 students, teachers and UNH scientists have collaborated to build a 20-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. Based on Forest Watch data, white pines have become healthier over these two decades until 2010.

2010 Needles

Current data presented in this report was collected by participating schools in either the fall of 2010 or the spring of 2011. These data are based on first-year needles which matured during the summer of 2010. The information in this booklet represents the work of students who have collected forestry data from 74 white pines near 15 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 20 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).

Chapter Three summarizes the tropospheric ozone conditions in New England in both 2010 and 2011. We discuss new research regarding changing conditions which produce tropospheric ozone. This chapter also introduces another powerful atmospheric pollutant, peroxyacetyl nitrate. This chapter lays the groundwork for both spectral and biometric measures presented in Chapter 4 and 5.

As always, the Data Book presents our analysis of spectral measures, including comparison of Red Edge Inflection Point (REIP) data with ozone reports, Chapter Four. 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 Five.

For the first time since Forest Watch students began collecting data, the average needle retention on our white pines has dropped below 2 years. Teachers and their students found almost no third-year needles on their trees and very few second-year needles. Is ozone the culprit? Our on-going research is continuing and we are excited to see that Forest Watch teachers and students can play a key role in seeking and finding the answer to that question.

Students can analyze Forest Watch data themselves. This year students at Concord High School and Gilmanton Middle School tackled the challenge. Their spectacular work with large data sets is presented in Chapter Six. Here, students clearly demonstrate that they can use the scientific method to pose a question, frame a hypothesis, select and build data sets to test the idea, and analyze their findings. This work also demonstrates that Forest Watch teachers are masters at adapting scientific material to the appropriate age level, skill set and interests in their classrooms.

Each school's spectral and biometric data are presented in Chapter Seven. We hope to find grant funds this year to improve access to our data files. Presently annual school data are available on the Forest Watch web site, www.forestwatch.sr.unh.edu. However, selecting sets of data for comparison between schools or across variables of the data is still a cumbersome task.

A new Chapter Eight concludes this year's Data Book. This year's findings about needle retention are worth a scientific paper for submission to a peer-reviewed journal. The Forest Watch staff will draft an article in spring 2012. Forest Watch teachers who submitted data for 2010 needles will be named as co-authors. Our new findings and the stunning work demonstrated in Chapter 5 prompts us to challenge Forest Watch teachers again. Chapter 7 identifies three new questions and protocols for research in 2012 and 2013.

One of the questions in Chapter Eight concerns the size of our white pines. At every Forest Watch site, white pines are getting bigger. At many schools, trees selected 15 or 20 years ago now tower over the forest, their branches too high for students to reach for samples, their tops too hidden in a crowded forest canopy to measure the height of the tree. Natural growth has resulted in the increased height of our pines, just as they should grow. In many cases, however, these scientific resources were not managed by our participating schools.

In 1992, no one anticipated a 20-year longevity for Forest Watch. Forest Watch provided no protocols to teachers and their administrators for thinning the forest, protecting the research trees and maintaining enough sunlight and space in study plots to allow the pines to retain their lower branches. This year, we propose that teachers and their students tackle this problem. Do they select new trees and, if so, how will the data from old trees compare with that from new trees? Will the response of younger trees to tropospheric ozone be the same as the response by original older trees? There are many exciting research questions to be answered.

Highlights of Forest Watch in 2011

Forest Watch updated its web page, www.forestwatch.sr.unh.edu, thanks to a grant from NH Space Grant Consortium and its director David Bartlett. Kristi Donahue, a designer for the Institute for the Study of Earth, Oceans and Space, designed our beautiful new pages. The site contains a new newsletter, *Twigs*. It also includes information about Maple Watch, our research concerning sugar maples and their response to climate change, as well as information and protocols for studies of tropospheric ozone and white pine. Numerous power points are posted on the site for use by students and teachers.

Forest Watch held a first Forest Watch Student Convention in May 2011. Students from Gilmanton School and Josiah Bartlett School came to UNH to display projects and to talk about their research. Gilmanton's outstanding work with Forest Watch white pine data is discussed in Chapter 5. Bartlett students presented projects from their sugar maple research. A pilot school in Maple Watch, Bartlett is helping us to develop curricula and activities for research regarding sugar maples and their response to climate change.

Teachers from Kittery, Maine, Keene, NH, and Lowell, MA, took our Forest Watch training in August. Another team of teachers from rural schools in Coos County, NH, learned about Forest Watch field techniques in a program presented by the Department of Education, UNH.

The New Hampshire Space Grant Consortium funds Forest Watch. This year, we presented highlights of our 20 years of work to a regional meeting of New England Space Grant Consortia. The meeting in Portsmouth was a farewell for longtime Forest Watch advocate Dr. David Bartlett, and a welcome for Space Grant's new director, Dr. Toni Galvin.

In October, 18 Forest Watch teachers met with UNH researchers and other educators to brainstorm future funding and directions for Forest Watch. Dr. David Moss, who studied at UNH under Dr. Rock, is now professor of Education at the University of Connecticut. David is developing plans for a grant that would take Forest Watch ideas into urban schools in New Haven, CT. Dr. Annette Schloss, developer of Picture Post and the DOME project at UNH, may ask Forest Watch teachers for help with a "virtual" forest program. As educators and scientists build on our shoulders, Forest Watch can support them best, perhaps, with continued and new research into our forest's key species and their health.

As this year's Data Book demonstrates, Forest Watch teachers and students are engaged in real science. We do not know the answers when we ask, "Why are some white pines healthier than other white pines?" As we discuss in this Data Book, the Forest Watch long term study allows us to make some statistically sound conclusions but it also allows us to question those conclusions and open up new areas of study. Some of our assumptions are beginning to face challenges. Thanks to Forest Watch students and teachers and this vast data base, we know the path to follow to find answers. 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 2010 Studies

Connecticut	Town	In Forest Watch since…	# Trees Reporting
RHAM High School – Frank Schmidt	Hebron, Andover, Marlborough	1997	5
Tolland High School – Fred Szczesiul	Tolland	2008	5
Maine			
Morse High School – Carolyn Nichols	Bath	2008	5
Massachusetts			
Hanson Middle School – Wes Blauss & Russ Young	Hanson	1996	5
Sewall-Anderson School – Louise James	Lynne	2002	5
Springfield Central School – Naomi Volain	Springfield	2007	5
New Hampshire			
Fall Mt. Regional High School – Bill Doran	Alstead, Acworth, Charlestown, Langdon, & Walpole	1999	5
Gilmanton Middle School – Mary Fougere	Gilmanton	1993	4
Lyme School – Skip Pendleton	Lyme	1994	5
New Hampton School – Jon Shackett	New Hampton	2003	5
Salem High School – Norma Bursaw	Salem	1994	5
Sant Bani School – Robert Schongalla	Sanbornton	1992	5
Souhegan High School – Melissa Chapman	Amherst	1993	5
Vermont			
St. Johnsbury School – Otto Wurzburg	St. Johnsbury	1997	5
Weathersfield School – Diana Day	Ascutney	2008	5
Number of Trees			**74**

Chapter Two – Ozone Basics

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

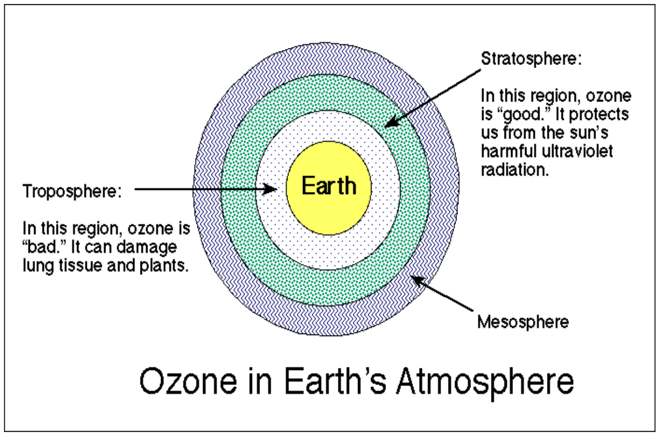


Figure 2.1: Ozone occurs in both the troposphere and the stratosphere. The Earth’s entire atmosphere is about 80 km thick. The troposphere is 10 to 15 km from the surface of the Earth. The next atmospheric layer is the stratosphere, 15 to 30 km thick. Beyond the stratosphere, are the mesosphere and a 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.”

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 $_{NO2}$), 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°F or more, when there is bright sun, and when

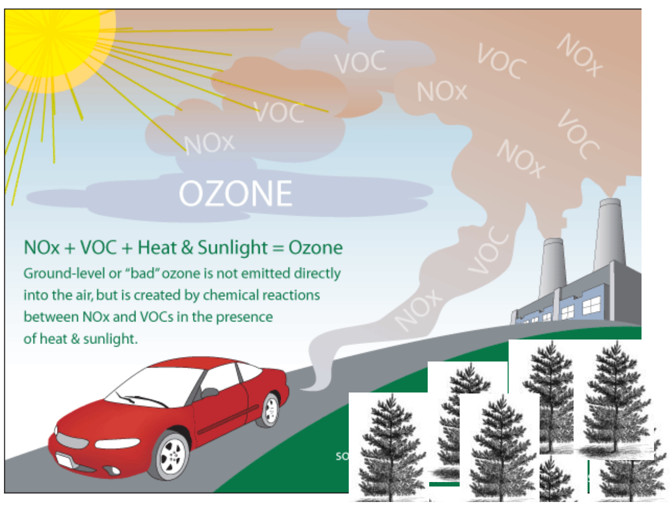


Figure 2.2: Tropospheric ozone is formed when high temperatures and bright sunlight allow NOx and VOCs to react.

NOx + VOCs in  ***and high heat =*** $\boldsymbol{O_3}$

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.

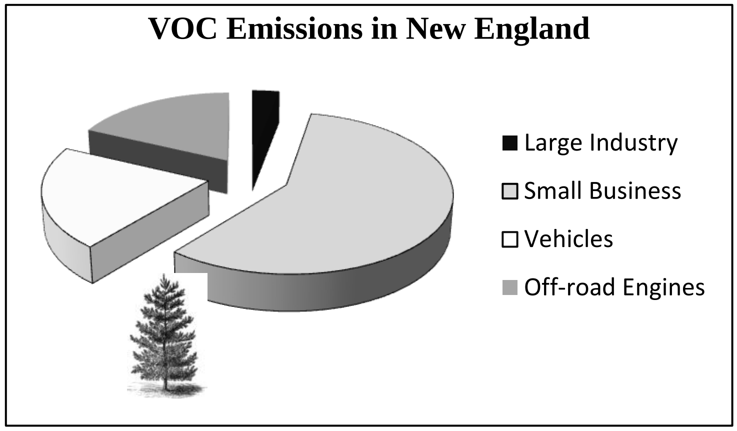


Figure 2.3: VOCs in New England come primarily from small business. Large amounts are produced by chemical plants in the mid-west. Homes also release VOCs. The New England forest also releases substantial amounts of VOCs.

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

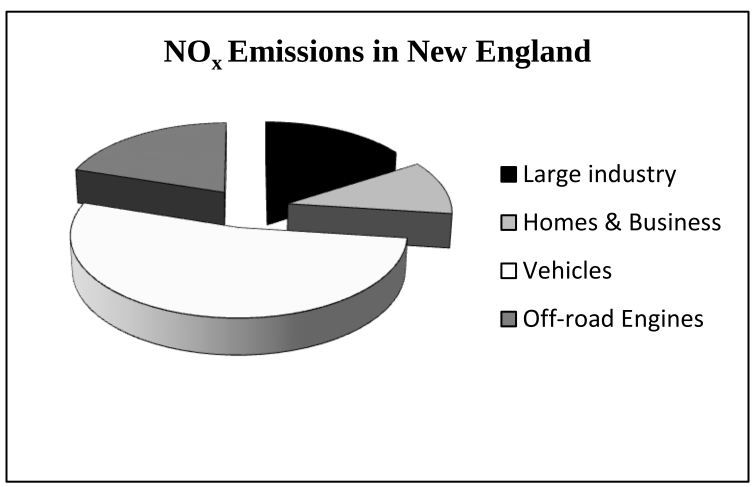


Figure 2.4: NO_x in New England is created primarily on the hot surface of automotive engines—cars and trucks in the densely populated urban corridor.

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.

Major Storm Patterns for the U.S.

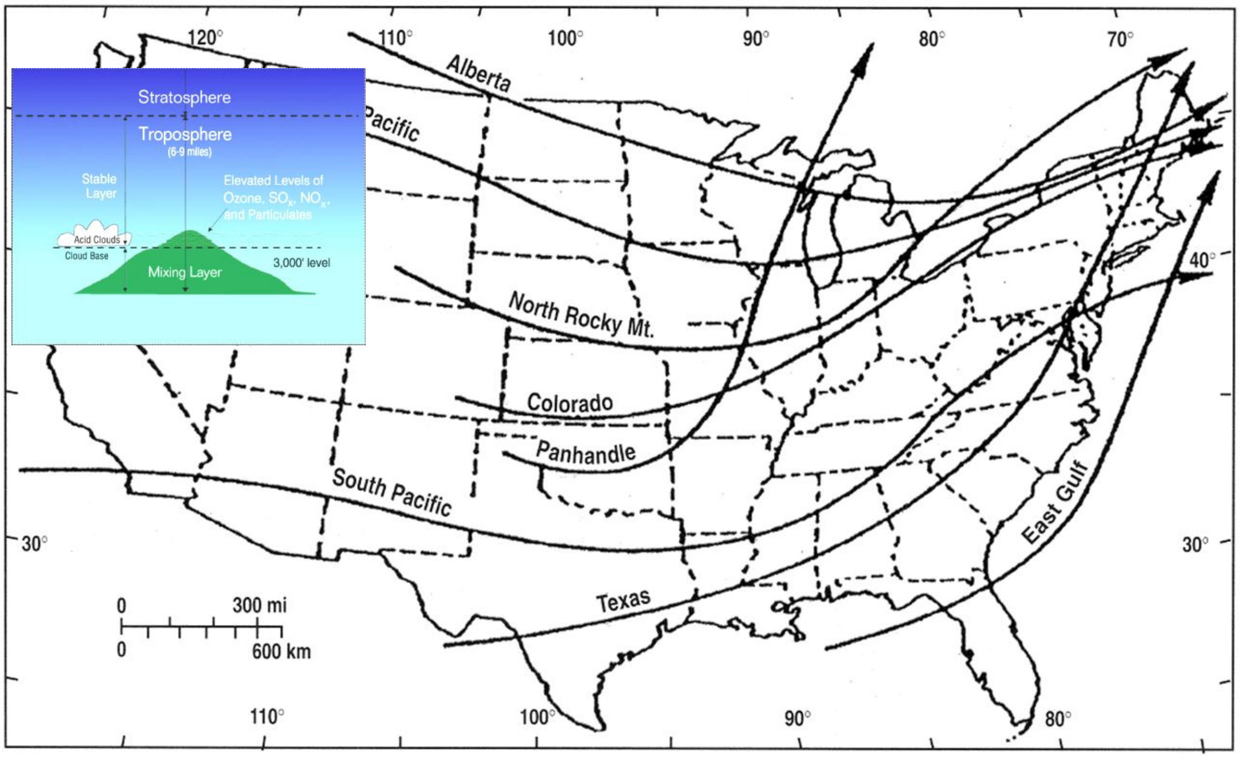


Figure 2.5: Westerly and southwesterly winds bring air pollutants from every part of the nation to New England. Pollutants are most heavily concentrated at about 3000 feet elevation.

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.

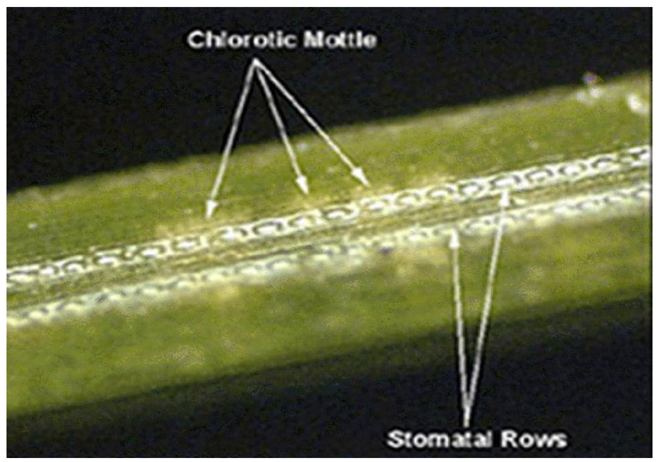


Figure 2.6: Chlorotic mottle at top and tip necrosis below are key indicators of ozone damage. Students measure both.

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.

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

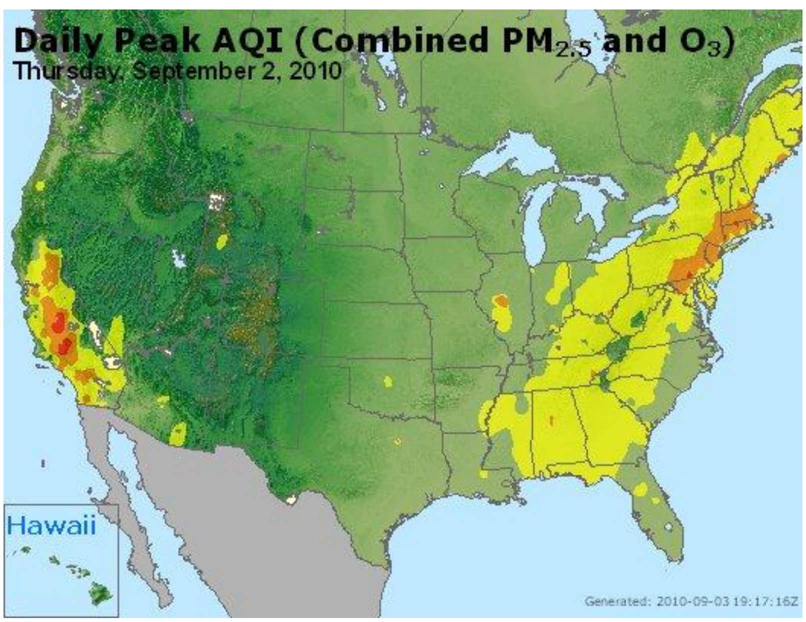


Figure 2.7: Ozone levels at peak concentrations on September 2, 2010. Temperatures sweltered in the high 90s under bright sunny skies to create perfect conditions for photochemical production of ground level ozone. Levels of ozone climbed just over 101 ppb in southern New Hampshire, enough to be of concern to infants, the elderly and people with asthma. Source: www.epa.gov/airnow/2010.

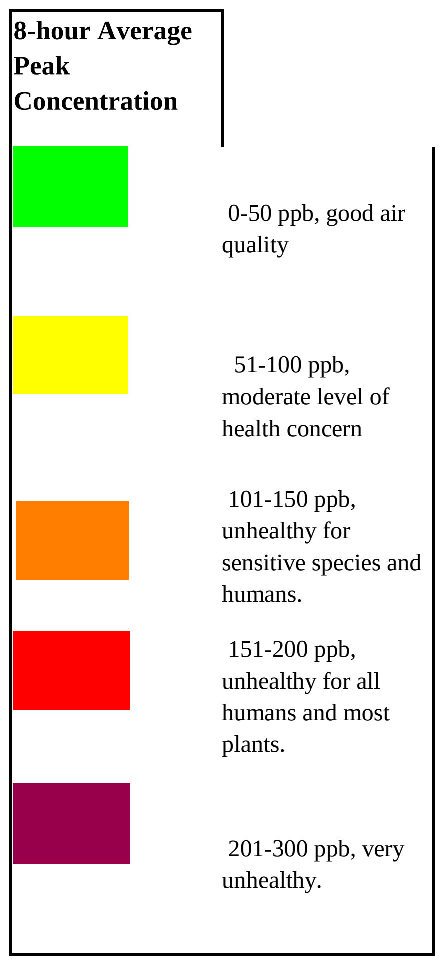


Figure 2.7 shows, levels under 100 parts per billion (ppb) are considered only moderately concerning. Levels above 100 ppb are considered to be unhealthy. During the early 1990s, levels in the low 100-150 ppb area were measured frequently on hot summer days. In 1990, the EPA set 85 ppb as the maximum allowed level. This was a goal which the EPA and 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. And, as we discuss in Chapter 3, EPA administrators have considered even tighter standards.

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.

Chapter 3
Atmospheric Chemistry in 2010-2011

Changing Ozone Conditions

The presence of tropospheric ozone and occurrences of high levels of this atmospheric pollutant appear to be changing subtly. Forest Watch studies by students and teachers open a unique window on these changes.

Each year, the Northeast experiences some degree of smog pollution depending on a complex interaction of a number of variables. One key factor in smog or ground-level ozone formation is high temperatures, at or above 90°F, making ozone primarily a summer pollutant. In the past two decades, air quality was most affected by the conditions present in June, July and August when the New England region experienced multiple days of high temperatures.

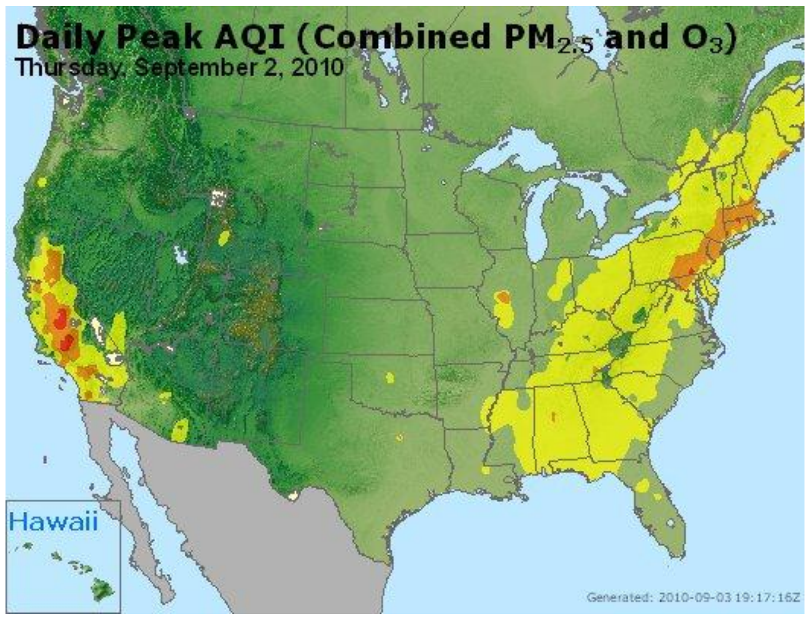


Figure 3.1: Ozone levels at peak concentrations on September 2, 2010. Temperatures sweltered in the high 90s under bright sunny skies to create perfect conditions for photochemical production of ground level ozone. Levels of ozone climbed just over 101 ppb in southern New Hampshire, enough to be of concern to infants, the elderly and people with asthma. Source: www.epa.gov/airnow/2010.

Recently, however, conditions prime for ozone production are occurring in May and September. Figure 3.1 maps ozone levels on September 2, 2010, the record for that entire year.

New research here at the University of New Hampshire is also expanding our understanding of where ozone comes from. At last year's Forest Watch annual meeting (December 2010), Dr. Robert Talbot, professor of atmospheric chemistry and director of the Climate Change Research Center at UNH, introduced us to emerging evidence that New England may be seeing reduced levels of tropospheric ozone in summer months but more frequent occurrences of higher levels of such ozone in other seasons, spring, and even winter (such as January 26, 2011). Dr. Talbot

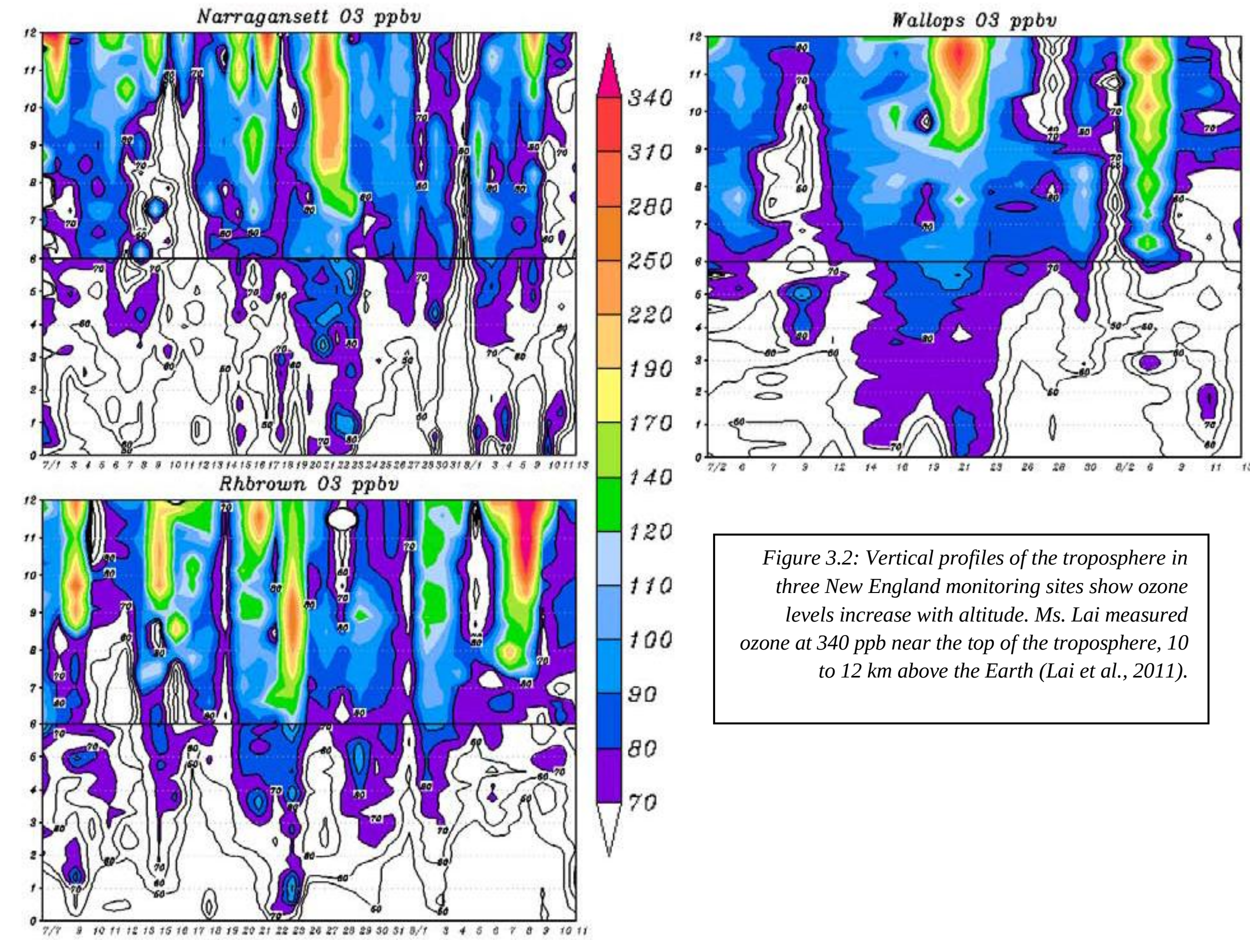


Figure 3.2: Vertical profiles of the troposphere in three New England monitoring sites show ozone levels increase with altitude. Ms. Lai measured ozone at 340 ppb near the top of the troposphere, 10 to 12 km above the Earth (Lai et al., 2011).

mentioned that he and his graduate students were studying two new ideas: infolding of ozone from the stratosphere into the troposphere and movement of ozone into New England on nighttime low-level jet stream winds.

This past November, Tzu-Ling Lai, a PhD candidate working with Dr. Talbot, presented her research. Ms. Lai focused on two episodes of high ozone: An occurrence of 151 ppb measured in Durham in August 2002 and a July 2004 occurrence of 111 ppb at Castle Springs high in the Ossipee Mountains, Moultonboro, NH. Normally, she explained, ozone levels rise when high pressure systems create "synoptic" or broad regional conditions for producing ozone, when the jet stream out of the west is on a path sweeping low over New England, and when the sea breeze is easterly (coming from the east), bringing together the chemical components, NOx and VOCs, which create ozone.

In her studies of weather, winds, pressure systems and the chemistry of the atmosphere, Ms. Lai (pronounced "lie") examined the Bermuda High, a key factor in high pressure systems that normally sit over New England in mid-summer. The Bermuda High appears to have moved off the East Coast into the mid-Atlantic. That may explain why episodes such as the 2002 high ozone day are becoming less frequent, Ms. Lai said. Instead, clouds from the Gulf of Mexico move northeast bringing New England wetter and slightly cooler summers, conditions that keep the number of ozone exceedance days low.

At the same time, high levels of ozone may be attributed to two other wind phenomena, the Appalachian lee wind and the low level jet stream. The first brings smog pollutants northeast along the eastern side of the mountains from the American metropolis to New England. The second, the low level jet stream, brings ozone from the Midwest industrial belt into New England at night.

The 2002 event which Ms. Lai studied had unusually high levels of tropospheric ozone over several days in August with levels remaining high even at night. Weather maps recorded a high pressure Bermuda high meeting a westerly high over New England during that period, providing the clear skies and high temperatures needed to produce and transport ozone. A low level jet stream brought mid-western ozone into the area at night. The two conditions, occurring simultaneously, maintained stagnant air over Durham, NH, for several days and pushed ozone levels to the 151 ppb high on August 14, 2002.

Ms. Lai also examined subsidence of ozone from the stratosphere. In her study of a July 2004 event, Ms. Lai looked at data recorded at Castle Springs, another AIRMAP monitoring station. Castle Springs sits at 400 meters elevation on a mountain ridge overlooking Lake Winnipesaukee. Regional or synoptic barometric pressure systems fell very low on the July day in 2004 which Ms. Lai studied. The 111 ppb measured at Castle Springs was not a measure of ozone produced locally, she believes. Instead, that ozone poured down out of the stratosphere, an infolding from the cold high atmospheric vault where ozone is produced, stored and transported long distances from its source. In a study of the vertical profile of the atmosphere (Figure 3.2), Lai found levels of ozone as high as 340 ppb at 10 to 12 km in the upper troposphere. Such subsidence of stratospheric ozone has only been discovered recently; researchers believe it may contribute as much as 23% of the ozone measured in the troposphere during the summer (Lai *et al*., 2011).

Additional ozone was contributed to the Castle Spring site by winds moving northeast from Virginia along the protected lee-side or eastern side of the Appalachians. Chemicals found in industrial and urban pollution, carbon monoxide, NOx, carbon chloride, acetone, benzene and others were measured at twice or three times normal levels at Castle Springs during this event, confirming that the chemical compounds in the air were of East Coast urban origins.

Ms. Lai's research poses exciting challenges for Forest Watch teachers and students. Wind patterns, high pressure systems and seasonal norms are changing. High levels of ozone might occur at almost any time in the year. Could Forest Watch schools monitor individual ozone exceedance events? Could they monitor white pine needles once a month? Would we be able to see an increase in chlorotic mottling or tip necrosis on first year needles over the course of the school year? If students did identify a change, could their data be used to alert research scientists to look for correlative ozone events at nearby monitoring stations (if they were operating)? Could student research help researchers keep ozone monitoring stations open year-round rather than just in the summer months, as is currently done at many stations? We discuss this possibility more in Chapter 8.

Ozone Exceedance Days

Examining 2010 data, ozone measurements which exceeded federal standards were higher in that year than in 2009. Hot dry weather in New England increased the number of exceedance days over what we saw in the rainy cloudy summer of 2009. In 2011, more rainy weather again reduced the exceedance days (Table 3.1 and Figure 3.3).

Table 3.1: Exceedance days 2000-2011 by New England State (EPA, 2011) ** indicates recent figures are subject to further analysis.*

Year	CT # days >		ME # days >		MA # days >		NH # days >		RI # days >		VT # days >	
	84 ppb	**75 ppb**	**84 ppb**	**75 ppb**	**84 ppb**	**75 ppb**	**84 ppb**	**75 ppb**	**84 ppb**	**75 ppb**	**84 ppb**	**75 ppb**
2000	13	23	3	5	5	16	1	5	8	14	1	2
2001	26	39	15	22	27	37	11	22	15	26	2	9
2002	36	49	17	28	30	43	13	23	17	33	5	13
2003	14	26	5	15	11	27	1	10	10	13	0	4
2004	6	20	1	11	8	16	5	10	4	5	2	4
2005	20	30	5	15	17	31	4	17	8	17	0	4
2006	13	29	2	10	12	26	2	10	3	13	0	0
2007	17	42	8	14	20	38	6	22	8	18	1	5
2008	8	22	0	3	8	18	2	8	4	6	1	3
2009	2	6	2	3	2	7	1	2	0	1	0	0
2010	8	24	2	6	4	15	0	9	1	6	0	0
2011*	10	14	2	3	5	10	1	2	0	6	0	1

Table 3.1 lists the number of exceedance days against early EPA national ambient air quality standards of 85 ppb and present standards of 75 ppb. Vermont had zero exceedance days in 2010. There were very few exceedances over 85 ppb, the less stringent standard. The highest number of exceedances occurred in Connecticut and Massachusetts where urban corridors and dense populations result in the highest levels of reactive nitrogen gases which form on the surfaces of hot automobile engines and power generators. Also note that the new standard (75 ppb) often more than doubles the number of exceedance days for each state.

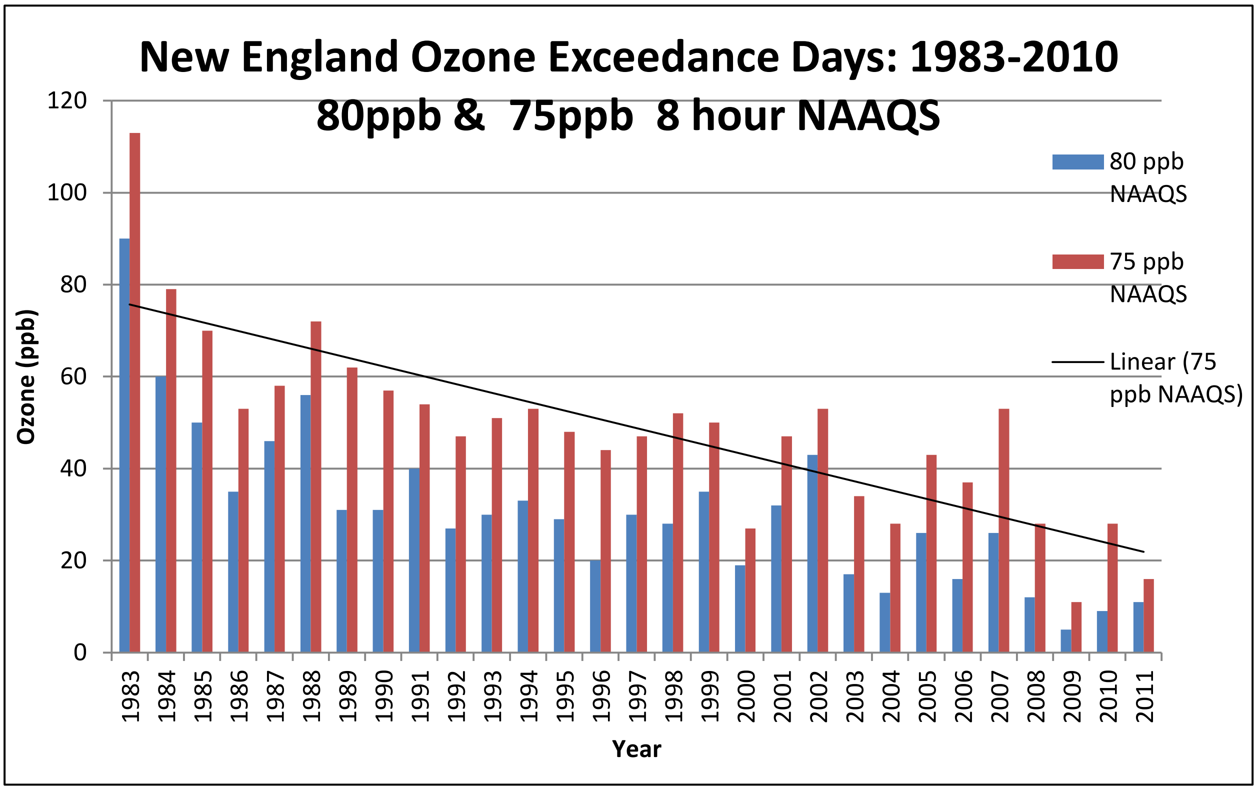


Figure 3.3: Exceedances continue a trend of fewer and fewer occurrences at lower and lower levels (EPA, Region 1, airquality) To allow for comparison of new national ambient air quality standards (NAAQS) against old standards, the EPA adjusts historic measures to fit new standards. We discuss this more in Chapter 4.

A Call for Tighter Standards

Despite the improvement in air quality over the past two decades, scientists and environmentalists believe our national ambient air quality standards should be even tighter than the 75 parts per billion (ppb) level set by the Environmental Protection Agency in 2008. Only a year later, the EPA proposed “to strengthen the 8-hour ‘primary’ ozone standard” to a level within the range of 60-70 ppb. EPA administrator Lisa Jackson recognized ground level ozone as a serious air quality problem. In New England the 75 ppb standard, an improvement over previous standards (80 ppb), was exceeded an average of 31 days each summer 2006 to 2010. The EPA announced in 2010 that it would set the new lower standard in July 2011.

July 2011 came and went. Then on September 2, 2011, President Barack Obama announced that the 75 ppb standard would remain unchanged. The decision was controversial.

Earlier last summer, scientists in Europe published reports warning that tropospheric or ground-level ozone levels will rise due to climate change and rising populations. The productivity of food crops, particularly in central Europe, could be reduced, a Swedish research team claimed (*ScienceDaily*, June 30, 2011). The European Respiratory Society’s Annual Congress warned that deaths caused by ground level ozone may increase by 10 to 14 percent over the next 50 years (*ScienceDaily*, September 27, 2011).

September 02, 2011

Statement by the President on the Ozone National Ambient Air Quality Standards

Over the last two and half years, my administration, under the leadership of EPA Administrator Lisa Jackson, has taken some of the strongest actions since the enactment of the Clean Air Act four decades ago to protect our environment and the health of our families from air pollution. From reducing mercury and other toxic air pollution from outdated power plants to doubling the fuel efficiency of our cars and trucks, the historic steps we’ve taken will save tens of thousands of lives each year, remove over a billion tons of pollution from our air, and produce hundreds of billions of dollars in benefits for the American people.

At the same time, I have continued to underscore the importance of reducing regulatory burdens and regulatory uncertainty, particularly as our economy continues to recover. With that in mind, and after careful consideration, I have requested that Administrator Jackson withdraw the draft Ozone National Ambient Air Quality Standards at this time. Work is already underway to update a 2006 review of the science that will result in the reconsideration of the ozone standard in 2013. Ultimately, I did not support asking state and local governments to begin implementing a new standard that will soon be reconsidered.

I want to be clear: my commitment and the commitment of my administration to protecting public health and the environment is unwavering. I will continue to stand with the hardworking men and women at the EPA as they strive every day to hold polluters accountable and protect our families from harmful pollution. And my administration will continue to vigorously oppose efforts to weaken EPA’s authority under the Clean Air Act or dismantle the progress we have made.

When we consider the EPA standards, a change from 75 ppb to 65 ppb seems small. How could another 10 parts per billion matter?

The new ozone standard of a top range between 60 and 70 ppb would have been stricter. The EPA estimated in January 2010 that while 515 counties in the United States violated a 70 ppb limit between 2006 and 2008, 650 violated a 60 ppb standard during that same period. Just the slight change in the standards from 80 ppb to 75 ppb produced some significant changes in the number of days considered unhealthy here in New England. As Table 3.1 shows, the number of days in exceedance more than doubles in some years when standards for 8-hour exceedance levels of ozone drop just 10 ppb. The new standard of 60 to 70 ppb would have provided even stricter health standards but at a higher economic cost.

Tighter standards would also prompt changes in monitoring ozone and in the designing of engines that produce reactive nitrogen gases. In 2010, the EPA hoped to allocate funds to build 270 more ozone monitoring stations to add to the present 1200 in the United States. The agency wanted to build the new monitoring sites closer to major roadways. Ozone may be much higher near highways than we currently see in rural sites such as Castle Springs, a wooded mountain site, or on the Thompson Farm in Durham. The new standards would also have forced engineers to design generators and engines that burn more efficiently at cooler temperatures, reducing NO_x production but adding to the cost of power generation and automobile manufacturing.

Rising Temperatures and Growing Populations Mean More Ozone

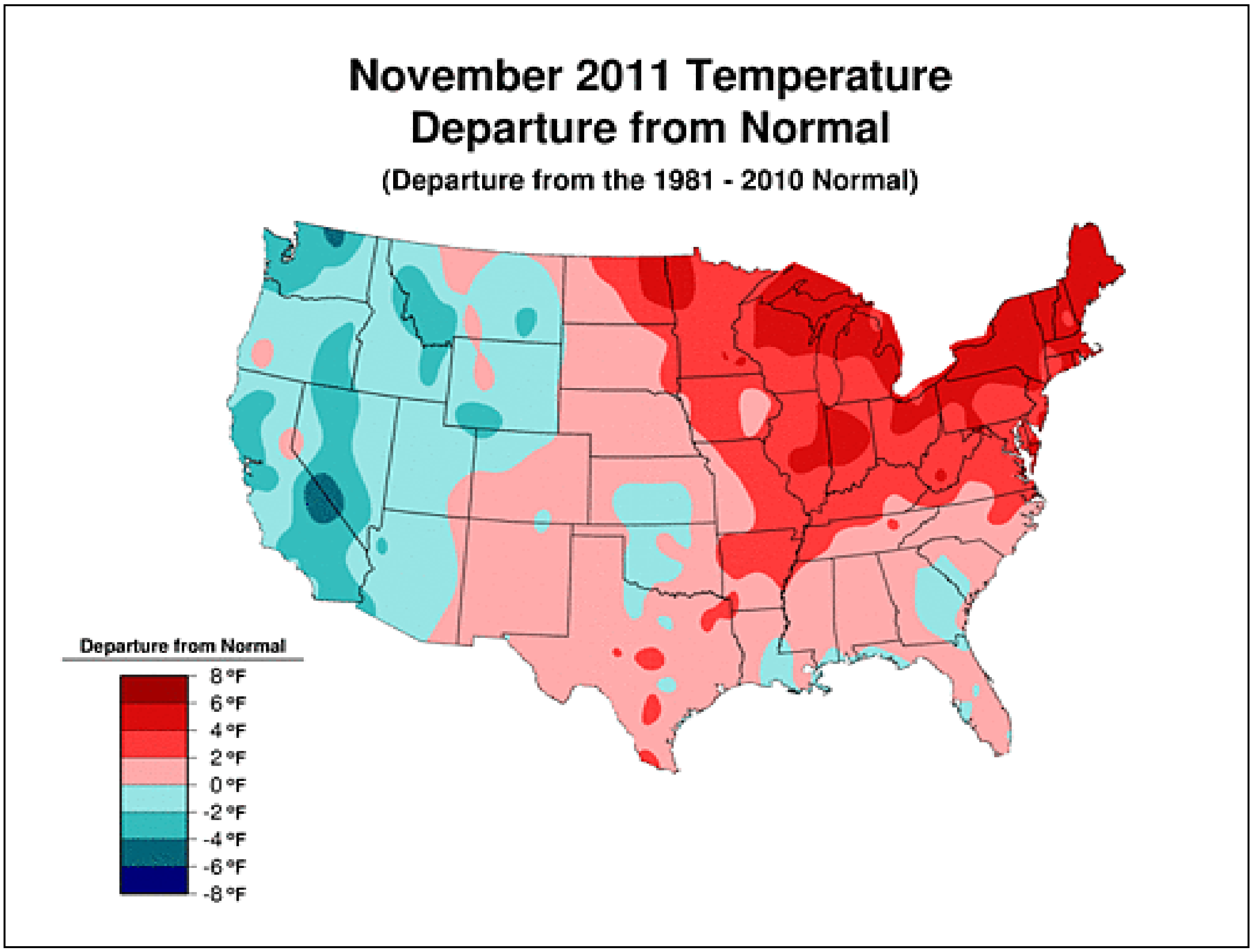


Figure 3.4: November 2011 was the hottest November on record in New England. Mean temperatures for the month were 6 to 8^{o} F above normal temperatures over the last 30 years. (www.ncdc.noaa.gov. departure *from norms.*

Stricter standards may become increasingly necessary as temperatures rise and as human beings produce more NOx and more VOCs.

Records of temperature data indicate that this decade has been the hottest on record with an increasing number of days with temperatures at or above 90^{o}F and even above 100^{o}F. The EPA released a report on climate change in 2009 in which the agency estimated that warming temperatures and other changes in weather patterns are likely to create more low level ozone in many regions of the United States (EPA, 2009). In 2010, Concord, NH, recorded 20 days when temperatures climbed above 90^{o} F. The average historic number of hot summer days for Concord is 11. In 2010, summer was hotter than normal by 6 to 8^{o}F across the Eastern Seaboard. Three of those days were in May and September, months in which the EPA monitoring stations generally do not record ozone levels under the assumption that it is not supposed to be that hot in spring and fall.

In 2011, temperatures in April, May, August and October were 1 to 2^oF hotter than normal, records from the National Center for Climate Data report. In July and September, temperatures climbed as many as 4^oF above normal over the last 30 years. In November, 2011, temperatures broke records, soaring 6 to 8^oF above historic norms even in northern New England (Figure 3.4).

The entire decade has been hotter than usual with many record-breaking hot days and months. High heat and clear skies are the key conditions for photochemical mixing of reactive nitrogen gases with volatile organic (VOCs). Swirled on the southeasterly sea breezes, the NO_x and VOCs produce ozone.

A second reason why environmentalists argue that the EPA should have imposed stricter standards this year is that we are producing more hot engines to make more NO_x. In the past decade alone, the number of vehicles on American roads has climbed by 11 million, a 4.25 million increase. Add to that the leaf blowers, lawn mowers, four-wheelers and other engines we produce and buy. There may also be more VOCs as growing human populations and rising economics build demand for paint, ink ,glue, fabric softener, wallboard and other products that contain and release VOCs. Warming due to rising temperatures, even the forests may release more VOCs.

PAN, Another Atmospheric Concern

In Chapter 2, we mentioned that ozone is only one of a number of atmospheric oxidants, chemicals which steal electrons from other molecules. Conditions in part of New Hampshire in late May 2010 appear to have been perfect for production of peroxyacetyl nitrate (PAN).

A stand of sugar maples (*Acer saccharum*) was defoliated on May 26, 2010, by an atmospheric event which appears to have been exposure to a compound we have identified as PAN. Rarely described in rural forest areas, PAN appears to have been the product of extensive forest fires in Quebec, a northerly wind which brought reactive nitrogen compounds and hydrocarbons south into New Hampshire, and record temperatures and intense sunlight at the site. A short-lived photochemical in warm conditions, the PAN is formed *in situ*; it affected a narrow zone of maples between 1700 feet and 2000 feet on the northeast- facing slopes of Bald Mountain, West Campton.

Examination of leaves and leaf morphology finds foliar damage matching PAN damage rather than frost or ozone damage. The leaves appeared to have been dipped in bronze. Some leaves were partially damaged on their tips. Others at higher elevations were completely bronzed and fell off the trees the next day. Stomates on the damaged leaves appeared to have been burned as if by tiny cigarettes, a sign that a powerful oxidant entered the stomates.

Within a few weeks, the maples produced new leaves. The partially damaged trees produced new leaves but also retained damaged leaves. Partially damaged leaves sealed off damaged areas and produced higher than normal chlorophyll levels in remaining cells. New leaves showed unusual morphology and were sensitive later in the season to ozone damage, unusual for maples.

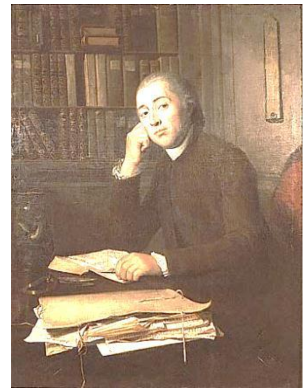
Damaged trees produced two to three times the normal number of buds yet leaf numbers and foliage health appear normal in 2011. In fact these trees had high spectral measures of health in 2011. While most maples produced seeds in 2011, the Bald Mountain maples did not, husbanding their strength for leaves.

This chance observation of an unusual event highlights the increasing occurrence of high heat and drought in springtime, the increase in boreal forest fires in the northern hemisphere, and consequent air pollution events which may occur in rural areas. The event introduces another stressor to the list, heat, drought, storms, which are consequences of climate change and which threaten to extirpate species such as *Acer saccharum* in much of its range. Our study reveals the remarkable resilience of the sugar maple under extreme stress. The chance discovery of this event illustrates the need for trained citizen scientists who may observe, report and help document such occurrences.

Did the Quebec fires and attendant air pollutants have any effect on white pines? We discuss this question further in Chapter 5.

Chapter Four - Spectral Measures of 2010 Needles

Reading Light



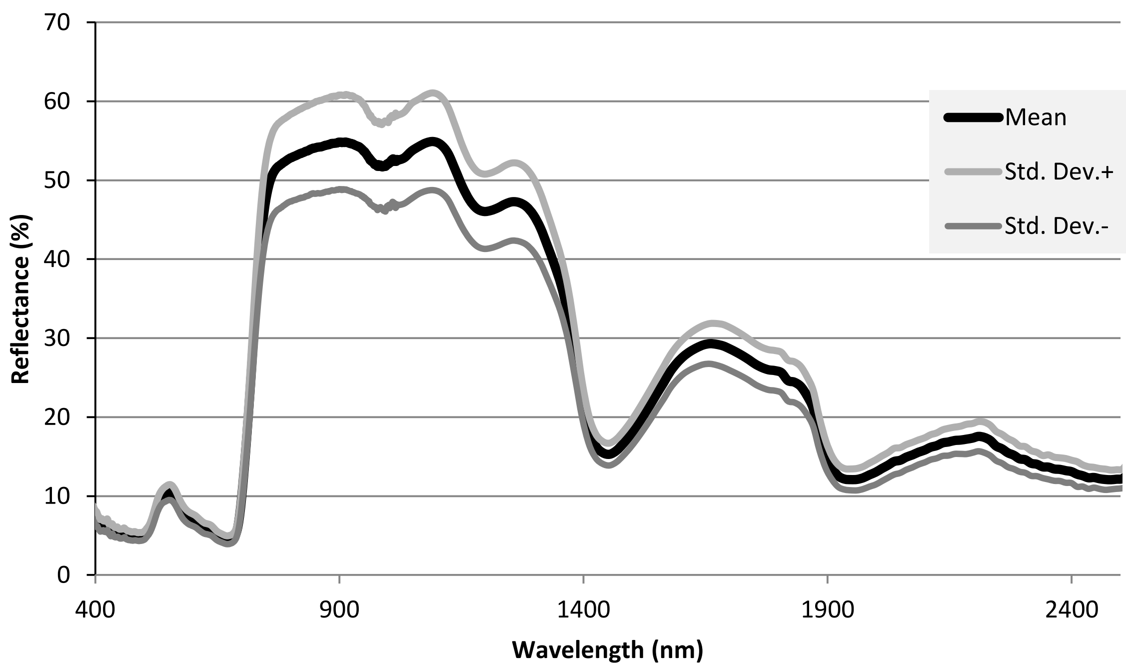
Rene Senebrier

Light is at the center of Forest Watch studies. Light is the key ingredient for life. Only 200 years ago, French scientist Jean Senebrier proposed that it is the light of the sun, not the heat of the sun, which promotes plant growth. Scientists are still unraveling the complex processes which we call photosynthesis. Forest Watch teachers and students are on the cutting edge of science, learning with scientists how plants and light work together to make plants grow.

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 because those 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 3.1) we can learn how much chlorophyll the needles contain, whether the needles contain

Figure 4.1: Reflectance - All Trees 2010
Means & Standard Deviations



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.

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 Ziplock bags and ship them overnight to UNH. We select from these needle samples only first year needles (in this case, 2010 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 (Figure 4.2). Areas on this spectrum are named for the bands of light measured by a satellite, the Thematic Mapper (TM) 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.

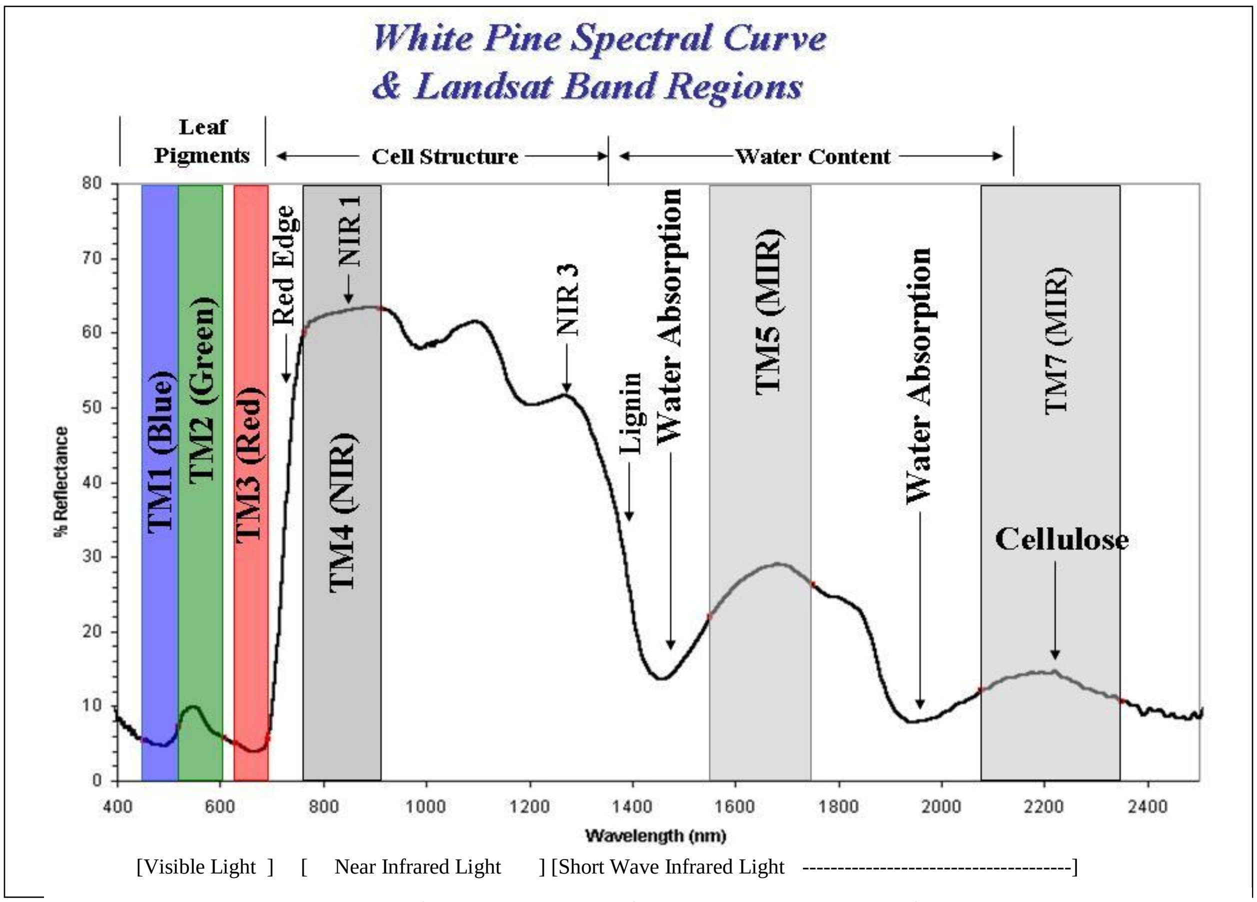


Figure 4.2:shows visible light, near infrared and short wave infrared light. TM bands are identified by number as they are in Landsat imagery sets as well as by the information they provide as to plant conditions.

On the left side of the spectrum, visible light shown in Figure 4.2, 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 4.2). 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 absorption. Lower REIPs indicate less chlorophyll in stressed or aging leaves or needles.

Figure 4.2 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.

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 flushed 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 3.1. 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.

The slope of the near infrared plateau in Figure 4.1 is slanted to the right, to longer wavelengths, showing a higher NIR 1 than the NIR 3. Even without calculating the ratio of NIR3/NIR1, Dr. Rock could surmise that the needles are young (after all, we know they are one-year-old needles).

The TM 5/4 ratio, deciphering water content takes a bit more practice. But deep valleys (the water absorption features at 1400 and 1900 nm) on either side of the TM5 area indicate we will probably get low ratios and healthy water content indicators when we do the math.

Reflectance Index	Number
All Needles from 74 trees, 2010	
Red Edge Inflection Point (REIP)	723.69
TM Band 5/TM Band 4 Ratio (TM54)	0.52
Near Infrared Band 3/Band 1 Ratio (NIR31)	0.85

Table 4.1: VIRIS indices for white pine needles, 2010.

Precise readings from the VIRIS give numerical accuracy to those interpretations. Table 4.1 shows the three major indices of reflectance and plant health which we use in Forest Watch (there are 81 different indices). All 74 trees monitored in the past year show high REIPS of more than 720 nanometers. All show young needle tissue with NIR 3/1 ratios in the 80% region. And all show high water content with TM 5/4 ratios at or under 55%.

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 4.3 shows. As the Red Edge Inflection Point rises, moving to longer

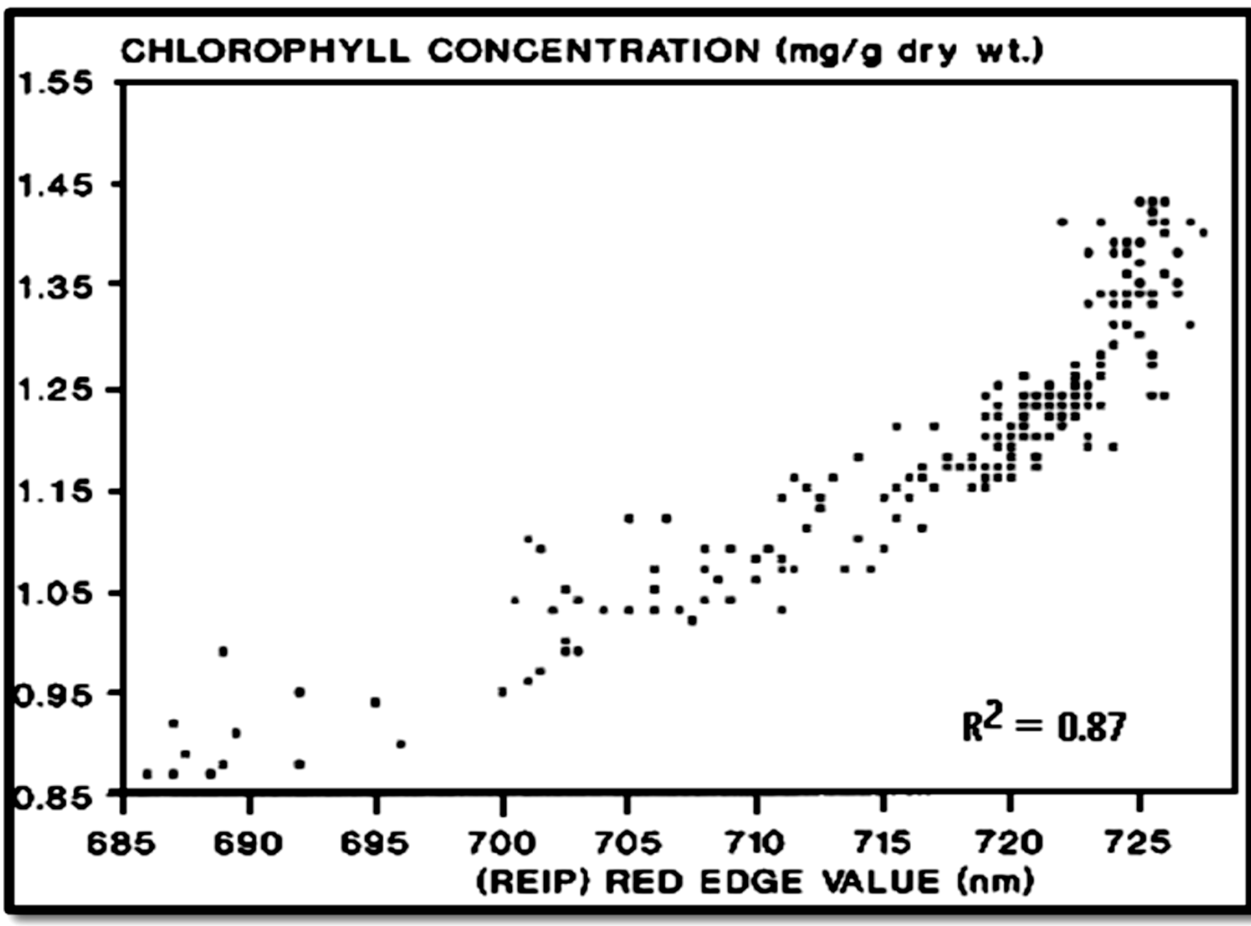


Figure 4.3: A positive correlation between chlorophyll and REIP (Moss & Rock, 1991.)

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

We would expect to see a negative or inverse correlation between water content and the TM5/4 ratio. Forest Watch students often calculate water content by weighing fresh pine needles, drying them for several days and then weighing them again. The difference in mass can be used to calculate percent water content.

This past year, students in five schools dried needles and calculated water content. Graphing their results with the TM5/4 ratios for the same trees as shown in Figure 4.4. All of these white pines are healthy and have plenty of water. White pines can do just fine in dry sandy soils and long dry spells in winter. So this chart shows wide variability in points. Perhaps we would need more samples, including some unhealthy ones or some second or third-year needles to see a clear trend in TM5/4 and water content. Low water content percentages would show higher TM 5/4 ratios. The key point in this chart is that, despite their differences, all trees in 2010 show healthy water content and low TM5/4 ratios.

This year, the 74 trees sampled on north sides and south sides produced very similar VIRIS scan indices. Table 4.2 presents the REIPs by state. All trees in all five states show healthy levels of chlorophyll. Students may want to compare their school or state's VIRIS data with data from other schools and states or look back for historic comparisons. Why are some schools' REIPs slightly higher than others? A geographic explanation is hard to see when Morse on the Maine coast has REIPs as high as Amherst, NH, or St. Johnsbury, VT. Why are some school's REIPs lower? Did other trees shade those trees' needles? Perhaps students who know their trees can hypothesize answers.

Table 4.2: REIP Summary by State
2010 Needles - Fall and Spring Samplings

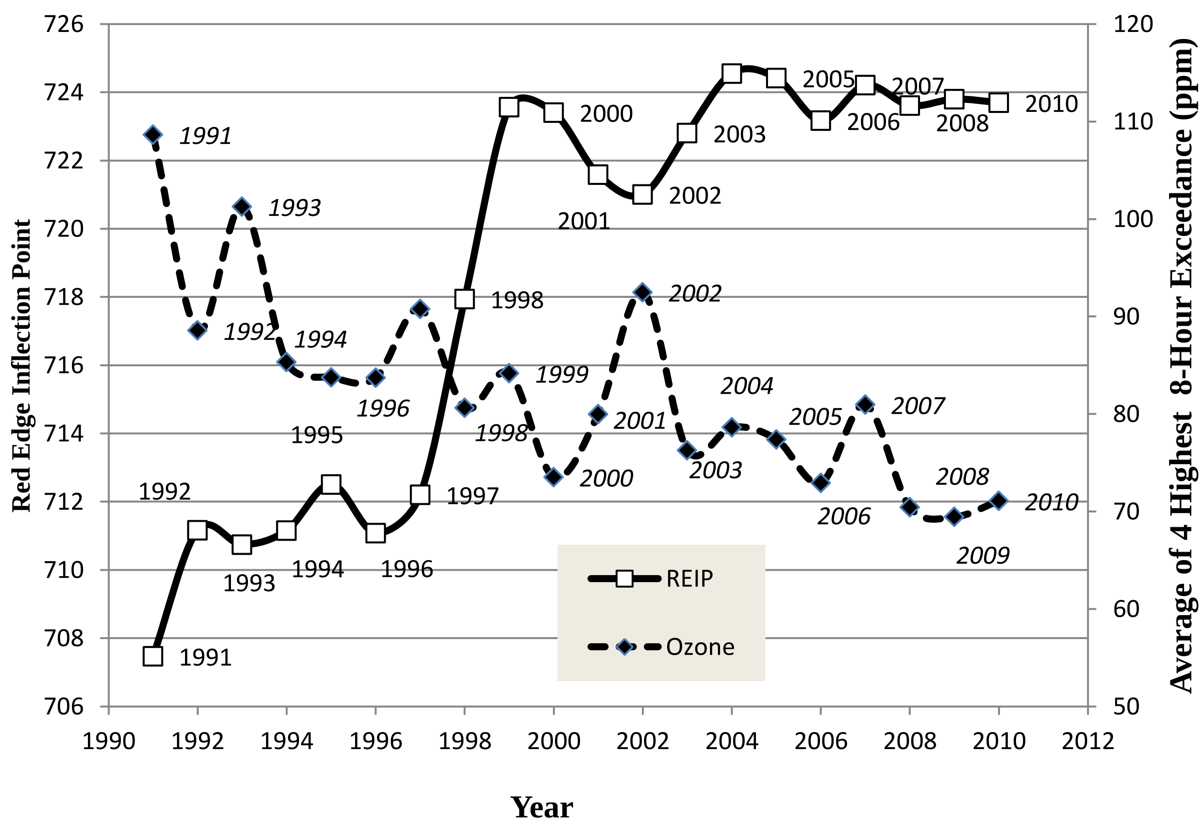
State: CT		Avg. REIP	Std. Dev.	# Trees
RHAM High School		724.0	1.28	5
Tolland High School		722.1	1.79	5
	State Average	723.0	1.53	
State: ME				
Morse High School		725.4	1.68	5
	State Average	725.4	1.68	
State: MA				
Hanson Middle School		723.7	1.60	5
Sewall-Anderson School		724	2.32	5
Springfield Central School		722.8	5.44	5
	State Average	723.5	3.12	
State: NH				
Fall Mt. Regional High School		725.8	1.92	5
Gilmanton Middle School		723.5	0.65	4
Lyme School		722.2	4.50	5
New Hampton School		725.0	2.59	5
Salem High School		723.0	4.10	5
Sant Bani School		721.1	3.65	5
Souhegan High School		725.5	1.76	5
	State Average	723.7	2.74	
State: VT				
St. Johnsbury School		725.7	1.79	5
Weathersfield School		723.4	2.79	5
	State Average	724.6	2.29	
New England Regional Average		**723.8**	**2.52**	
Number of Trees				**74**

The Ozone Correlation

Since 1991, when Forest Watch began, the chief correlation our research examines is one between the REIP of needles and ozone levels during the same growing season. Over the past 20 years, the Environmental Protection Agency has changed the way it monitors ozone exceedances and even the way it calculates an average for the year. Maintaining data that is accurate and calculating averages the same way over 20 years can be a challenge.

We used to average the annual ozone maximum by selecting the top ozone occurrences in seven air quality monitoring stations around New Hampshire for three months: June, July and August. In 2005, the EPA changed its way of calculating ozone exceedances to 8-hour periods, not 1-hour periods. That changed the averages. As more exceedances occurred in April, May and September, the EPA changed again to list the top four exceedances for the year. Again, annual averages appear to have changed slightly. Rather than adding new data to old charts, we have reworked the entire chart, using revised EPA data for the period from 1991-2010. The results are shown in Figure 4.4.

Figure 4.4: Needle Health Against NH Ozone, 1991-2010



The Forest Watch inverse correlation between REIPs (chlorophyll) and ozone concentrations still holds (Figure 4.4). In 1991, when ozone levels were very high, over 100 ppm for the season, REIPs were low. White pines had RIEP values below 712 nm, levels generally seen in aging and highly stressed foliage.

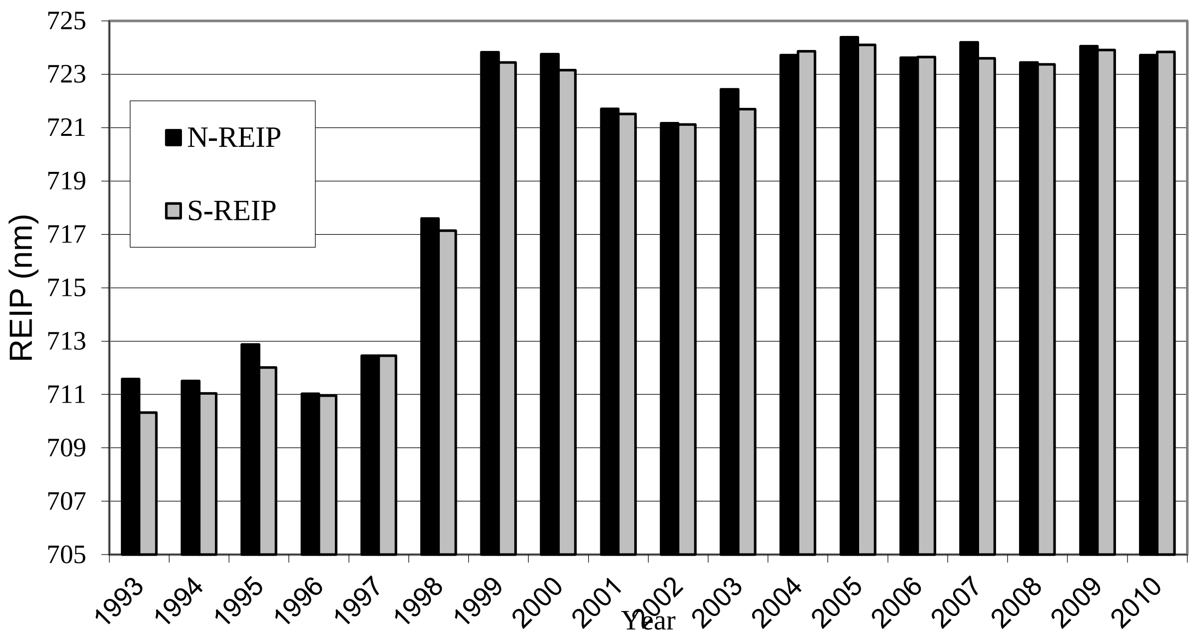
In 1997, 1998 and 1999, REIPs rose dramatically as ozone levels fell. We assume that tighter regulations on ozone emissions detailed by the Clean Air Amendment Act of 1990 were taking effect. The decline in high occurrences of ozone continues today. That decline may also be attributed to changing weather patterns, such as the shift in the Bermuda High and more rain in summer, as discussed in Chapter 3. REIPs have risen to about 724 nm and held there consistently for most of the past decade. In 2002, an interesting anomaly, falling REIP and rising ozone demarcate a hotter than usual summer when ozone levels rose.

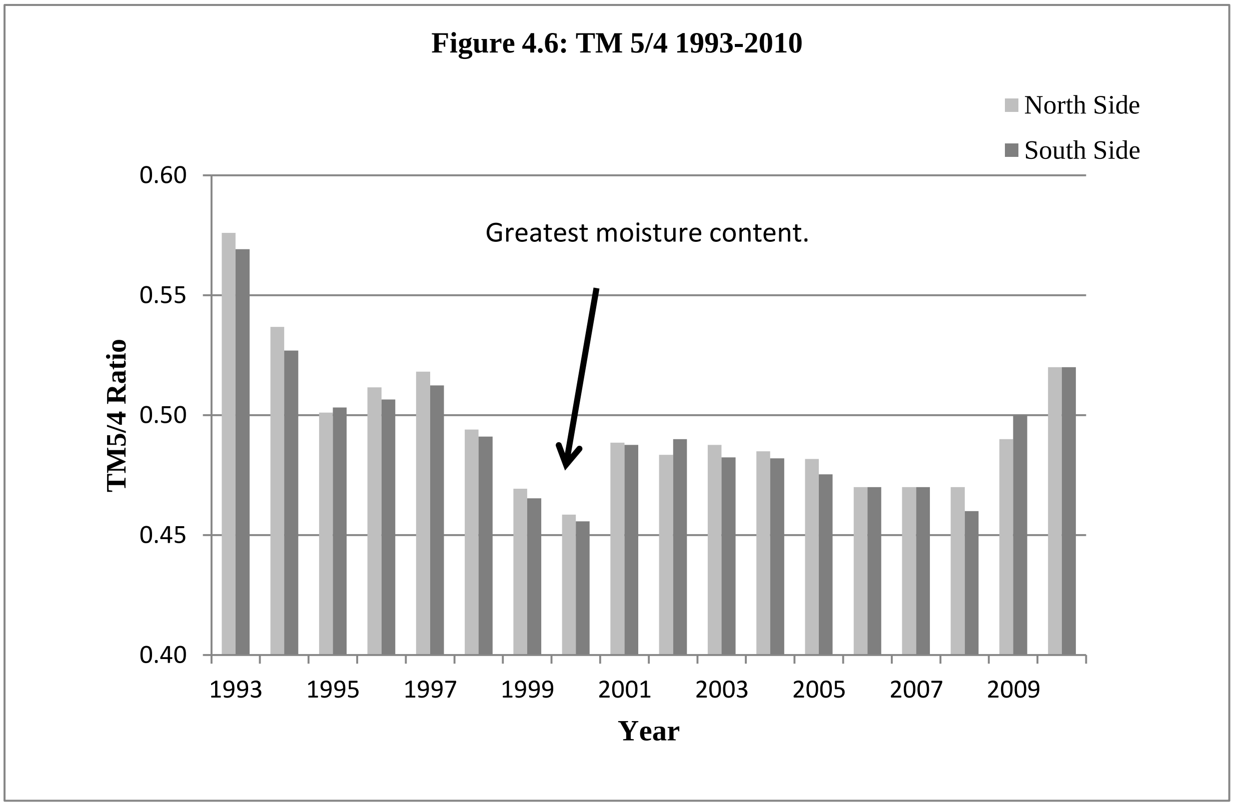
We should continue to evaluate the data and how it is gathered. The 8-hour exceedance, for example, may greatly reduce the number of recorded ozone highs in coastal areas simply because sea breezes generally make an 8-hour hot spell very rare, even on the hottest summer days. High levels of ozone might be present but for fewer than eight hours.

Long Term Spectral Analysis

Another perspective on this year's data comes with long term comparisons of one index over time. REIPs from both noth and south sides of the trees climbed in the late 1990s and have remained high as shown in Figure 4.5. In 1991 when Forest Watch began, research at Penn State suggested that south side needles might be healthier since they receive more sunlight than north side needles. Our early records did show a difference—North side needles had slightly higher REIPs, an indication of more chlorophyll, perhaps to balance the south side's advantage. In most years, there is little or no difference between chlorophyll content in north side and south side needles.

Figure 4.5: REIP Values 1993-2010

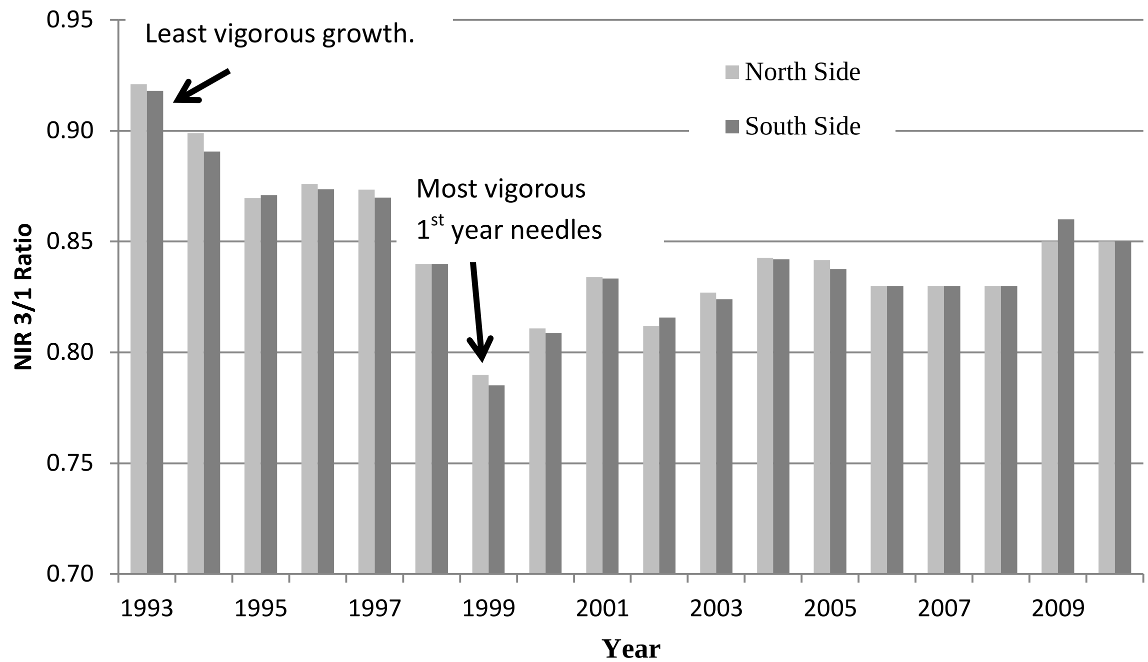




Water conditions in the white pines show a bit less water in the 2009 and 2010 needles than in past years (Figure 4.6). With a ratio below 0.55, however, these needles still show no water stress. Only 1993 shows a TM5/4 ratio considered to show initial water stress. Water content was reduced in the last two years despite ample overall rains. The slight loss of water may mirror changing weather patterns. Total precipitation in the last two years has been above normal but almost all of the rain has fallen in just three or four intense rainstorms. Between storms, the soil was dry.

The NIR 3/1 ratios, Figure 4.7, tell a similar story. The 1993 needles showed the most mature or most aged needles, a sign that in that year ozone conditions stressed the needles. In past years, including this year, needles show vigorous growth and appear healthy enough to remain on the trees for another year or two. The NIR 3/1 ratios were a bit higher in 2009 and 2010, mirroring the droughty conditions which may have aged or stressed the young first year needles.

Figure 4.7: NIR 3/1 Ratio, 1993-2010



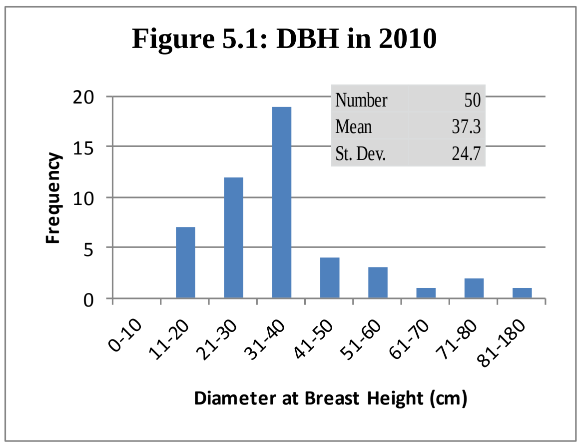
Chapter Five -
Forest Watch Biometric Data Analysis

Biometrics are measurements of the biological features, in this case of the white pine: tree height, diameter at breast height, needle length and symptoms of disease or environmental damage on the needles. Biometric data is also collected for forest stands, such as canopy closure and ground cover. Trees are growing living organisms. They respond to growing conditions, such as 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 biometric data. Carefully following the same protocols, schools all across New England make useful and accurate measurements. Together, these data build a highly accurate picture of white pine health and related stand conditions.

The Forest Watch Data Book examines the data just for 2010 needles and it compares this year's biometrics with student measurements from past years.

Histograms of 2010 Data

Each year we create histograms of the student data. At a glance, histograms display the "frequency" of how data is distributed. The histogram in Figure 5.1, for example, shows us that the greatest frequency of diameter at breast height (DBH) is between 31 and 40 centimeters (cm) with a mean or average DBH of 37.3 cm.

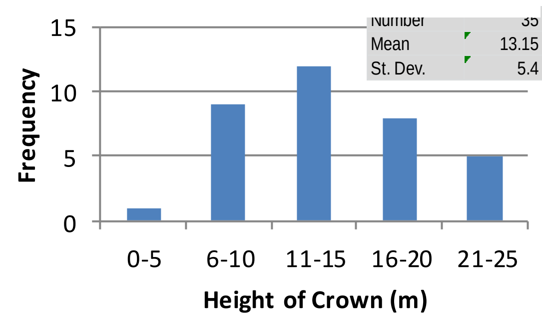


In addition to the frequency of data, we also compute some simple statistics and display them on each histogram. The number, often shown in research as "*N*," tells us the number of trees or samples that were measured in the data set. The *mean* tells us what the overall average of all these measurements is. The tallest bar in each graph represents the mode. The *mode* is the range of values that occurred most often. The mean is often within the mode or very close, depending on the overall distribution of the data. In the case of the 2010 DBH values, the mean does fall within the mode.

As the histogram shows in Figure 5.1, the majority of the 50 trees monitored this year were in the smaller size categories. Why the high mean? The data was skewed by a few large trees including one enormous tree measured by students at the New Hampton School. Tree 1721 has a DBH of 178 cm, more than 5.8 feet. The third statistic, St. Dev., *standard deviation*, is a statistic that tells us how tightly all the measurements are clustered around the mean in the set of data. This measurement gives us detailed information about differences between the overall average and the mode. When the data are spread apart, the standard deviation will be high, as it is in Figure 5.1.

Histograms are only as good as the data they are built on. Scientists learn to examine their charts, graphs and statistics closely. We compare one chart with another to see if they are an accurate representation of the data. For example, let's look at a histogram of Canopy Height, Figure 5.2. The average crown of our white pines is 13.15 meters in size, a green biomass of needles reaching from the top of the tree down to the lowest branches of greenery. When we compare this measure with tree heights, as Figure 5.3 shows, it appears that our canopies are growing richer and greener over the years. (To make this graph look more like trees, we've turned it upside down).

Figure 5.2: Crown Height



But those numbers do not match other numbers. If the average tree height is 15.9 and the average live crown takes up the upper 13.15 of those meters, than the lowest branches must be only 2.75 meters from the ground. A student, about 1 meter tall, would only need one pruning pole (almost 2 meters long) to reach the lower branches. With two poles, students could easily reach the sunlit denser branches in the mid-canopy. But look at the histogram of Collecting Heights, Figure 5.4. The average is 5.38 m and many schools report much higher heights, including a number of schools who are reaching 10 meters or more into the air to collect samples. Why?

Figure 5.3: Tree Height and Crown Height

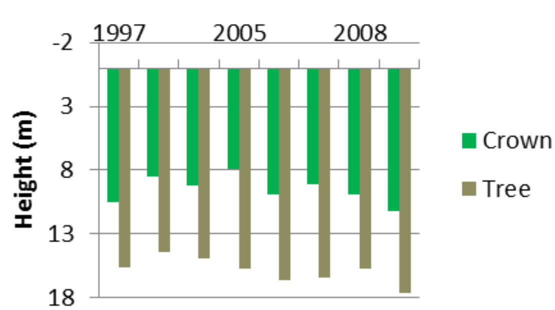
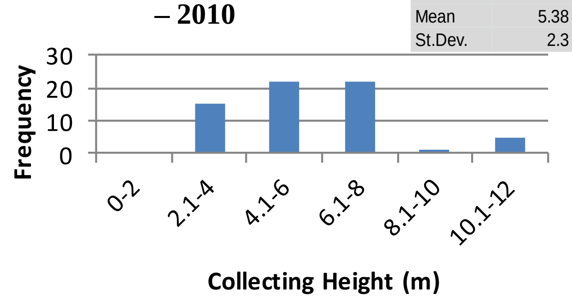


Figure 5.4: Collecting Heights – 2010



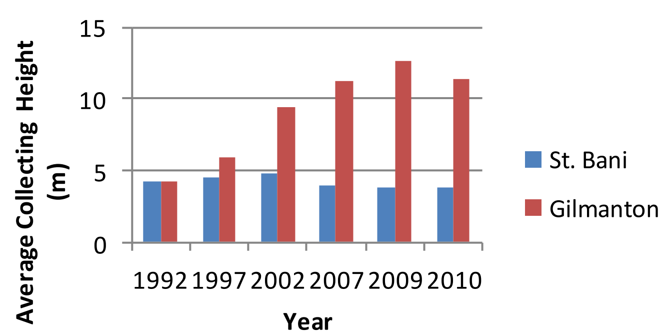
To answer this question, let's take a trip back in time to two schools whose trees were among the first white pines measured by Forest Watch teachers and students.

Change Over Time

Forest Watch students learn that trees grow taller year by year. Five trees at the Sant Bani School in Sanborton, NH, have been measured annually since 1992. These trees grow an average of 0.58 meters in height each year and add 1.08 cm to their diameter each year. Many schools check these comparisons annually not only to see growth in their trees but to check whether students this year are measuring accurately and using consistent metric quantities. If trees suddenly grow shorter or thinner, students and their teachers can easily see where errors have occurred.

Even when all measures are accurate, however, not all trees grow in the same manner. This year we compare tree heights and collection heights from two of our longest participating schools, Sant Bani and Gilmanton School. Figure 5.5 shows a remarkable difference. Sant Bani students have consistently collected needle samples at about 4 meters. This is about two pruning poles, plus a student's height, from the ground. Students of all ages can manage two poles and easily collect samples.

Figure 5.5: Collecting Heights over Time



But look at Gilmanton's collecting height. In 1992, Mrs. Fougere and her students began collecting at the same height as Sant Bani. They needed only two pruning poles to reach their needles. But the collecting height grew dramatically until 2009 when, with the help of Michael Gagnon, our former Forest Watch coordinator, students reached up more than 12 meters to collect samples. Twelve meters required 4 or 5 pruning poles, plus Mike's tremendous arm strength and height to reach needles. This year, our new coordinator, Martha Carlson, visited Mrs. Fougere's class. Four poles of the slender and supple spruce pruners were fitted together to reach into the canopy. Even with almost six feet of height, Mrs. Carlson could not reach one of Mrs. Fougere's trees. The four poles wobbled back and forth, nearly crashing into a crowd of students several times. Four poles were ineffective and even dangerous.

Live crown height is a measure of the actively growing branch and needle section of the tree*. The live crown extends from the top of the tree to the base of the living portion of the canopy. The branches at the base of the live crown of a mature white pine will generally be dead or nearly dead. Needle growth is sparse or totally absent on these lower branches as the sunlight is shaded from above. Trees in which a large proportion of the crown has healthy green needles have a high photosynthetic potential and may therefore show more growth from year to year than adjacent trees with less needle mass and/or chlorotic (yellow) needle (Forest Watch Protocols).*

Why couldn't Gilmanton students collect samples at lower heights? How are Gilmanton trees different from Sant Bani trees? We constructed a table using the best data we have, Table 5.1.

Both sets of trees grew taller but Sant Bani trees grew at a faster rate each year. Why? The live crown measurements tell the story. As Sant Bani's trees grew, the green crown of needles grew bigger also. Every meter of growth in the stem of the tree was accompanied by growth in branches, twigs and green photosynthesizing needles. The live crown of the Sant Bani trees increased in size from the lowest branches to the top of the tree by 91.6 percent. That huge growth in green chloroplasts allowed Sant Bani trees to produce enough sugar to add 1.08 cm in wood every year.

Table 5.1

	Sant Bani	Gilmanton
Gain in Hgt. (m)	9.9	7.3
Avg. Hgt. growth (m)	0.58	0.41
Growth of Canopy (m)	9.9	-2.1
Change in Canopy (%)	91.60%	-25.30%
Gain in DBH (cm)	18.28	12.8
Avg. DBH growth (cm)	1.08	0.85

What happened in Gilmanton? Here trees also grew taller but the live crown, the green portion of the stem shrank by 25%. These trees still grew wider at breast height but they added wood more slowly, widening DBH just 0.85 cm per year.

What caused the difference? Did Sant Bani manage its Forest Watch trees over the past 18 years so that each tree could retain a full round canopy? We asked Robert Schongalla. Here is his answer:

> We do have low branches, but unfortunately it's not due to a management strategy. It's due to the fact that way back in 1991 (maybe 1992) during the first year of Forest Watch when I picked out my trees I don't think the protocol for choosing trees was written. Or, if it was, I missed that part. I went to one of the first teacher training sessions that was held north of Franconia Notch in Bethlehem or Twin Mountain. So, when I picked my trees, I had two primary guidelines: Choose trees that were out of the way of the human activity and the school and Sant Bani Ashram and to select trees at the edge of the forest so that we would always be able to reach the branches. Almost all the pines in the forest would have been out of our reach already – even from our short pole pruner. As a result I had to choose trees that were a distance apart from each other.
>
> Choosing edge trees has worked for the most part, although now we need 14' or 16' step ladder & pole pruner to reach some of the branches, and we don't get north samples from 2 trees (#99 & #100) most of the time. Over time other more dominant trees have encroached on some of ours, especially the north side trees 96, 99 &100.

Although I chose trees at the perimeter of peoples' activities – and they mainly still are, I have had to protect and defend each of them in various ways over the years. Tree #96 had several good, lower limbs removed by someone who was our "handyman" (for lack of a better title) when he wanted to drive the big tractor under its limbs, as this tree is next to one access point into our woods. He wanted a more manicured look, too. Neither reason was really necessary. Tree #97 was in some jeopardy when people wanted a better view of our pond, and they cut down trees along the edge of the pond. I had to be sure they left it, and it became a stand-alone tree. Tree #98 is on the other side of the pond and was at the southwest corner of a wooded area. The Ashram wanted to definitely cut down tree #98 to order to move a dirt road. It took work to persuade everyone to move over toward the tree just a little and curve around it. It also essentially became a stand-alone tree at that point. At tree #99, someone dug up 4 big, high blueberry bushes, a couple of which were within the tree's drip-edge. Finally, at least twice, people have dumped debris within the drip edge of tree #100. I was forced and able to move the piles.

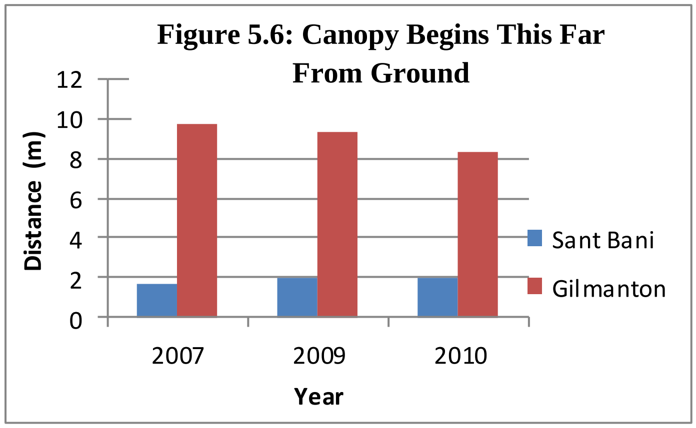


Figure 4.3. Reported collection heights, live crown height and height of tree measures indicate that the canopy begins at very different locations on the Sant Bani and Gilmanton trees. Yet, reading Robert Schongalla's story, one has to question either the data or our interpretation of the data. One possibility is that we have different conceptions of what "live crown height" means and how we measure it.

It's been challenging. Unfortunately we aren't sampling [mid or upper] crowns and never have, but the branches & needles usually look pretty good in terms of being important photosynthetically for the tree--Robert Schongalla.

At Gilmanton, the pines began as a beautiful planted stand of young pines. But no one thinned them. The small trees grew taller and taller, shading one another, competing with one another for light. Some trees in the grove have died. Others have lost numerous lower branches as needles were starved for light. As Table 4.1 indicates, the crown height on these trees, the canopy of needles, actually got smaller.

Gilmanton is not the only school with trees whose branches have grown beyond the reach of teachers and students. Across New Hampshire, in Vermont and Massachusetts, Forest Watch trees have grown taller—which is a good thing. Many have lost their lower branches. In some cases, dense growth around the trees makes it hard for students to even see the shape of the tree, the top of the tree for height measurements, to reach north sides and south sides, and to measure live crown of the tree.

We need to rethink our protocol. Is it really necessary to reach into the middle third of a live crown when that may be impossible. Sunlit healthy foliage can grow on lower branches if those branches are not shaded by other trees.

But how do we provide that sunny spot for a growing tree. We need to rethink how we select and care for Forest Watch trees over decades. Trees that have scientific purpose for teachers and students have not been recognized by principals, school boards or groundskeepers as having special value or as needing special care. Why not? Because we never talked about such an idea with them. Perhaps it is time for Forest Watch to share our knowledge about trees with others in our schools. Should teachers do this? Students? The Forest Watch team at UNH?

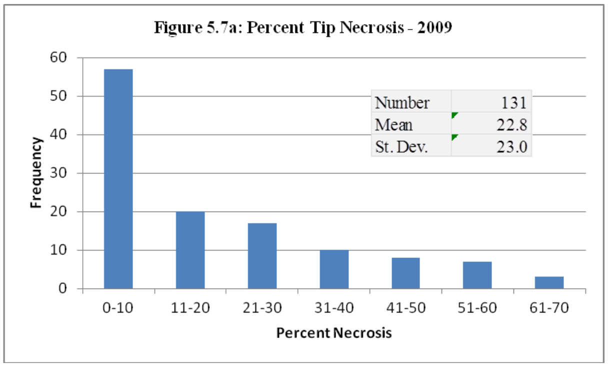
In the next year, Forest Watch plans to work with several pilot schools to help teachers and their students to develop long term management plans for their white pines or sugar maples. We hope students will learn how to build an argument for maintaining these trees on the school grounds as a valuable educational resource. The data above may guide students in how they might build such arguments. Students will need to present their proposals to administrators and policy makers in the school or district. And, if their management plan is approved, they may need to educate younger students and new school managers so their trees will continue to be protected long after the students have grown up. If you would like to involve your school in this new stewardship initiative, give us a call. Or, if you already do this kind of planning and communicating with school officials, please share your expertise with us.

Other Histograms Graphed from Student Measurements

“Welcome to science,” Dr. Rock said recently. His forestry student patiently peeled the coats and inner skins off sugar maple samaras to study the bright green seeds within. “It took me four minutes to peel each one,” Pavel Pluhar said.

Collecting, observing and measuring biological samples is a long and tedious process. Forest Watch students and teachers collected, bagged, labeled and shipped 145 samples of fresh pine needles this year. While they were visiting their trees, the students measured the heights of their trees and diameter at breast height. Some cored trees. Others set up site plots to measure canopy density and to inventory ground cover. In their classrooms, students measured and examined 7,958 needles, measuring the length of each one, examining each for chlorotic mottle and tip necrosis. For each set of needles, students then made 1508 calculations about their size and the symptomology common to ozone damage. Working in teams, each student helped to measure 30 needles and to assess 7 different questions about their health. Some students also massed their needles and later calculated water content. These studies provide a rich body of data about white pine health.

Histograms are easy to build and interesting to examine. Students can compare one year’s damage to needles with another year’s. In Figure 5.7, we compare the percent of tip necrosis in 2009 with the percent of tip necrosis in 2010. In these histograms, simple frequency is shown. How many needle samples had only 10 percent damage or less? How many had 41-50 percent? In 2009, more needle samples had little or no damage. The graph is spread out widely because a few needle samples had very high damage. In 2010, the spread is different, more of a bell-shaped curve with most needles showing damage in the 11-20 percent range and no damage over 70 percent.



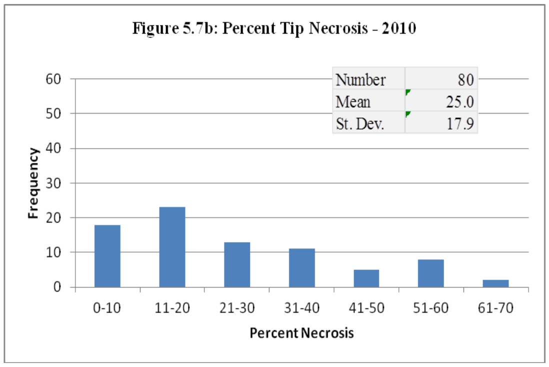
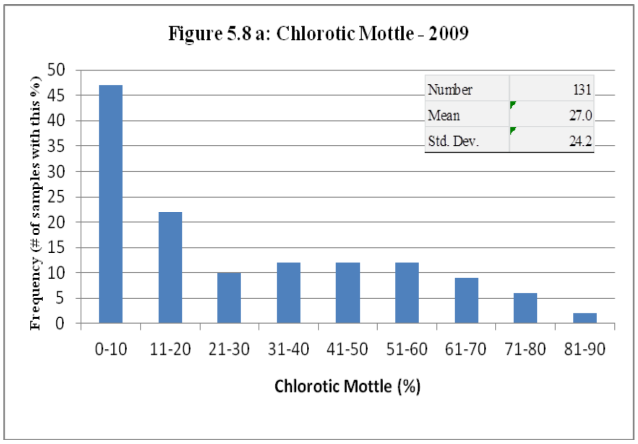


Figure 5.7: Comparison of percent tip necrosis in 2009 and 2010.

Histograms can also display “relative frequency,” the percent of samples in each category. Again, as Figure 5.8 shows, a slightly different spread shows more widespread damage in 2010 but less damage in the upper categories. This might indicate slightly more severe damage in 2010 or more ozone events which caused a little damage each time.



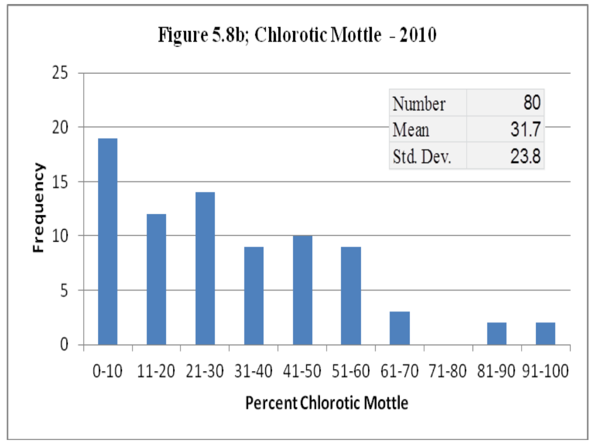
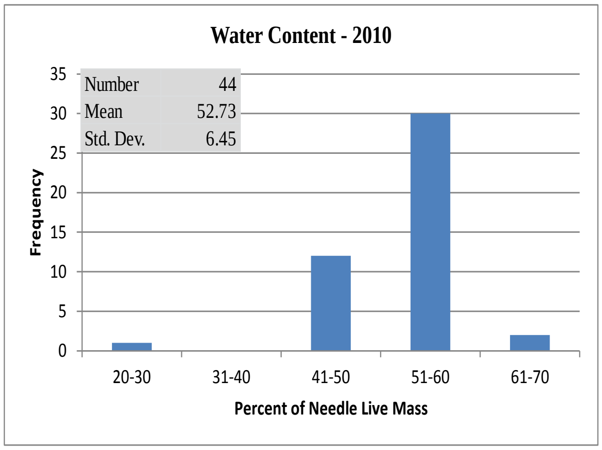


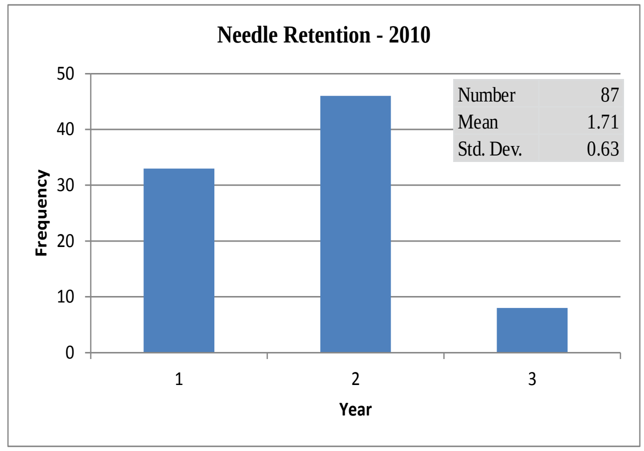
Figure 5.8: Comparison of relative frequency or percentages, changes the spread a bit.

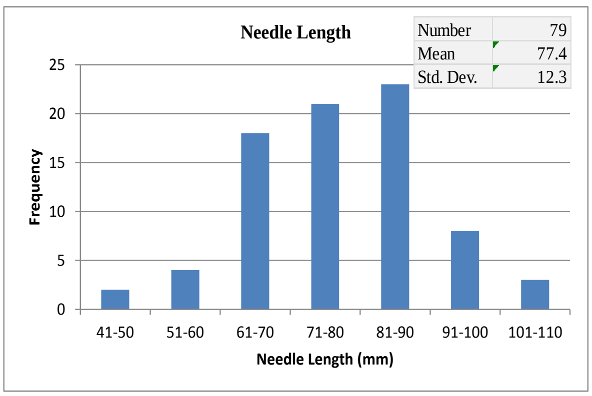
Numerous hypotheses are possible. Notice that there were many more ozone exceedance days in 2010 as those young 2010 needles grew compared to ozone exceedance days in 2009. In the next chapter we examine student ideas.

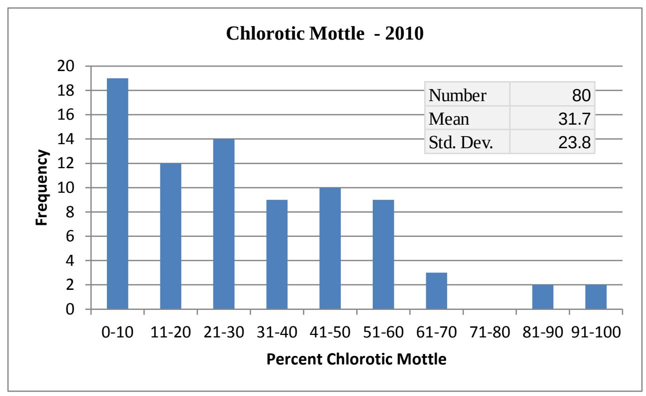
Table 5.1: Exceedance days 2000-2011 by New England State (EPA, 2011) ** indicates recent figures are subject to further analysis.*

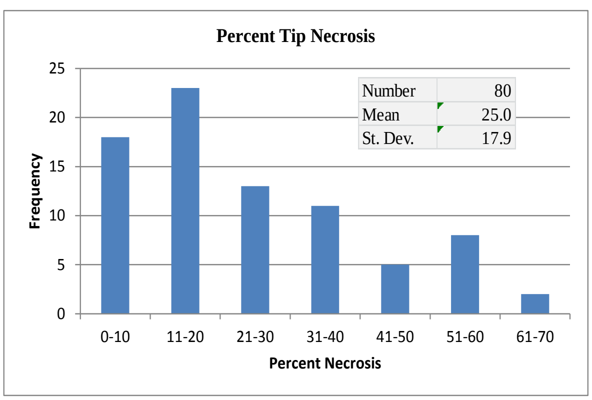
Year	CT # days >		ME # days >		MA # days >		NH # days >		RI # days >		VT # days >	
	84 ppb	75 ppb	84 ppb	75 ppb	84 ppb	75 ppb	84 ppb	75 ppb	84 ppb	75 ppb	84 ppb	75 ppb
2009	2	6	2	3	2	7	1	2	0	1	0	0
2010	8	24	2	6	4	15	0	9	1	6	0	0











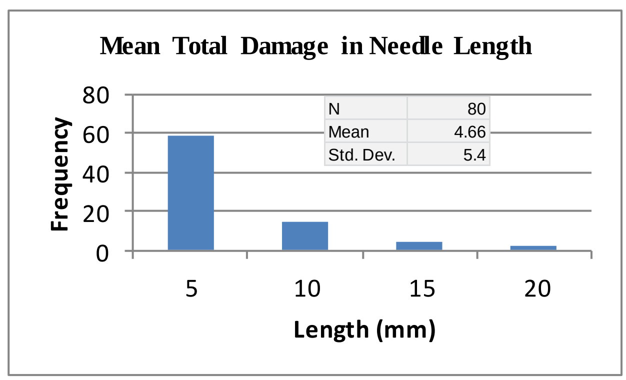
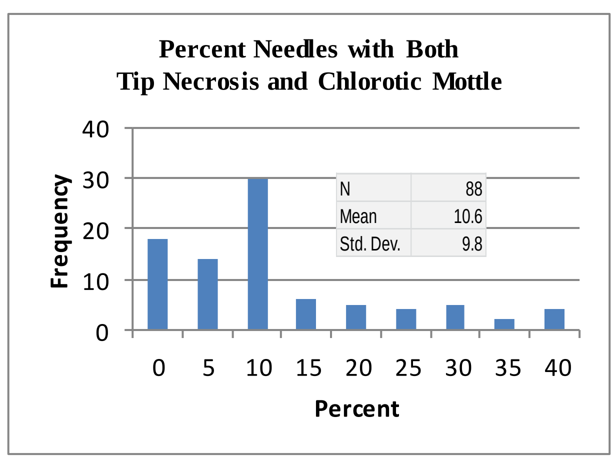
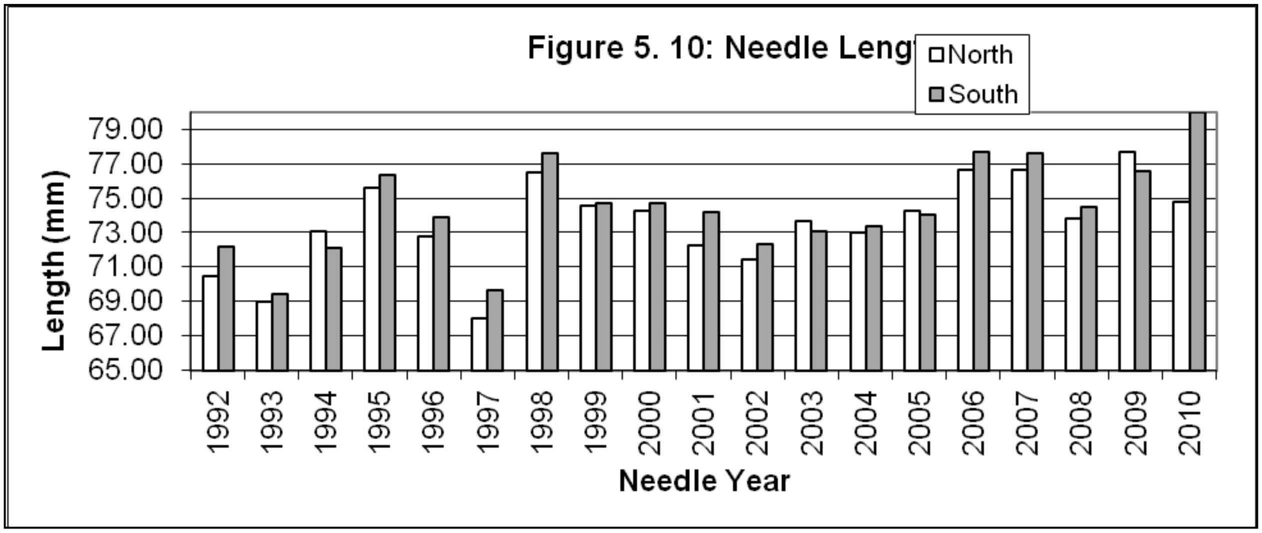


Figure 5.9: Some histograms show a bell-shaped curve, such as Needle Length shows. This indicates that most white pine needles really do average 77.4 mm in length. Other histograms such as Percent Chlorotic Mottle show a falling frequency from lots of needles with little or no damage to a wide spectrum 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. The low percentage of chlorotic mottling matches the high REIPs measured in 2010 needles.

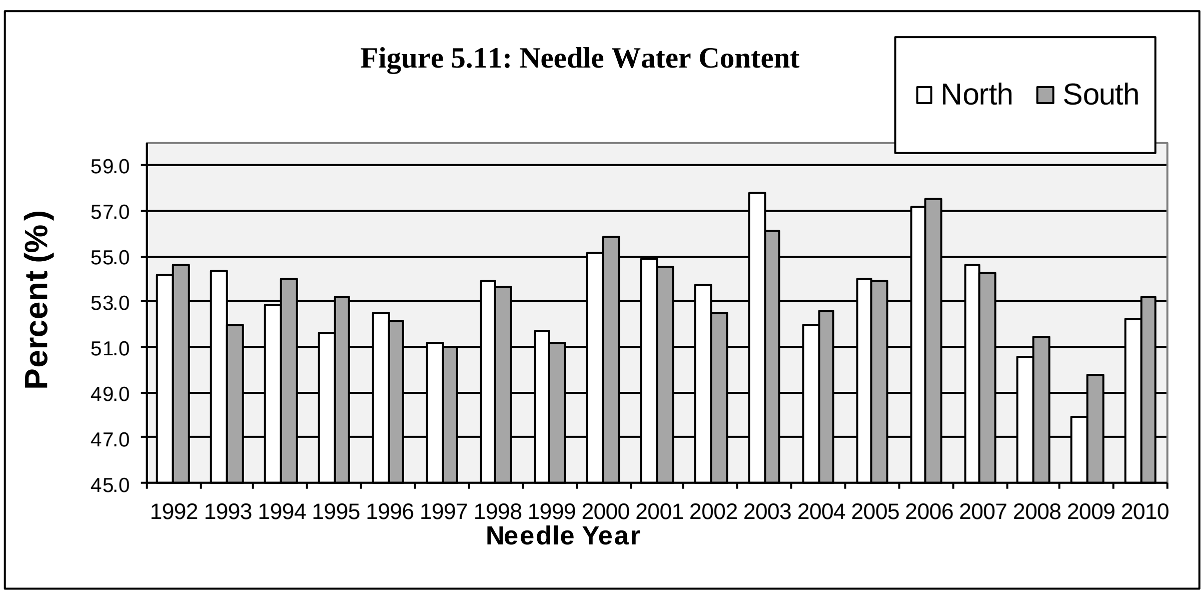


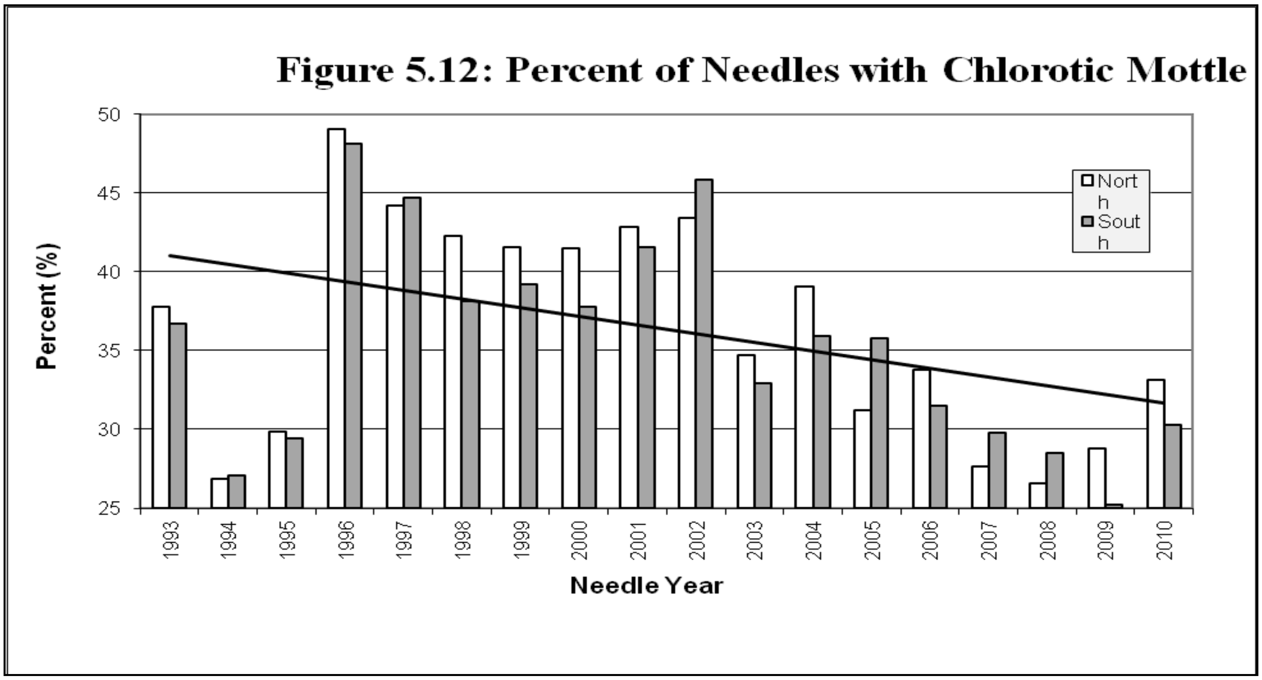
Long Term Biometric Analyses

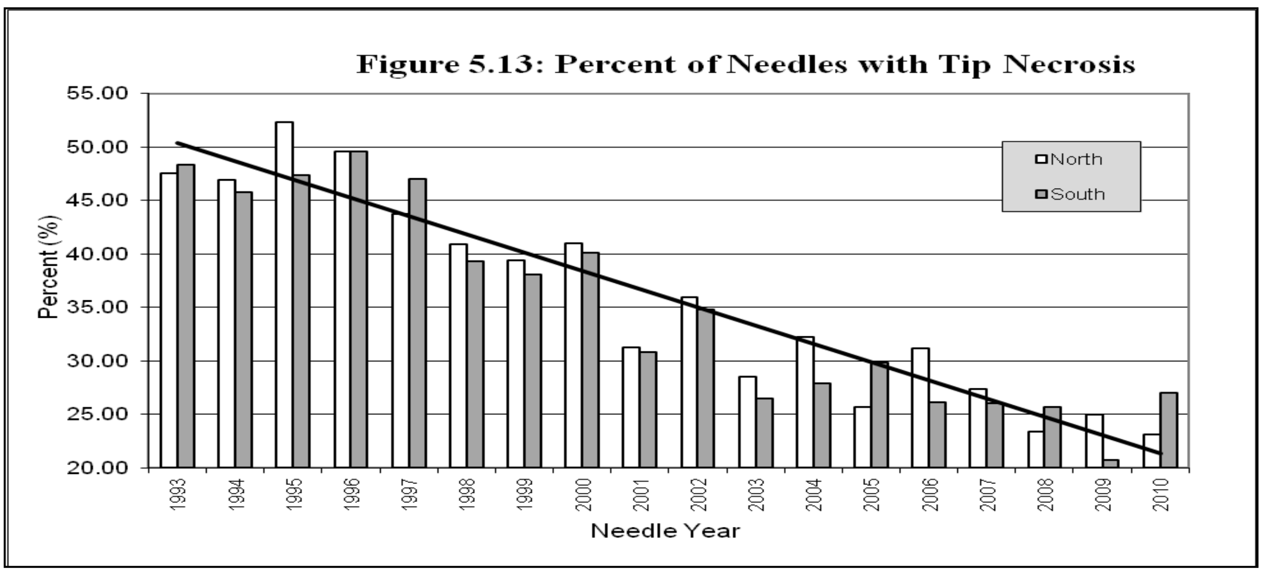
This year, our long term comparisons of biometric data tell an interesting story. The average length of white pine needles continues to increase, adding to a long term trend we see in 20 years of biometric studies (Figure 5.10).



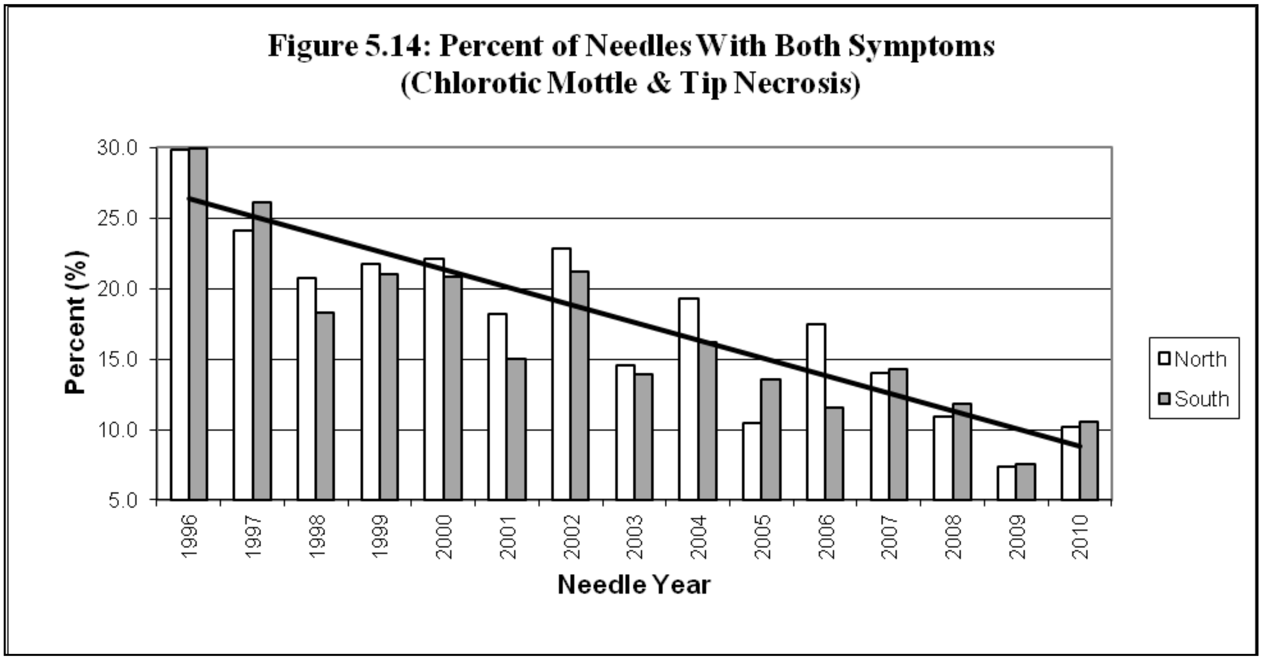
Water content in the needles is also up in 2010 needles, compared with 2009 and 2008, another indication of good health (Figure 5.11). Needle length and water content reflect plentiful water in the 2009 and 2010. In these analyses, needle length and water content both show marked differences between north side and south side needles.







Other observations recorded by our biometric analysts show some increase in ozone during the year June 2010 to June 2011. First year needles, those which were formed in June 2010, showed an increase in chlorotic mottle, the yellowing caused by ozone (Figure 5.12) and an increase in tip necrosis, the burning of the distal ends of needles also caused by ozone (Figure 5.13).



These observations do not change the present long term trend in declining visible damage on the white pine needles. The slight increase in damage during the 2010 first year of growth fits the pattern of annual fluctuations in needle health.

Total percent of total damage to needles was also up in 2010 but the trend continues to show less long term overall damage.

Needle Retention Tells Another Story

One other longterm measure, however, indicates that something stressed the white pines in 2010. Needle retention is a simple count of how many years of needles remain on the branches when students make collections of needles. This year, for the first time in 20 years of study, the average retention fell below 2 years to 1.8 years. Many Forest Watch teams found no third-year needles and few or no second-year needles (Figure 5.15). At the University of New Hampshire, we also noticed a decline in needle retention on white pines in Durham.

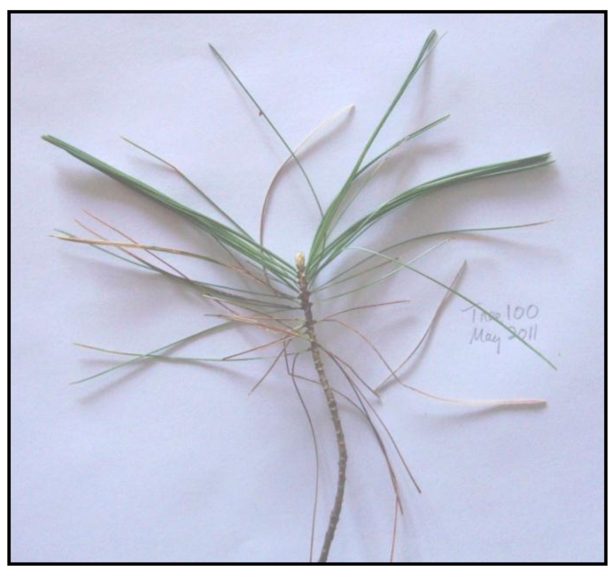
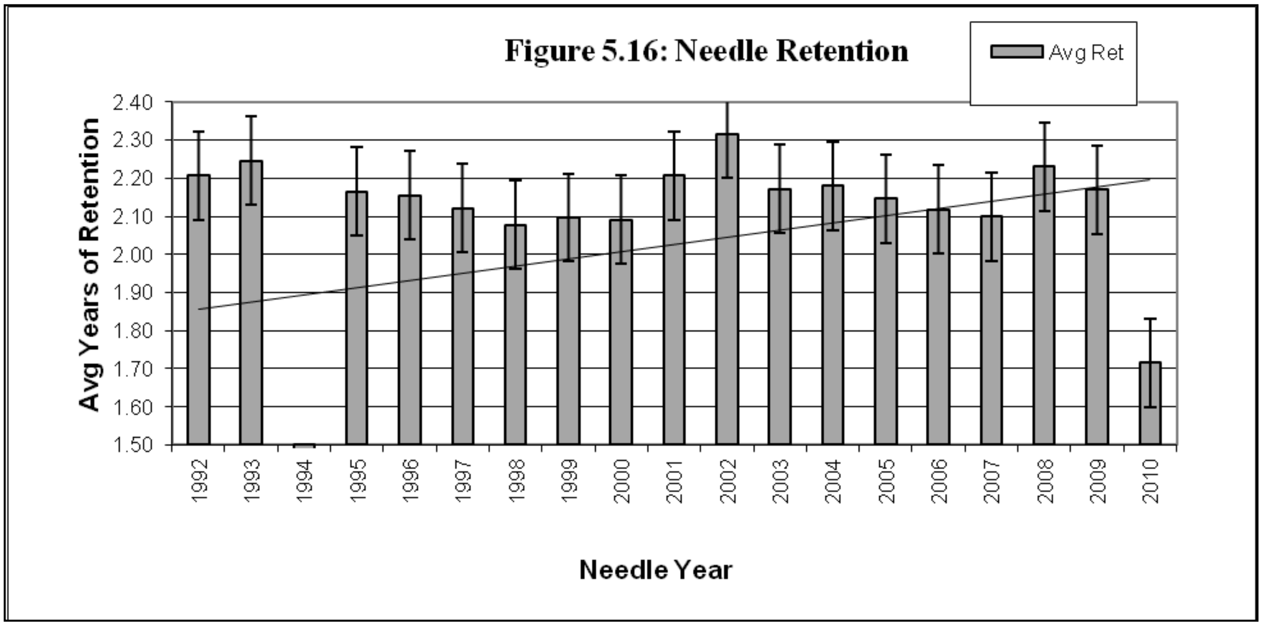


Figure 5.15: A sample from a Forest Watch school shows damaged 2010 needles and no 2009 needles.

Our initial retention average was calculated to 1.7

years as shown in Figure 5.16. When RHAM High School sent its data, we recalculated to the higher but still less-than-2.0 number.



This loss of needle retention is disturbing. White pines in peak health can retain needles as long as four years. In the past, a few trees in our studies have shown this remarkable health. As ozone levels have dropped and white pine health improved over the last two decades, Forest Watch has hoped to see average retention reach 2.5 years. Loss of needles means loss of photosynthetic machinery. Needles are cast only when a tree is highly stressed, when the cost of maintaining and repairing needles requires more energy than those needles can produce in photosynthesis.

What would account for a loss of needles? The question is a serious one. A tree will make less sugar if it loses half of its photosynthetic equipment. We wonder if the loss of second and third-year needles might be related to the defoliation we observed in late May on Bald Mountain in

West Campton, NH. Sugar maples at 500 meters elevation were defoliated on May 26, 2010, by an atmospheric pollutant we believe was peroxyacetyl nitrate (PAN). We believe that this highly reactive nitrogen gas was caused by forest fires in Quebec and coincidental sunny skies and unusual hot weather, 97^{o}F. In the week that followed, more fires continued to break out across Quebec. Smoke drifted south as far as Rhode Island. That smoke may have contained the hydrocarbons and reactive nitrogen gases which form PAN. The sun and heat provided perfect conditions for photochemical production of an oxidant that is even more reactive than ozone. PAN is known to burn plant tissues, causing bronzing of leaves and defoliation, just what we observed in Campton.

Soon after the 2010 fires, many people in New Hampshire noticed an unusual needle drop in white pines. Are the two related? The lowest needle retention average of 1.2 years, calculated from 10 samples, was from the Lyme School, just west of Campton, NH. Other low averages were found at Fall Mountain Regional High in the hills just east of the Connecticut River in southwest New Hampshire and on the seacoast in Lynne and Hanson, MA, and at Morse High in Bath, ME. Needle retention of 2.0 or just over 2 years was measured in central New Hampshire, south central New Hampshire and Springfield, MA. The highest needle retention was at RHAM High School in south-central Hebron, Connecticut. If PAN was involved, it is possible that northerly winds by passed RHAM and carried smoke and its hydrocarbons southeast to the coast. Figure 5.17 shows a National Oceanographic and Atmospheric Administration HYSPLIT model of winds on May 26 received at Campton at 500 meters. Those winds appear to be bound for the New Hampshire seacoast and coastal Massachusetts.

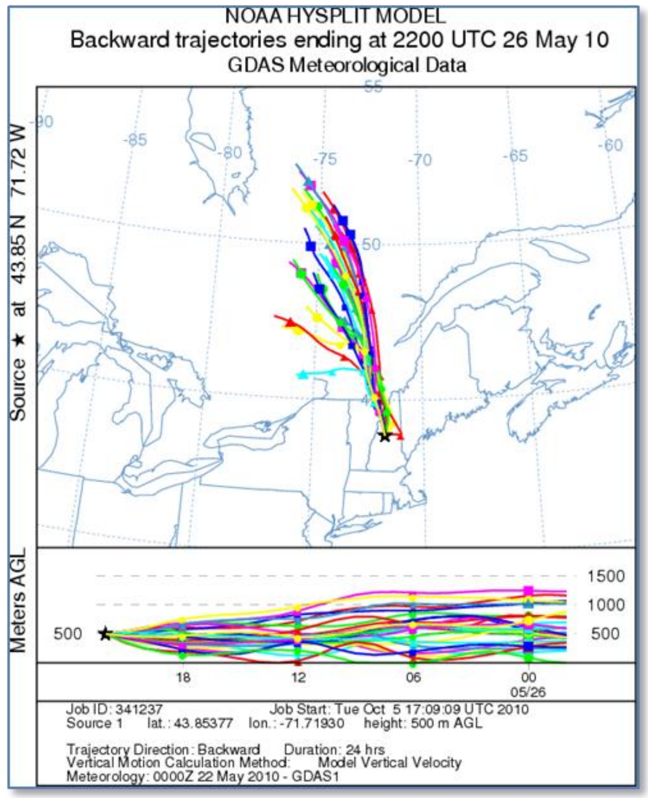


Figure 5.17: Northerly winds on May 26 brought smoke from Quebec south to Campton and then further south, southeast to Boston and Rhode Island.

Extension foresters claimed the loss of needles was called by a needle cast fungus. We challenge that conclusion. The needle cast fungi usually causes needle loss in the fall, not in June. In the Forest Watch labs were have not seen any signs of fungal hyphae in sample needles. We will ask Forest Watch teachers and students to help us with further research in spring 2012 (See Chapter 7).

Could the needle cast have been caused by ozone? Levels of ozone are measured year-round at the Thompson Farm in Durham. During the May 23 to June 5, 2010 period, ozone levels never exceeded federal levels (75 ppb) (Figure 5.18). There were diurnal peaks almost every day that reached more than 50 ppb but the average level was just 32.99 ppb. This year, ozone levels during the same period were almost exactly the same, 32.78 ppb. Continued exposure to late afternoon peaks of ozone at 55 to 60 ppb might cause damage to the pines but we have seen no needle cast in other years with similar levels. Could ozone and another powerful oxidant, the PAN, have caused critical damage to the older needles?

Frost can probably be ruled out. Two-year-old needles are quite well adapted to winter temperatures.

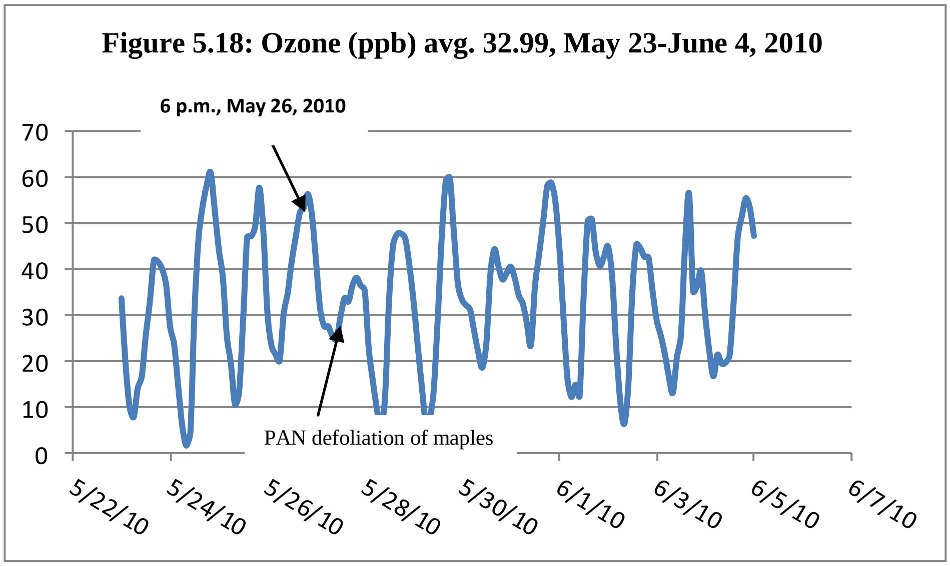
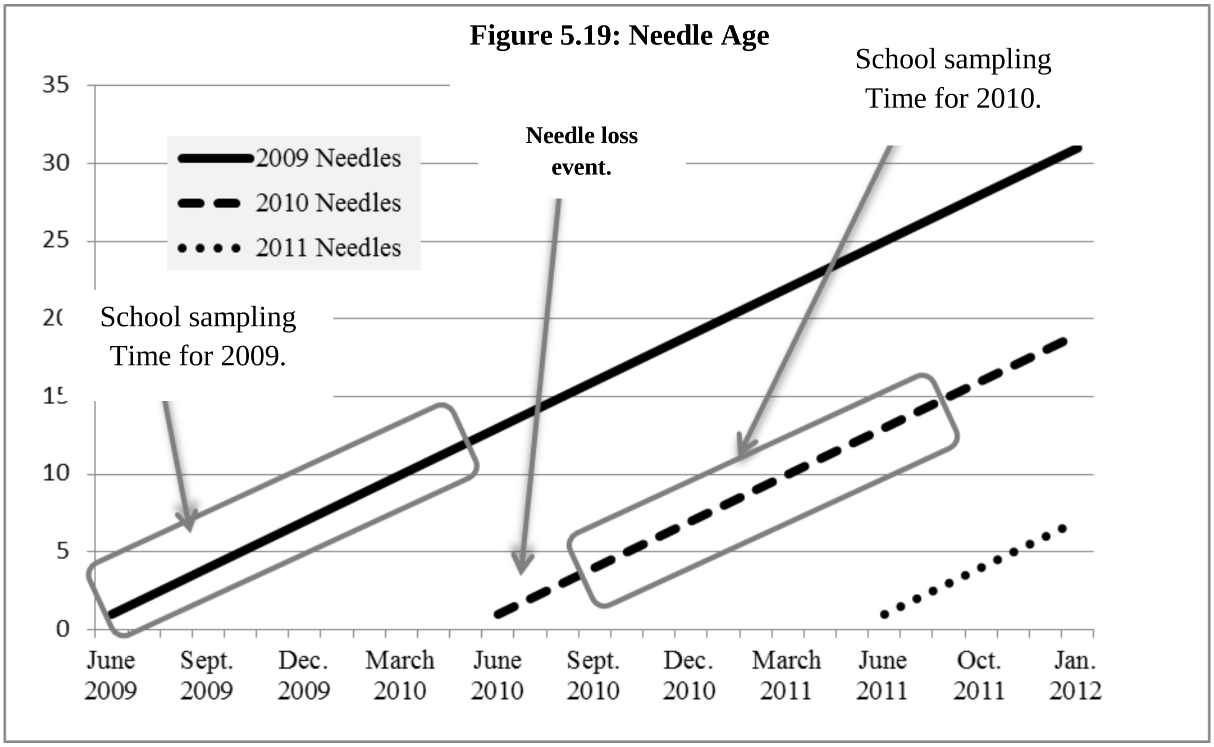


Figure 5.18:Ozone levels from May 23 to June 4, 2010were recorded at the Thompson Farm, Durham, NH, during the period when fires raged in Quebec, releasing enough hydrocarbons to the winds to build photochemical pollutants such as ozone and peroxyacetyl nitrate, PAN. From AIRMAP. www.airmap.unh.edu.

AirMap data can be downloaded for free at airmap.unh.edu. The remarkable data on this site allows students and researchers to examine atmospheric conditions and chemistry of all kinds in a wide variety of times and formats. Figure 5.18 of daily ozone was requested in two-hour averages. The diurnal (day to night to day) rise of ozone during the daytime and the fall each night is marked in this dataset. Ozone generally begins building at about 2 p.m. and falls after 8 p.m.

Looking for Clues in 2009 Data



Forest Watch data offers some insight in exploring the mystery regarding the low needle retention in 2010. Forest Watch schools focus their sampling primarily on first year needles. These are the needles which were formed in April and May of 2010 and which opened from candles in June 2010. The needles we are missing are those which were formed and opened in June 2009.

As Figure 5.19 shows, when 2009 needles were suddenly cast in June 2010, monitoring by schools would have just been completed on 2009 needles. They missed seeing any evidence of damage. In September 2010, Forest Watch schools began monitoring 2010 needles. Those needles, just opening in June 2010, missed the PAN events. Or, if they were in bud or immature stages, PAN would have caused little or no damage; research on other plants has found that PAN damages maturing foliage, not newly formed foliage.

Can Forest Watch tackle such a mystery? The drop in needle retention is very unusual and calls for further study. Some needles from 2009 may still be retained on our white pines. They would now be third-year needles. What hypothesis or questions might we ask for such research? What would we expect to see this coming spring? How would those three-year-old needles differ from two and one-year needles? Would damage to needles by PAN look different from damage by ozone?

We will raise these questions again in Chapter 8.

Chapter Six- Research by Two Outstanding Schools

This year we highlight the outstanding work that two of our schools did in 2011 with statistics and data. Their pioneer efforts lay the groundwork for new curricula and projects in learning about statistics. Both middle and high school students demonstrate that they have an interest in this kind of mathematical thinking and abundant talent for exploring it.

Concord High School Students Learn Statistics

"The idea," Phil Browne told Forest Watch, "was to use AP Stats students (teams of 4-5) in my wife Patricia Jared's class at Concord High to work on analyses of a variety of original data sources …."

Forest Watch sent 20 years of data to Phil and Patty. A few weeks later Concord students sent emails with their data analyses. A number of teams were delighted to find correlations that were statistically significant. They emailed Forest Watch to make sure.

Email from Emily Houle, Kyle Roy, Laura Hapke:

Our project was to look at information about REIP's and Ozone (Figures 5.1), and if there is any correlation between them. We analyzed data from 1993 to 2005, using histograms, regressions, power models, and line graphs. We learned that ozone levels and REIP's negatively correlate; when ozone levels are low, REIP's are high, and vice versa. … Our results seem to match up with similar studies done on the same topic. – *Emily Houle.*

Reply email from Martha Carlson:

Outstanding! Yes, there is a negative correlation

*(Emily's email continues…*Negative correlations are just what we expect in ozone studies. A perfect fit, however, is complicated by a single peak in high ozone when good growing conditions maintained high REIPs anyway.

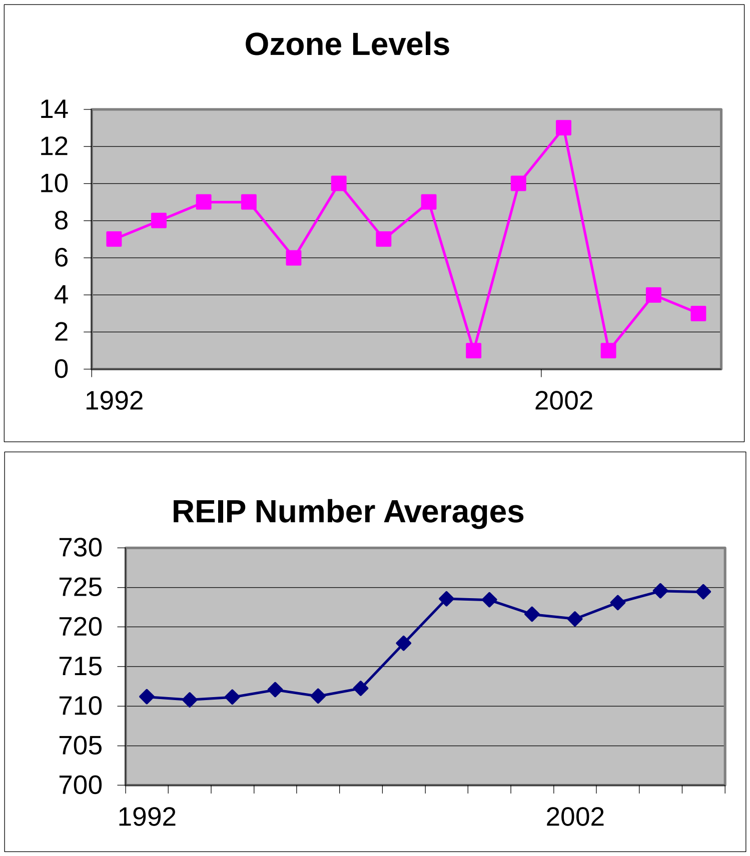


Figure 6.1: An inverse correlation is apparent in this comparison of ozone levels with REIP averages. It is exciting to see Emil, Kyle and Laura building their first Excel charts. As they practice, they will become masters of x and y axis labels and even double axes so they can combine the two variables.

Even with more data, our research here shows a similar correlation but weak one.

Carlson's email continues*: Why is it weak? I suspect that one factor is that big jump in 2001 and 2002 in ozone exceedance days while the REIPs remained pretty high. What do you think causes the difference?*
...So, use that weak correlation to talk about why it occurred. Maybe you have a different theory. And use it to explain what weak correlations tell scientists about our theories, our research methods and future research needs. Science is never over! We keep stumbling over new questions.

Phil Browne and Dr. Rock met last summer to welcome new Forest Watch teachers.

A second Concord team was concerned when their hypothesis proved false. They found no correlation between needle length and REIPs. Correct again! There is no correlation. The data are exactly what Dr. Rock expects!

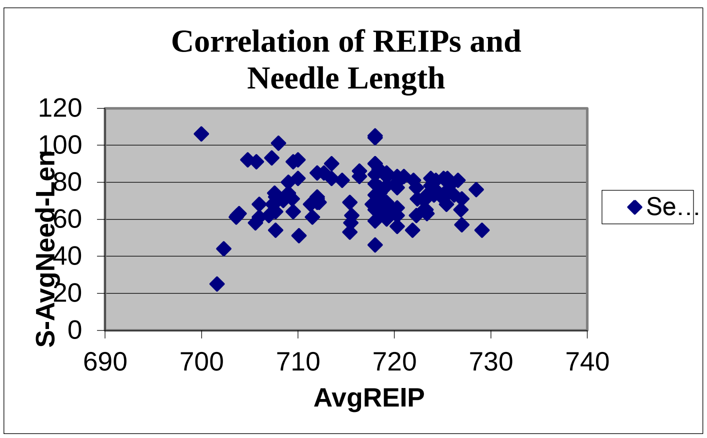


Figure 6.2: A correlation of ozone levels with Red Edge Inflection Points, above, showed a "weak" inverse relationship, just as FW has found. Below, REIPs and needle length do not correlate, an equally valuable finding by Vanessa Benincasa and her teammates.

Email from Martha Carlson to Vanessa Benincasa and Team:

Congratulations on your hard work. It looks right to me. Sorry you did not get a correlation trend line, a beautiful 45^{o} angle and a high r2 value. I thought that needle length and REIP might be correlated also. It seems logical. But Dr. Barrett Rock, founder of Forest Watch, says that needle length is more closely correlated to water availability in a particular growing year.... Sometimes, finding that things do not correlate is just as important as finding out that they do correlate. I think this is such a case. So you should be proud of the hard work you've done. And your wonderful analysis explains why there is no correlation. So use those numbers proudly!

Phil and Patty plan to continue developing their unit in statistics. Phil has recently established a website on which scientists and Concord students can post data and their analyses. Finding other sets of data and willing scientists poses a daunting challenge. Many scientists will not release their data. Forest Watch and AirMap data are unique. Good luck, Concord. You are pioneers.

Gilmanton Seventh Graders Use the Scientific Method

In Gilmanton, 7th grade students worked in teams to build histograms and graphs of their school's data. Mary Fougere, their teachers, walked the students through the entire scientific

Mary Fougere, top right, and her Gilmanton School students sampled their trees for 2010 needles in May 2011..

method from initial questions to final analysis. Students formally presented their studies in beautiful bound booklets and scientific posters at our first Forest Watch Student Convention in May 2011.

Student work began with questions:

- "What does our spectral data tell us about the health of our white pines?" Miranda Bushnell, Haleigh Patch, Caleb Price, Dana Ruchti, Sierra Juneau, Nicholas Waring, Parker Plourde, Drouin Brullote, Jessica Ladd and Joseph Lempke asked.
- "How does Gilmanton's white pine trees' health compare to the health of trees from other sites?" asked Austin Ralls, Hunter Stevens, Matt Waite, Brianna Spoor, Rebecca Simpson, Corrina Marengo, Jordan Drew, Owen Sanborn, Breanna Thibodeau, Eric Potter, Ayden Ernst, and Rachelle Bent.
- "Is there a relationship between weather and our white pine trees' overall health?" asked a third team, Jayme Strzepek, Lexi Jakubens, Audrey Malek, Bobby Barton, Dylan Tiede, Mekayla Collett, Jacob Forst, Mikey Bugnacki, Cortlynn Danby and Sarah Tasker.

- “How have Gilmanton’s white pines changed over time?” asked Maddie Baughn, J.T. Richardson, Justin Bellissimo, Emily Hudson, Sophia Prevost, Courtney Stevens, Tim Rice, Hannah Thompson, Hannah Roy, Bri-Anne Conley, Hunter Sanborn and Savannah Plummer.

Gilmanton’s Forest Watch white pines.

Next, students learned about correlations and how to compare one set of data with another. On each team, each student took on a piece of the question, isolating two measures to compare.

They laid out the date from their school’s 14 years’ of participation in Forest Watch. They learned how to use the web to look up ozone data, rainfall, and temperature. They tapped into Forest Watch archives to find other schools’ data. Students learned to build Excel data sets and then to graph one factor as a function of the other. All of the mathematics that seventh graders have mastered—basic math, percentages, decimals—and new lessons in concepts such as “line of fit” helped them to analyze what their charts showed.

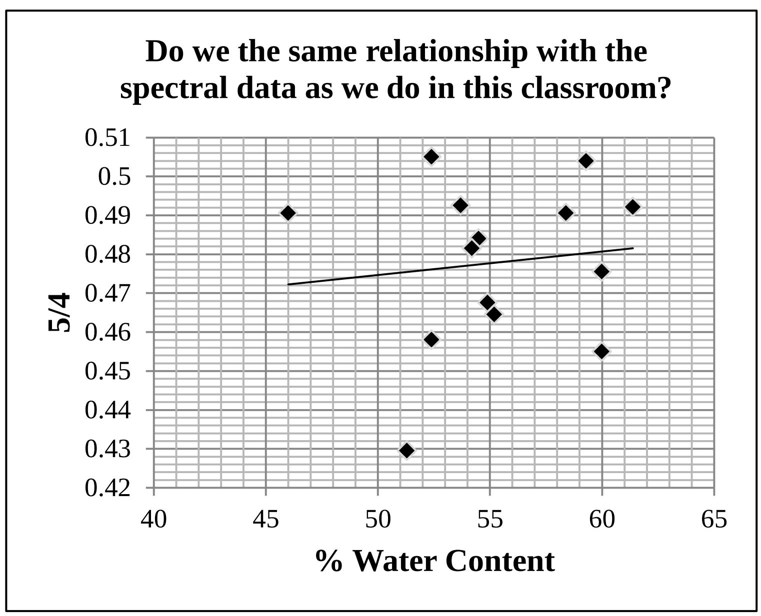


Figure 6.3: A study of water content and the TM 5/4 ratio shows a trend. If outliers were removed, that trend would be even stronger. .

“The water content is at about 60%,” Haleigh Patch discerned in her study of water content and TM5/4 ratios.

Some of the comparisons failed to find any dramatic correlations. Others hit the t

"There is a relationship between the NIR 3/1 and the needle length. If the needle is larger, the NIR 3/1 becomes smaller. If the needle length is smaller, the NIR 3/1 is larger," Caleb Price concluded.

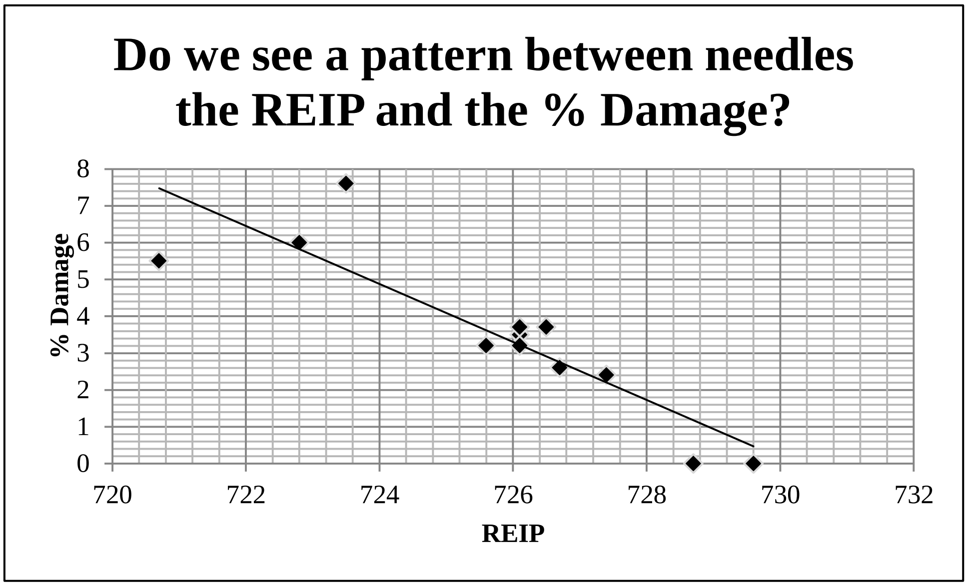


Figure 6.4: A comparison of REIP and % total damage in needles found a strong correlation. When he saw this study, Dr. Rock commented, "This is a relationship that I have considered. These results are very interesting. Great!"

Sierra Juneau also found a strong inverse correlation in her comparison of REIPs with the percent of damage measured on Gilmanton needles: "…the higher the REIP is, the lower the percent damage of the needles. For example, when the REIP was 729.6 in 2008-2009, the percent damage was 0; but when the REIP was 720.7 in 1998-1999, the percent damage was 5.5, one of the highest." Dr. Rock found this correlation exceptional (Figure 6.4).

Comparing data from schools in Salem, Concord and Cape Cod with their own, students looked at tree height, DBH, needle length and every other biometric and spectral measure. These exercises led students to consider geography, change over time, and differences in air pollution, soils and growing conditions.

"What the results tell me is that Gilmanton's trees are different in health than Cape Cod and Salem's," Hunter Stevens concluded after his study of needle lengths over time. "…Gilmanton's trees are healthier than Cape Cod and Salem's because Salem is more of a city than Gilmanton so they get more pollution than Gilmanton. Cape Cod is near the ocean so they get different materials in their trees than Gilmanton."

Ms. Fougere's students also examined the issue we discuss in Chapter 5, the tight canopy and increasing height of their trees. The team reported, "*…the canopy became more dense, the amount of ground cover was reduced. This is due to the lesser amount of sunlight reaching the ground…. since 2005, the canopy in our PSSP is extremely closed, over 90%! This means that the trees have grown so tall and so tight together that it is hard for sunlight to penetrate to the ground. The data supports the fact that the forest has indeed changed in the past fifteen years."*

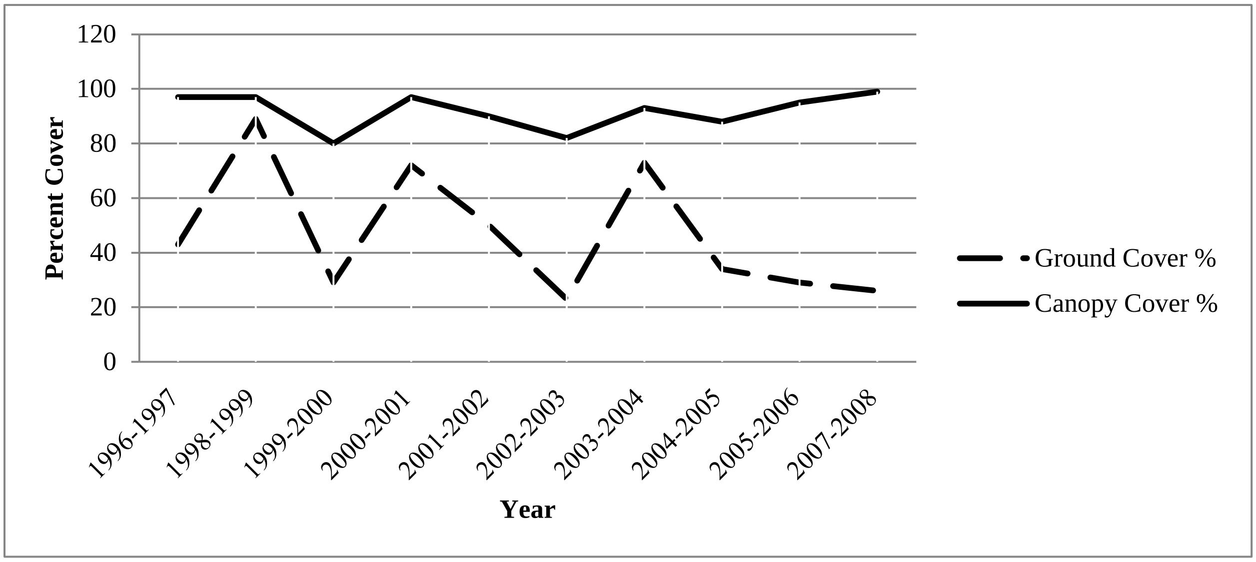


Figure 6.5: A study of change over time, comparing Gilmanton's canopy cover and ground cover documents the increasing density of this stand of white pines. Dr. Rock said that he was surprised by this study. Perhaps we can learn more in the future. Are species in the groundcover changing as the canopy grows denser?

Congratulations to Mary Fougere and her students, to Patricia Jared and Phil Browne and their students. All of you have clearly demonstrated that students are keen on science. Your work inspires us to challenge more Forest Watch schools to go the whole way with white pine research.

The Second Forest Watch Student Convention will be held on May 25. We invite every Forest Watch and Maple Watch school to participate. At UNH we will print the posters, set them up for your display, and provide lunch and tours.

Chapter Seven - Student Data

In the following pages, we present curves of mean reflectance values based on the white pine needles submitted by each school. Standard deviation values (+ and -) are plotted with the mean to illustrate the variability between each curve used in the average. Using standard deviations is a way scientists determine how representative a mean value of the population is, in this case 2010 first-year needles for 74 pines. A small standard deviation value indicates the mean value is very representative of all the values. A large standard deviation value suggests there is a lot of variation around the mean.

Teachers receive a file of similar reflectance curves, one for each tree and its needles. Teachers also receive a data file with which they and students can build their own curves and graphs of the light reflectance features of their trees.

The second page of each school's data presents four indices of the spectral data and all biometric data which students measured, recorded and sent to UNH.

Forest Watch data is also available on-line at the Forest Watch web page. We are working to improve access to these data sets. As students demonstrate in earlier chapters, they are very capable of asking questions of the data and analyzing it statistically. As the data becomes more accessible on-line, we hope more schools will share and compare their findings.

The size of this set of data is quite impressive. This year students and teachers collected, bagged, labeled and shipped 145 samples of fresh pine needles. While they were outside, the students measured the heights of their trees and diameter at breast height. Some cored trees. Others set up site plots to measure canopy density and to inventory ground cover. In their classrooms, students measured and examined 7,958 needles and made 1508 calculations about their size and the symptomology related to ozone damage. Some massed their needles and later calculated water content.

At Hanson Middle School, Wes Blauss and Russ Young teach 175 sixth graders. Every student participates in Forest Watch. Teams of Hanson students measured, recorded and analyzed 6,068 needles.

Then, when the pole pruner and measuring tapes were put aside, students looked at their data and thought about what it might tell them about their trees, their rates of growth and their health. Every summary number on the following pages demonstrates a student's effort and a teacher's amazing skill at managing lessons, students and the demands of a living white pine samples that require particular handling.

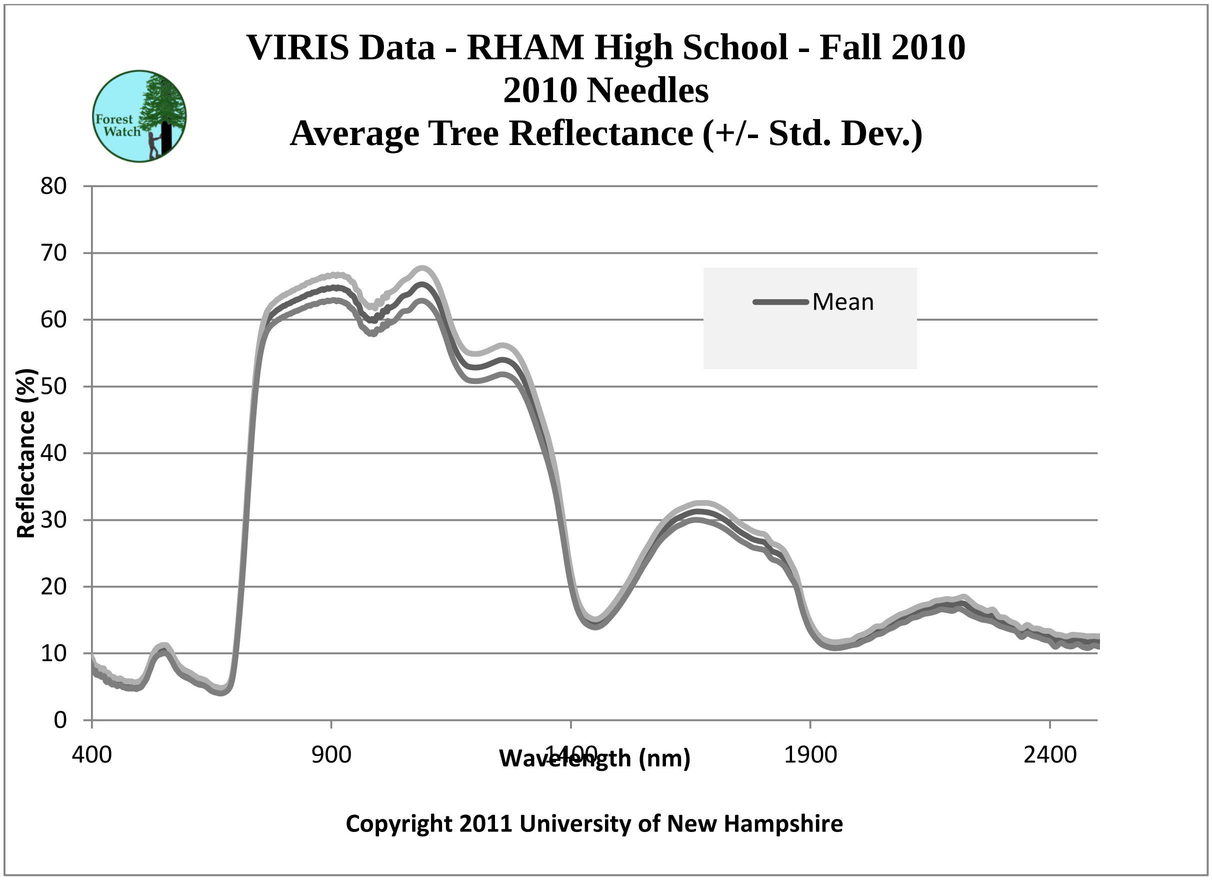
These data are printed directly from the Forest Watch database; if you notice any errors in your school's data set, please let us know. Also, please check the overall data; we want to make sure we have the latest height and diameter at breast height for your trees.

RHAM High School

2010 Needles — Spectral Data — CT

	REIP	NDVI	TM54	NIR31
1331N	725.4	0.879	0.443	0.761
1331S	722.4	0.864	0.482	0.836
1332N	725.4	0.845	0.493	0.845
1332S	723.9	0.853	0.46	0.811
1333N	722.4	0.845	0.481	0.811
1333S	725.4	0.859	0.434	0.778
1334N	725.4	0.847	0.478	0.831
1334S	722.4	0.863	0.451	0.789
1335N	723.9	0.862	0.463	0.81
1335S	723.1	0.841	0.472	0.814

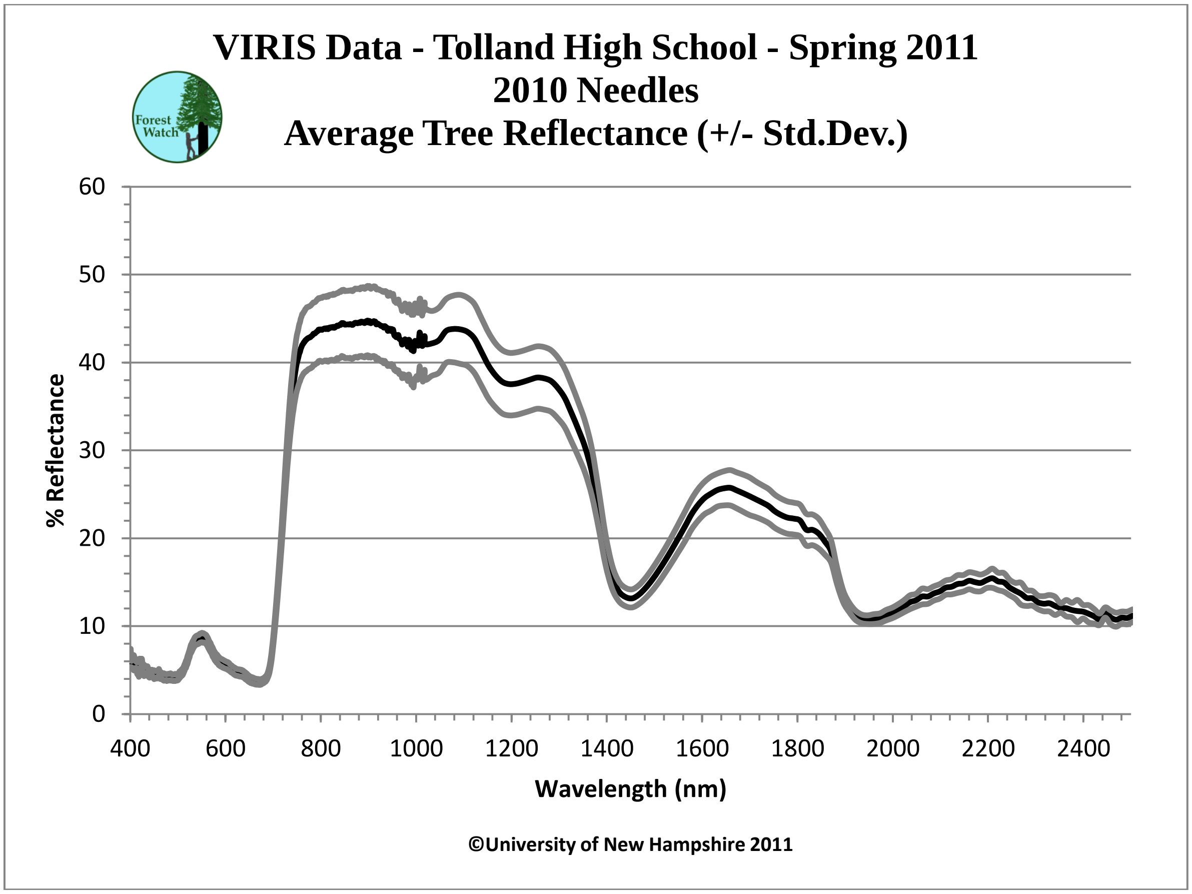
Needle Year	2010	2010	2010	2010	2010
Sampling Date	June 1, 2011				
Tree Number	1331	1332	1333	1334	1335
SubmittedBy	Frank Schmidt				
DBH	17.5	8.2	25.5	32	30.2
CrownHeight	4.9	4.1	9.3	10.8	10
TreeHeight	9.9	6.8	15	14.8	15.5
N-Coll-Ht	7	5	11	11	11.8
S-Coll-Ht	7	5	11	12	11
N-Fas-Len	97	89	75	84	71
S-Fas-Len	87	88	82	86	75
N-Need-Ret	3	2	4	3	3
S-Need-Ret	3	3	2	3	2
N-Water	52	53.1	51.3	50.1	51.4
S-Water	57.1	57.6	52.4	53.5	48.9
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	95	89	82	86	73
S-AvgNeed-Len	87	88	81	82	78
N-PerTipNec	0	3	1	33	10
S-PerTipNec	0	1	0	23	3
N-PerChlMot	1	4	0	17	7
S-PerChlMot	4	1	0	17	10
N-AvgTotDamg-Len	0	1.2	1	10	1
S-AvgTotDamg-Len	0	1	0.5	11	0
N-PerNeedBothSymp	0.5	0	0	10	0
S-PerNeedBothSymp	10	0	0	13	0
N-AvgPerDamage	0.2	1.1	1.4	8.1	1.2
S-AvgPerDamage	0.2	1	0	12.9	0.9


VIRIS Data - RHAM High School - Fall 2010
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
Mean
Reflectance (%)
80
70
60
50
40
30
20
10
0
400
900
1400
1900
2400
Wavelength (nm)
Copyright 2011 University of New Hampshire

Tolland High School

2010 Needles Spectral Data CT

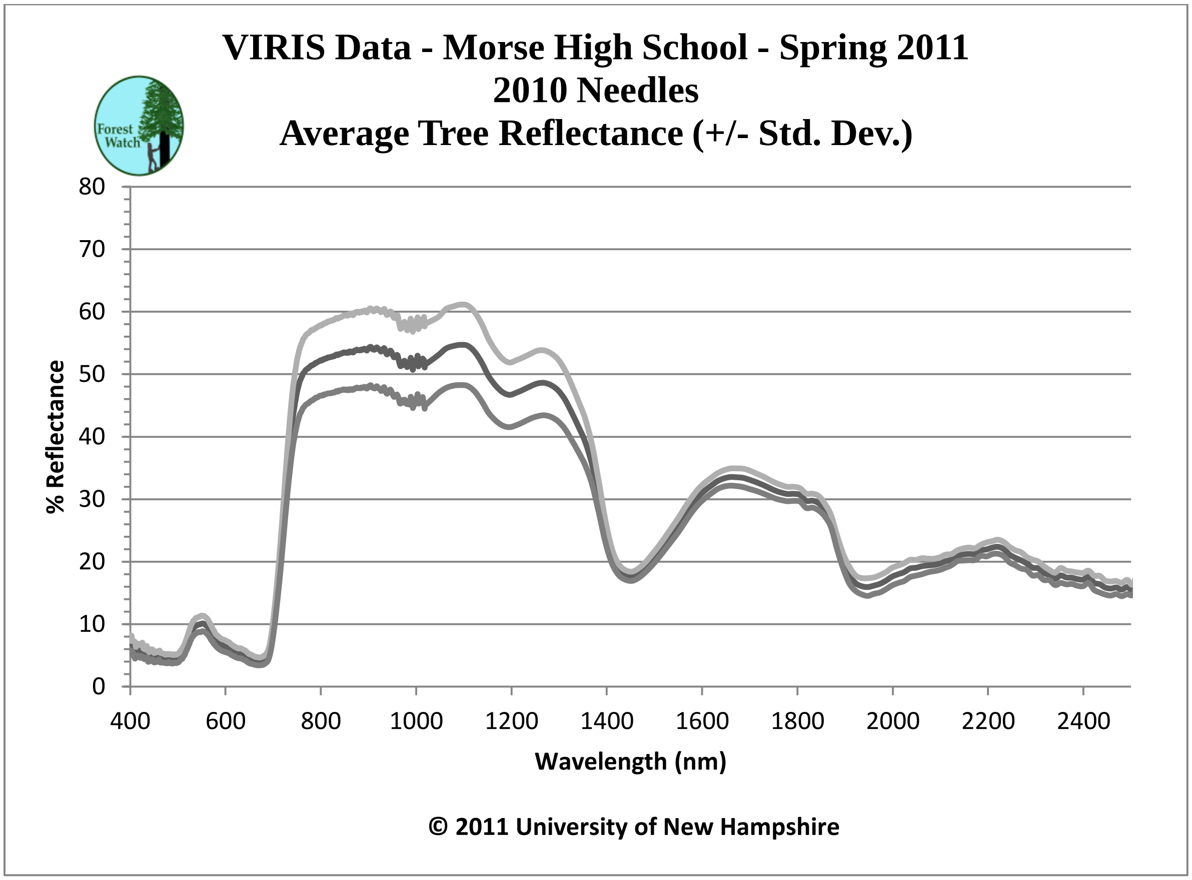
Index	REIP	NDVI	TM54	NIR31
1751N	722.4	0.812	0.526	0.847
1751S	722.4	0.792	0.539	0.819
1752N	719.3	0.85	0.558	0.85
1752S	720.8	0.84	0.532	0.796
1753N	719.3	0.828	0.543	0.815
1753S	723.9	0.826	0.547	0.815
1754N	722.4	0.853	0.527	0.821
1754S	725.4	0.848	0.54	0.839
1755B	722.4	0.819	0.589	0.851
1755S	722.4	0.84	0.589	0.896



VIRIS Data - Tolland High School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std.Dev.)
Forest Watch
% Reflectance
0
10
20
30
40
50
60
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
©University of New Hampshire 2011

Index	REIP	NDVI	TM54	NIR31
1741N	723.9	0.851	0.563	0.886
1741S	727	0.836	0.63	0.862
1742N	725.4	0.862	0.547	0.88
1742S	725.4	0.821	0.571	0.884
1743N	722.4	0.796	0.616	0.854
1743S	723.9	0.833	0.561	0.904
1744N	727	0.86	0.539	0.865
1744S	728.5	0.865	0.653	0.903
1745N	725.4	0.838	0.692	0.892
1745S	725.4	0.857	0.662	0.928

NeedleYear	2010	2010	2010	2010	2010
CollectionDate	6/6/2011	6/6/2011	6/6/2011	6/6/2011	6/6/2011
TreeNumber	1741	1742	1743	1744	1745
SubmittedBy	Carolyn Nichols & George Schaab	Carolyn Nichols & George Schaab	Carolyn Nichols & George Schaab	Carolyn Nichols & George Schaab	Carolyn Nichols & George Schaab
DBH	14	14	20	11	15
TreeHeight	4.20	6.20	5.00	4.80	6.20
N-Fas-Len	91	90	63	96	83
S-Fas-Len	89	101	92	65	70
N-Need-Ret	1	1	1	1	1
S-Need-Ret	1	1	1	1	
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	89	83.8	71.2	70.8	93
S-AvgNeed-Len	95.1	110.3	90.2	82.2	109.8
N-PerTipNec	0	13	60	17	20
S-PerTipNec	17	27	6	10	8
N-PerChlMot	17	83	100	23	60
S-PerChlMot	20	63	100	40	3
N-AvgTotDamg-Len	4.4	7.5	9	5.1	3
S-AvgTotDamg-Len	2.6	15.8	17.7	13.7	4.8
N-PerNeedBothSymp	0	10	40	0	20
S-PerNeedBothSymp	6.7	20	6	10	9
N-AvgPerDamage	2.5	8.9	12.5	7.2	3
S-AvgPerDamage	4.8	15	19.6	16.6	4

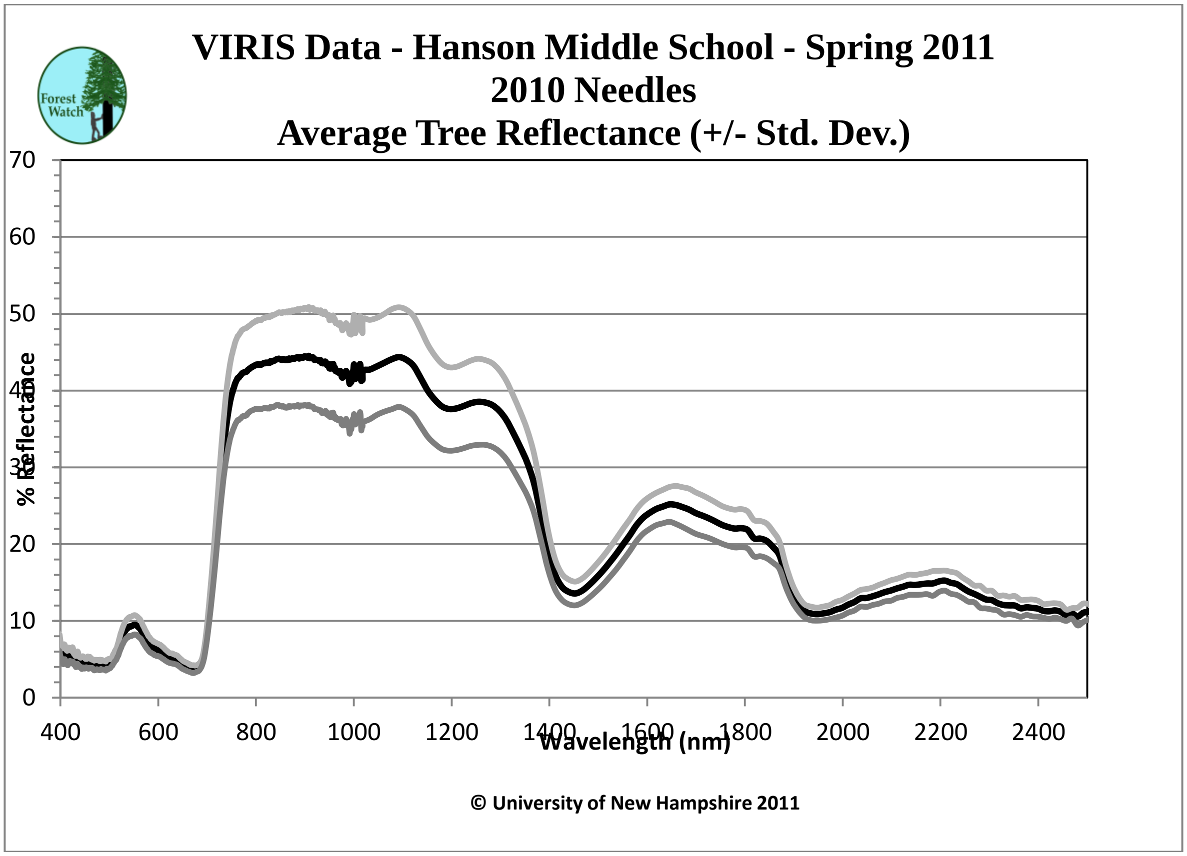

VIRIS Data - Morse High School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
Wavelength (nm)
0
10
20
30
40
50
60
70
80
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
© 2011 University of New Hampshire

Hanson Middle School

2010 Needles Biometric and Spectral Data MA

Index	REIP	NDVI	TM54	NIR31
1661N	723.9	0.833	0.501	0.838
1661S	723.9	0.815	0.545	0.833
1662N	725.4	0.823	0.524	0.846
1662S	723.9	0.81	0.54	0.827
1663N	725.4	0.834	0.54	0.881
1663S	720.8	0.808	0.524	0.855
1664N	725.4	0.837	0.553	0.851
1664S	723.9	0.837	0.568	0.858
1665N	720.8	0.795	0.569	0.828
1665S	723.9	0.824	0.571	0.849

NeedleYear	2010	2010	2010	2010	2010
CollectionDate	5/25/2011	5/25/2011	5/25/2011	5/25/2011	5/25/2011
TreeNumber	1661	1662	1663	1664	1664
SubmittedBy	Wes Blauss	Wes Blauss	Wes Blauss	Wes Blauss	Wes Blauss
DBH	28	30.6	25.5	29.9	34.4
CrownHeight	10.50	13.10	8.00	9.80	12.70
TreeHeight	11.5	15.5	10	10.7	18.1
N-Coll-Ht	3	7	5	5	7
S-Coll-Ht	3	7	5	5	7
N-Fas-Len	77	7.5	95	56	80
S-Fas-Len	76	79	92	50	82
N-Need-Ret	1	2	1	2	2
S-Need-Ret	1	2	1	2	2
N-NumNeedles	526	720	585	695	327
S-NumNeedles	992	765	492	332	634
N-AvgNeed-Len	75	74	78	55	78
S-AvgNeed-Len	84	75	71	48	82
N-PerTipNec	25	14	18	16	26
S-PerTipNec	16	19	16	15	18
N-PerChlMot	50	57	43	50	40
S-PerChlMot	65	36	49	38	56
N-AvgTotDamg-Len	4	3	2	2	3
S-AvgTotDamg-Len	3.5	2	2	3	3
N-PerNeedBothSymp	16	10	9	11	13
S-PerNeedBothSymp	9	12	4	5	11
N-AvgPerDamage	5	4	3	4	4
S-AvgPerDamage	4	3	3	6	4

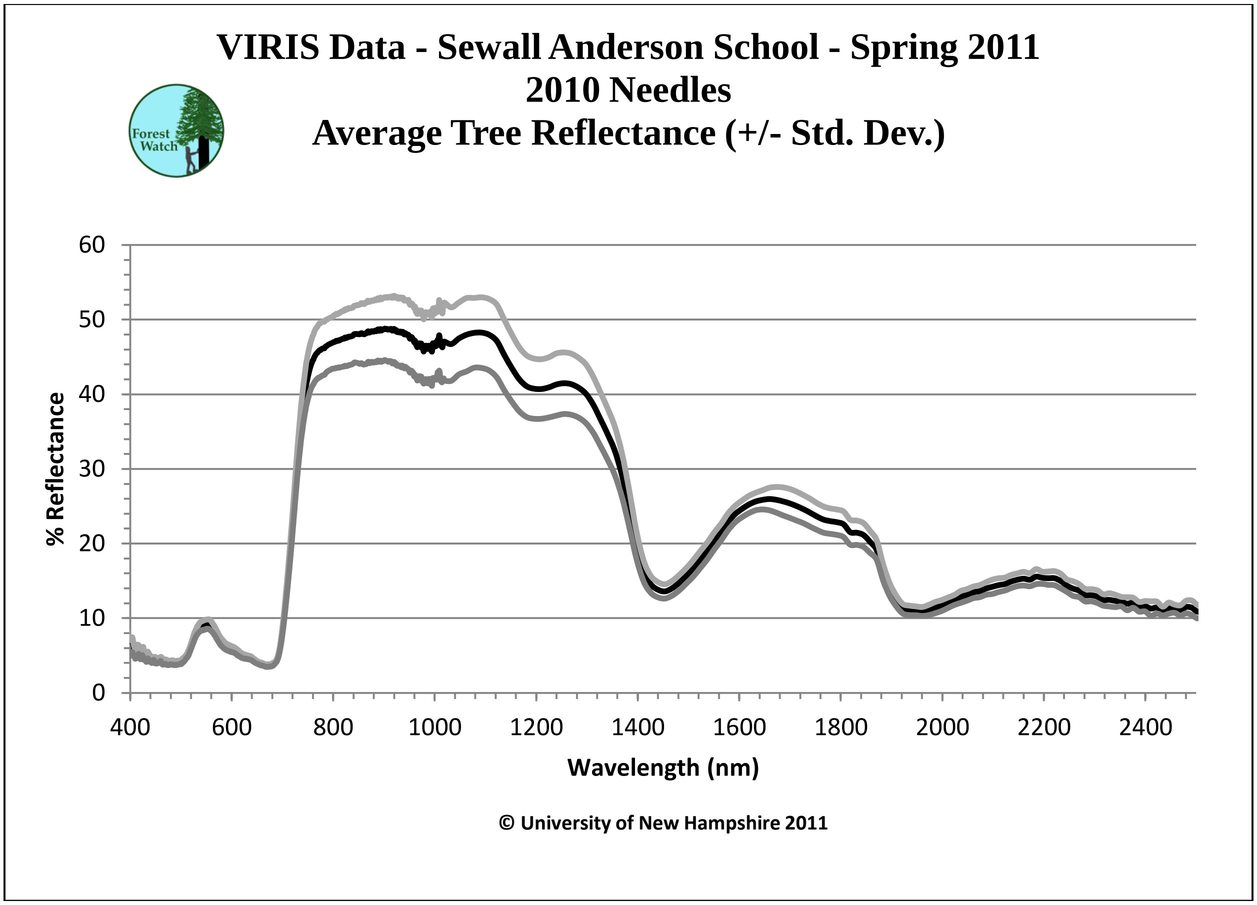

VIRIS Data - Hanson Middle School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
© University of New Hampshire 2011

Sewell Anderson School

2010 Needles — Biometric and Spectral Data — MA

	REIP	NDVI	TM54	NIR31
1196E	723.9	0.841	0.529	0.821
1196S	725.4	0.838	0.523	0.825
1197N	720.8	0.82	0.548	0.811
1197S	725.4	0.851	0.507	0.839
1198S	722.4	0.846	0.492	0.832
1198SW	722.4	0.847	0.496	0.843
1199N	728.5	0.849	0.525	0.861
1199S	720.8	0.835	0.508	0.803
1200N	725.4	0.851	0.508	0.859
1200S	725.4	0.835	0.518	0.817

NeedleYear	2010	2010	2010	2010	2010
CollectionDate	5/18/2011	5/18/2011	5/18/2011	5/18/2011	5/18/2011
TreeNumber	1196	1197	1198	1199	1200
SubmittedBy	Louise James	Louise James	Louise James	Louise James	Louise James
DBH	33.5	38.9	38.8	34	30.6
TreeHeight	15.10	17.40	19.70	20.10	15.80
N-Fas-Len	84	67	44	69	70
S-Fas-Len	82	81	63	81	75
N-Need-Ret	2	1	2	1	1
S-Need-Ret	2	2	2	2	1
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	84	67	44	69	70
S-AvgNeed-Len	82	81	63	81	75
N-PerTipNec	46	20	0	27	40
S-PerTipNec	33	0	20	13	57
N-PerChlMot	67	47	53	47	87
S-PerChlMot	27	27	33	30	57
N-AvgTotDamg-Len	3.2	1.2	1.2	3.1	3.4
S-AvgTotDamg-Len	0.9	0.5	0.9	1.1	3.4
N-PerNeedBothSymp	27	17	0	10	33
S-PerNeedBothSymp	13	0	7	7	33
N-AvgPerDamage	4	2	3	5	5
S-AvgPerDamage	1	0.6	1	1	5

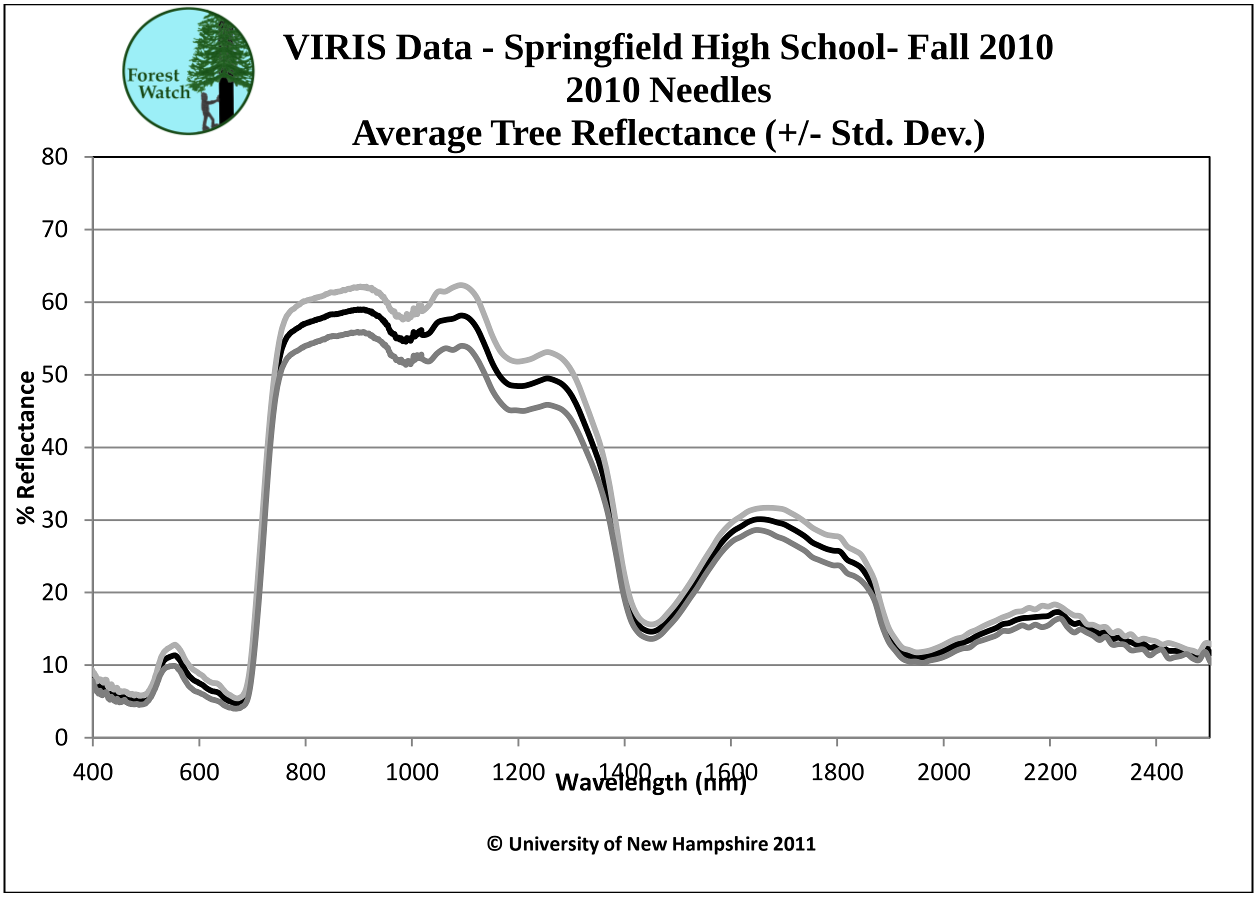

VIRIS Data - Sewall Anderson School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
60
50
40
30
20
10
0
% Reflectance
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
© University of New Hampshire 2011

Springfield Central High School

2010 Needles Biometric and Spectral Data MA

	REIP	NDVI	TM54	NIR31
1733S	722.4	0.828	0.447	0.741
1735S	723.9	0.858	0.532	0.898
1736S	710	0.777	0.518	0.845
1737S	723.9	0.839	0.482	0.775
1738S	723.9	0.849	0.473	0.809

NeedleYear	2010	2010	2010	2010	2010	2010	2010	2010
CollectionDate	10/19/2010					10/18/2010		
TreeNumber	1731	1732	1733	1734	1735	1736	1737	1738
SubmittedBy	Naomi Volain	Naomi Volain	Naomi Volain	Naomi Volain	Naomi Volain	Naomi Volain	Naomi Volain	Naomi Volain
DBH	26.7		16.4	25.18	7.15	27.15	31.8	36.1
CrownHeight	8.15	15.73	21.32	24.17	6.37	18.21		
TreeHeight	27.78	25.44	23.37	28.61	14.80	28.35	17.83	18.30
S-Coll-Ht				3.08	3.00	3.58	8.90	
S-Fas-Len				78.6	89.1	81	92	
S-Need-Ret				2		1	3	3
S-NumNeedles				30	30	30	30	30
S-AvgNeed-Len				79	86.5	84	85.5	100.3
S-PerTipNec				30	57	67	56	33
S-PerChlMot				6.7	60	43	36	17
S-AvgTotDamg-Len				1.3	12.1	2.3	6.1	0.8
S-PerNeedBothSymp				3.3	37	27	26	10
S-AvgPerDamage				2	13.15	30.4	7.82	79

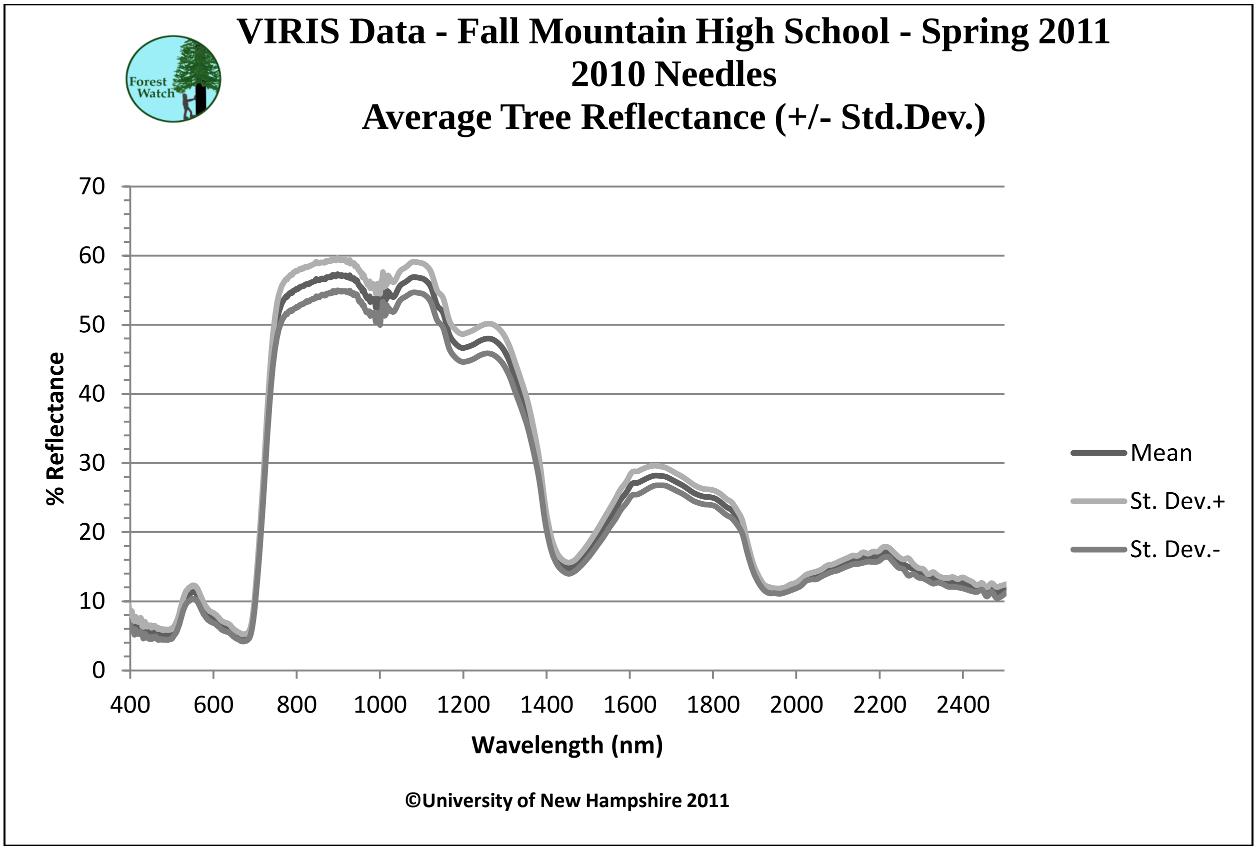

VIRIS Data - Springfield High School- Fall 2010
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
Wavelength (nm)
80
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
© University of New Hampshire 2011

Fall Mt. Regional High School - Spring

2010 Needles Biometric and Spectral Data NH

Index	REIP	NDVI	TM54	NIR31
1811N	727	0.82	0.508	0.86
1811S	728.5	0.823	0.484	0.852
1812N	726.2	0.834	0.474	0.83
1812S	725.4	0.831	0.455	0.803
1813N	725.4	0.797	0.475	0.812
1813S	723.9	0.83	0.487	0.845
1814N	722.4	0.818	0.464	0.797
1814S	727	0.848	0.474	0.824
1815N	723.9	0.828	0.46	0.799
1815S	728.5	0.841	0.463	0.769

NeedleYear	2010	2010	2010	2010	2010
CollectionDate	5/18/2011	5/18/2011	5/18/2011	5/18/2011	5/18/2011
TreeNumber	1811	1812	1813	1814	1815
SubmittedBy	William Doran	William Doran	William Doran	William Doran	William Doran
DBH	38.3	37.5	53.5	43.75	45.9
CrownHeight	10.10	11.00	11.10	16.42	16.70
TreeHeight	11.20	12.00	12.30	17.90	18.60
N-Coll-Ht	0.00	6.40	10.00	6.00	7.00
S-Coll-Ht	0.00	7.40	10.00	5.80	6.40
N-Fas-Len	81	84	89	65	81
S-Fas-Len	84	105	95	81	89
N-Need-Ret	2	1	1	2	1
S-Need-Ret	2	1	2	2	1
N-Water	52.1	51	42.5	48.7	53
S-Water	55.5	51	44.5	48.9	66
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	78	68	91	78	87
S-AvgNeed-Len	80	74	94	91	83
N-PerTipNec	13	17	30	40	56
S-PerTipNec	27	23	13	40	43
N-PerChlMot	30	17	23	17	10
S-PerChlMot	30	6	24	17	27
N-AvgTotDamg-Len	7	3	3	2	3
S-AvgTotDamg-Len	9	1	3	1	4
N-PerNeedBothSymp	10	3	7	10	10
S-PerNeedBothSymp	10	0	3	3	20
N-AvgPerDamage	15	5	4	3	3
S-AvgPerDamage	12	1	3	3	12



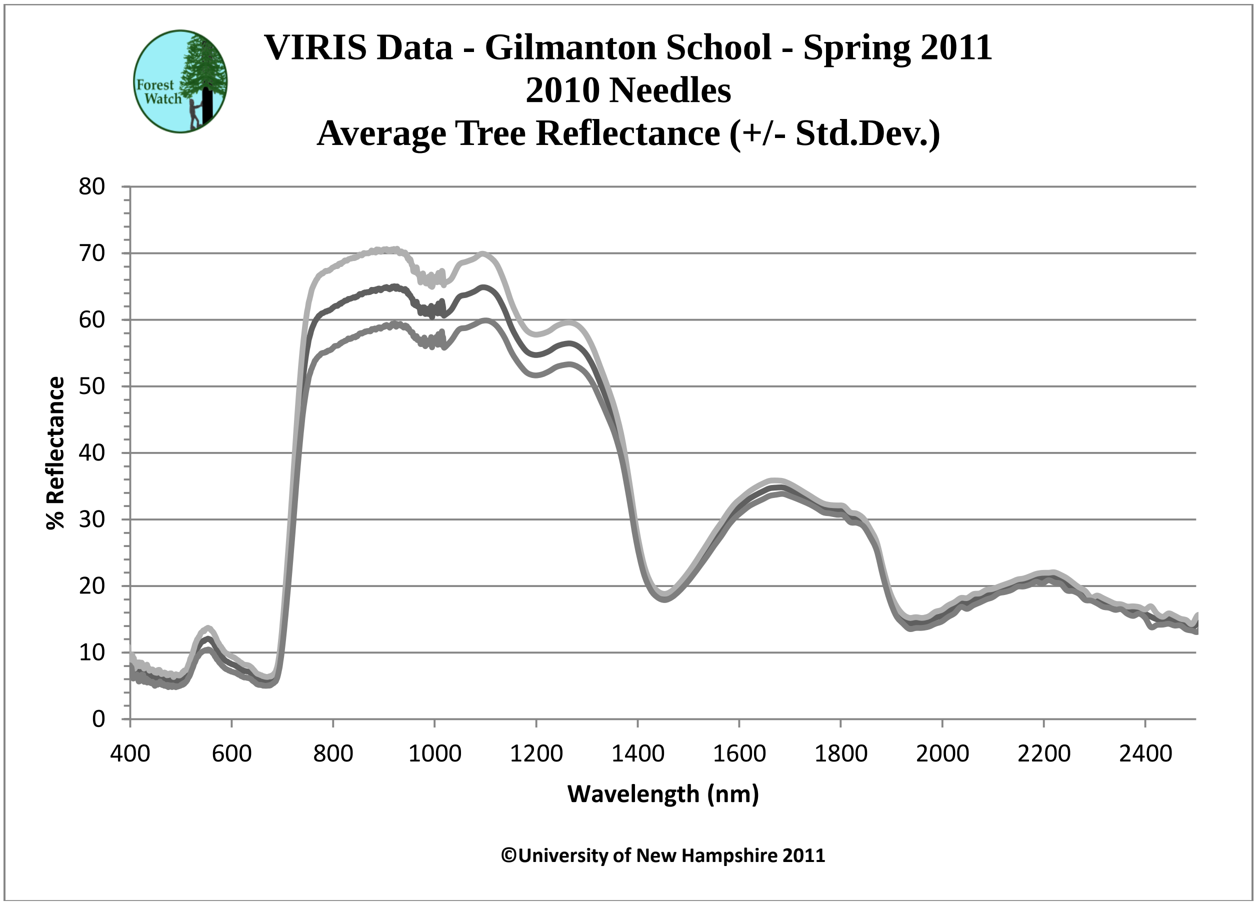
VIRIS Data - Fall Mountain High School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std.Dev.)
Forest Watch
% Reflectance
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Mean
St. Dev.+
St. Dev.-
©University of New Hampshire 2011

Gilmanton Middle School

2010 Needles Biometric and Spectral Data NH

Index	REIP	NDVI	TM54	NIR31
371	723.9	0.812	0.502	0.867
372	722.4	0.825	0.467	0.802
373	723.9	0.838	0.559	0.888
375	723.9	0.806	0.562	0.895

NeedleYear	2010	2010	2010	2010	2010
CollectionDate		4/18/2011		4/18/2011	4/18/2011
TreeNumber	371	372	373	374	375
SubmittedBy	Mary Fougere	Mary Fougere	Mary Fougere	Mary Fougere	Mary Fougere
DBH	29.9	28	33.8	38.3	38
CrownHeight	11.7	10.7	11.6		11.6
TreeHeight	14.5	18.6	16.8	16.7	20.4
N-Coll-Ht	11.7	10.7	11.6		11.6
N-Fas-Len	82	87	79		77
N-Need-Ret	2	3	2		3
N-Water	56.5	56.7	56.5		54.5
N-NumNeedles	30	30	30		30
S-NumNeedles	30	30	30		30
N-AvgNeed-Len	67.7	67.6	68.2		65.3
N-PerTipNec	1	2	2	0	3
N-PerChlMot	1	2	1	0	1
N-AvgTotDamg-Len	2.40	4.6	1	0	3.6
N-PerNeedBothSymp	10	2	2		0
N-AvgPerDamage	4.5	6.1	1.5		6.4



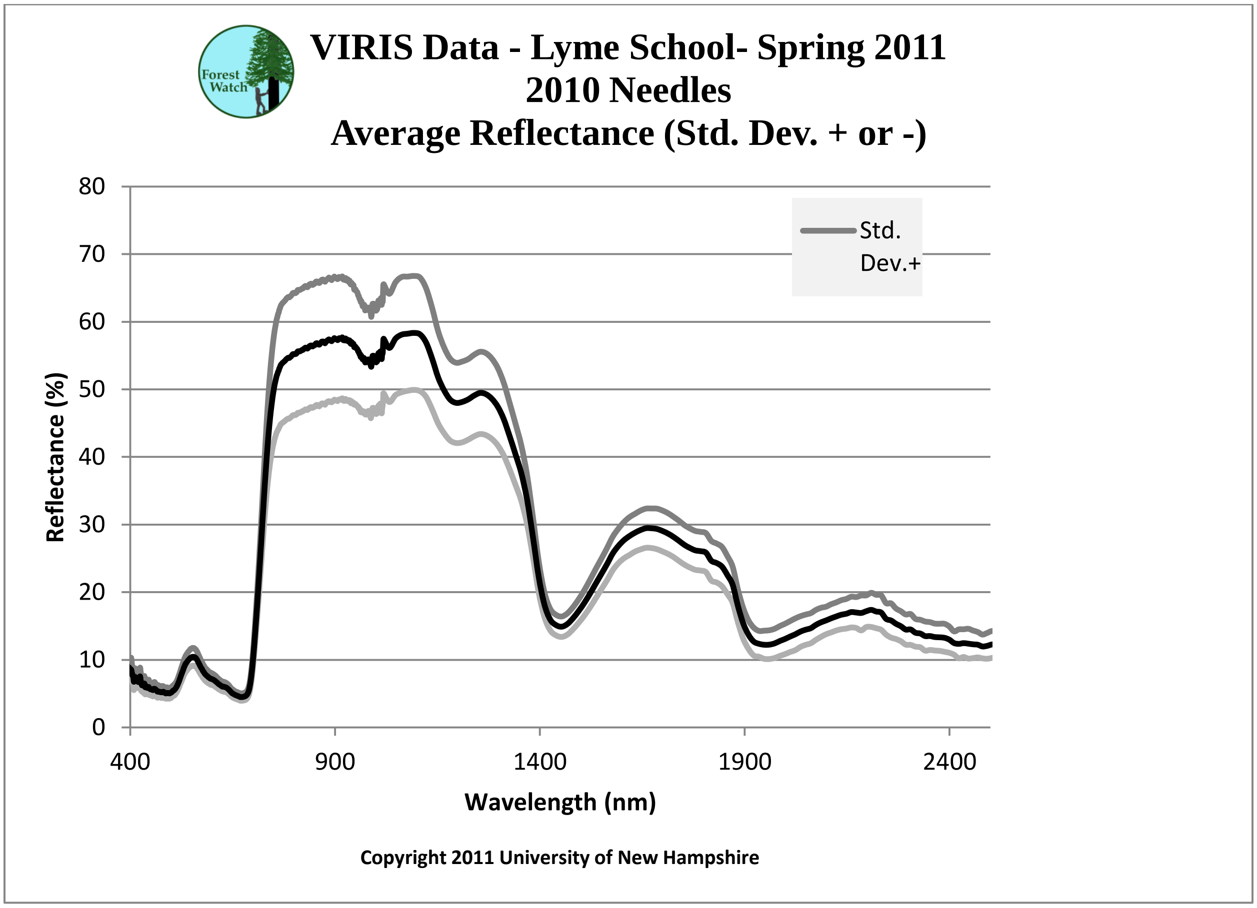
Forest Watch
VIRIS Data - Gilmanton School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std.Dev.)
% Reflectance
Wavelength (nm)
80
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
©University of New Hampshire 2011

Lyme School

2010 Needles Biometric and Spectral Data NH

	REIP	NDVI	TM54	NIR31
1366N	722.4	0.849	0.445	0.766
1366S	728.5	0.855	0.441	0.794
1367N	723.9	0.843	0.451	0.785
1367S	723.9	0.832	0.451	0.789
1368N	720.8	0.809	0.488	0.846
1368S	716.2	0.827	0.459	0.827
1369N1	723.9	0.829	0.497	0.842
1369N2	719.3	0.818	0.764	1.023
1369S1	723.9	0.831	0.483	0.832
1369S2	711.6	0.798	0.625	0.933
1370N	727	0.847	0.495	0.863
1370S	725.4	0.862	0.484	0.855

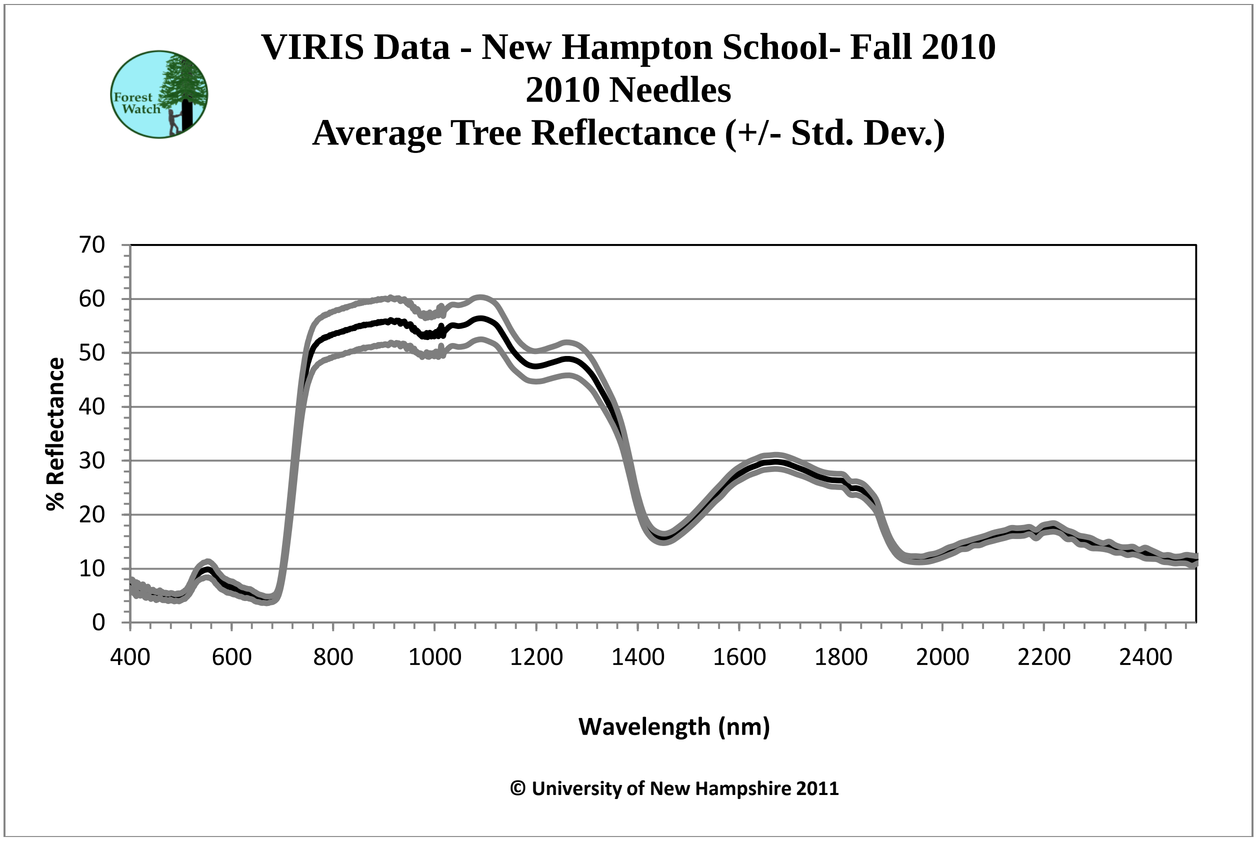
NeedleYear	2010	2010	2010	2010	2010
CollectionDate	11/23/2010	11/23/10	11/23/2010	11/23/2010	11/23/2010
TreeNumber	1366	1367	1368	1369	1370
SubmittedBy	Skip Pendleton	Skip Pendleton	Skip Pendleton	Skip Pendleton	Skip Pendleton
DBH	12.5	19	53.3	30	22.6
TreeHeight	9.70	9.70	14.30	16.50	15.80
N-Coll-Ht	6.00	6.00	6.00	6.00	6.00
S-Coll-Ht	6.00	6.00	6.00	6.00	6.00
N-Fas-Len	83	104	88	84	89
S-Fas-Len	88	105	101	87	80
N-Need-Ret	1	1	1	1	1
S-Need-Ret	2	1	1	2	1



Forest Watch
VIRIS Data - Lyme School- Spring 2011
2010 Needles
Average Reflectance (Std. Dev. + or -)
Std. Dev.+
Reflectance (%)
80
70
60
50
40
30
20
10
0
400
900
1400
1900
2400
Wavelength (nm)
Copyright 2011 University of New Hampshire

	REIP	NDVI	TM54	NIR31
1721N	723.9	0.865	0.486	0.802
1721S	727	0.855	0.472	0.813
1722N	727	0.835	0.517	0.878
1722S	723.9	0.854	0.568	0.897
1723N	722.4	0.833	0.522	0.877
1723S	727	0.819	0.565	0.918
1724N	730.1	0.87	0.533	0.883
1724S	723.9	0.828	0.497	0.851
1725N	720.8	0.847	0.535	0.865
1725S	723.9	0.813	0.484	0.839

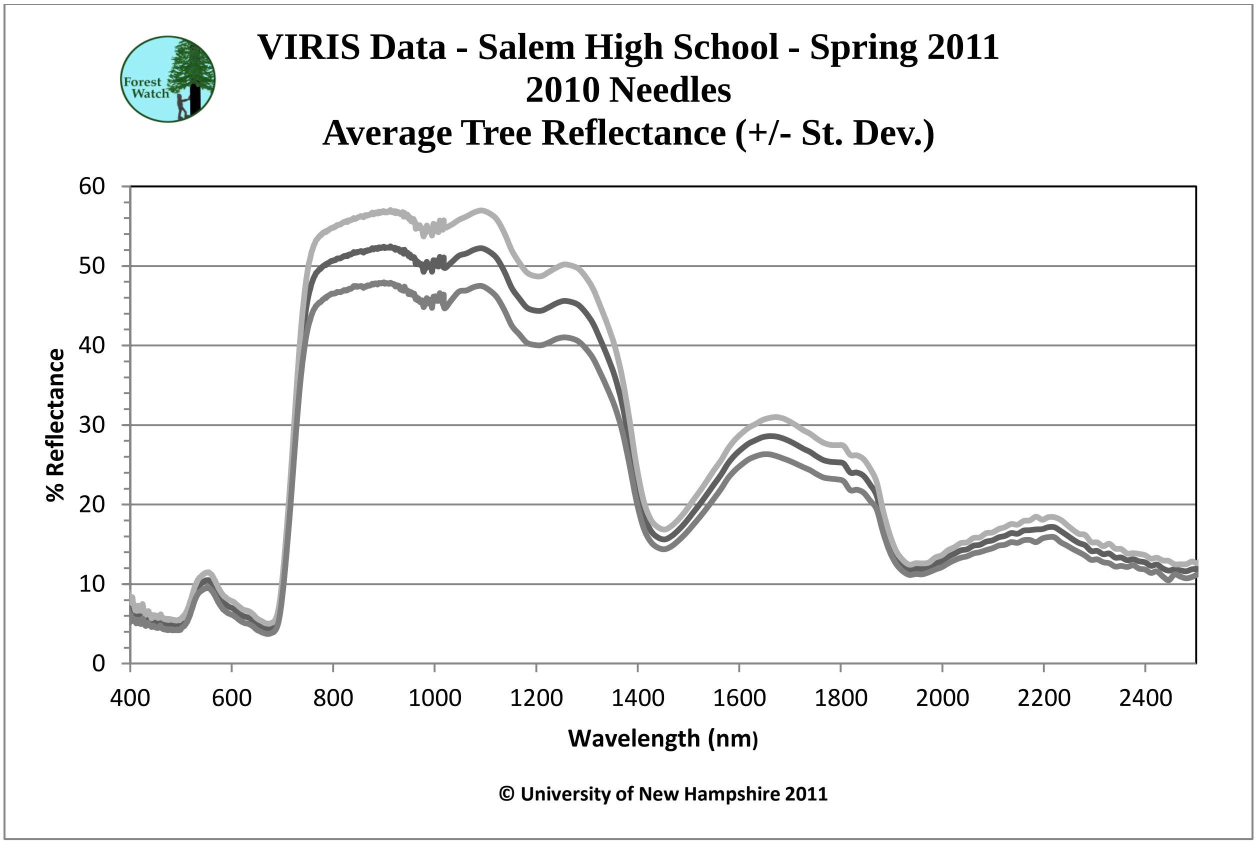
NeedleYear	2010	2010	2010	2010	2010
CollectionDate	5/6/2011	5/6/2011	5/6/2011		
TreeNumber	1721	1722	1723	1724	1725
SubmittedBy	Jon Shackett	Jon Shackett	Jon Shackett	Jon Shackett	Jon Shackett
DBH	178.2	41.9	12.4	35.9	56.1
CrownHeight	16.80	10.90	5.00	12.20	19.80
TreeHeight	38.40	15.10	5.20	14.50	21.30
N-Coll-Ht	5.00	4.00	3.00	4.00	4.00
S-Coll-Ht	5.00	4.00	3.00	4.00	4.00
N-Fas-Len	10.1	8	8.9	6.9	6.6
S-Fas-Len	7	6.3	7.7	6.9	7
N-Need-Ret	2	2	2	2	2
S-Need-Ret	2	2	2	2	2
N-Water	27	44	58	47	52
S-Water	51	51	59	50	49
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	100	68	86	57	53
S-AvgNeed-Len	67	55	84	69	68
N-PerTipNec	6.6	0	1	35	6.7
S-PerTipNec	17	17	0	37	13
N-PerChlMot	20	0	27	60	37
S-PerChlMot	1	17	0	60	13
N-AvgTotDamg-Len	25	0	10	0.1	2.2
S-AvgTotDamg-Len	3.1	9	0	0.8	1.4
N-PerNeedBothSymp	0	0	3	0	7
S-PerNeedBothSymp	1	8	0	23	0
N-AvgPerDamage	1	0	12	2	4
S-AvgPerDamage	5	9	0	8	2


VIRIS Data - New Hampton School- Fall 2010
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
© University of New Hampshire 2011

Salem High School

2010 Needles Spectral Data NH

Index	REIP	NDVI	TM54	NIR31
1351N	725.4	0.797	0.54	0.874
1351S	722.4	0.806	0.518	0.787
1353N	714.6	0.799	0.539	0.864
1353S	720.8	0.803	0.517	0.825
1354N	725.4	0.828	0.52	0.869
1354S	727	0.842	0.53	0.844
1355N	722.4	0.834	0.514	0.858
1355S	730.1	0.85	0.508	0.848
1504N	722.4	0.848	0.52	0.858
1504S	719.3	0.837	0.55	0.883



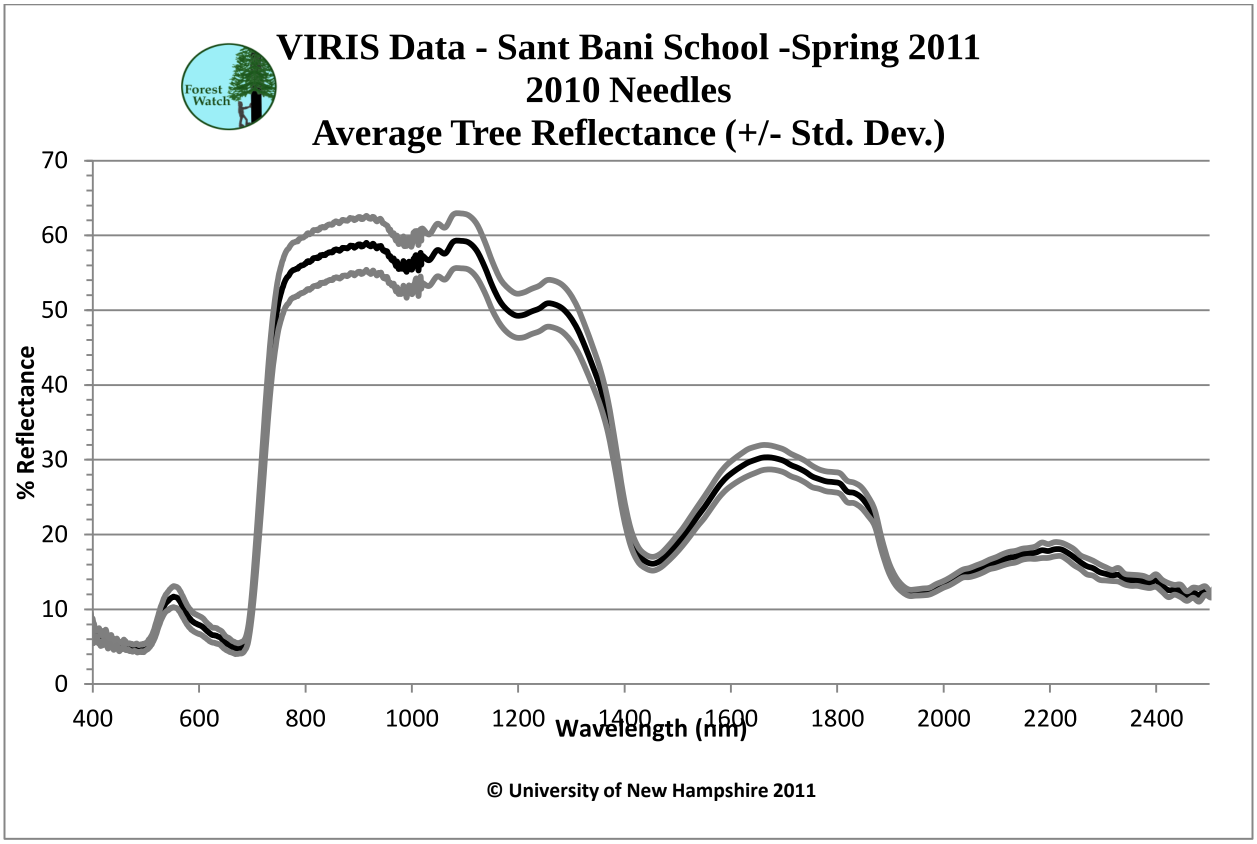
VIRIS Data - Salem High School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- St. Dev.)
Forest Watch
% Reflectance
0
10
20
30
40
50
60
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
© University of New Hampshire 2011

Sant Bani School

2010 Needles Biometric and Spectral Data NH

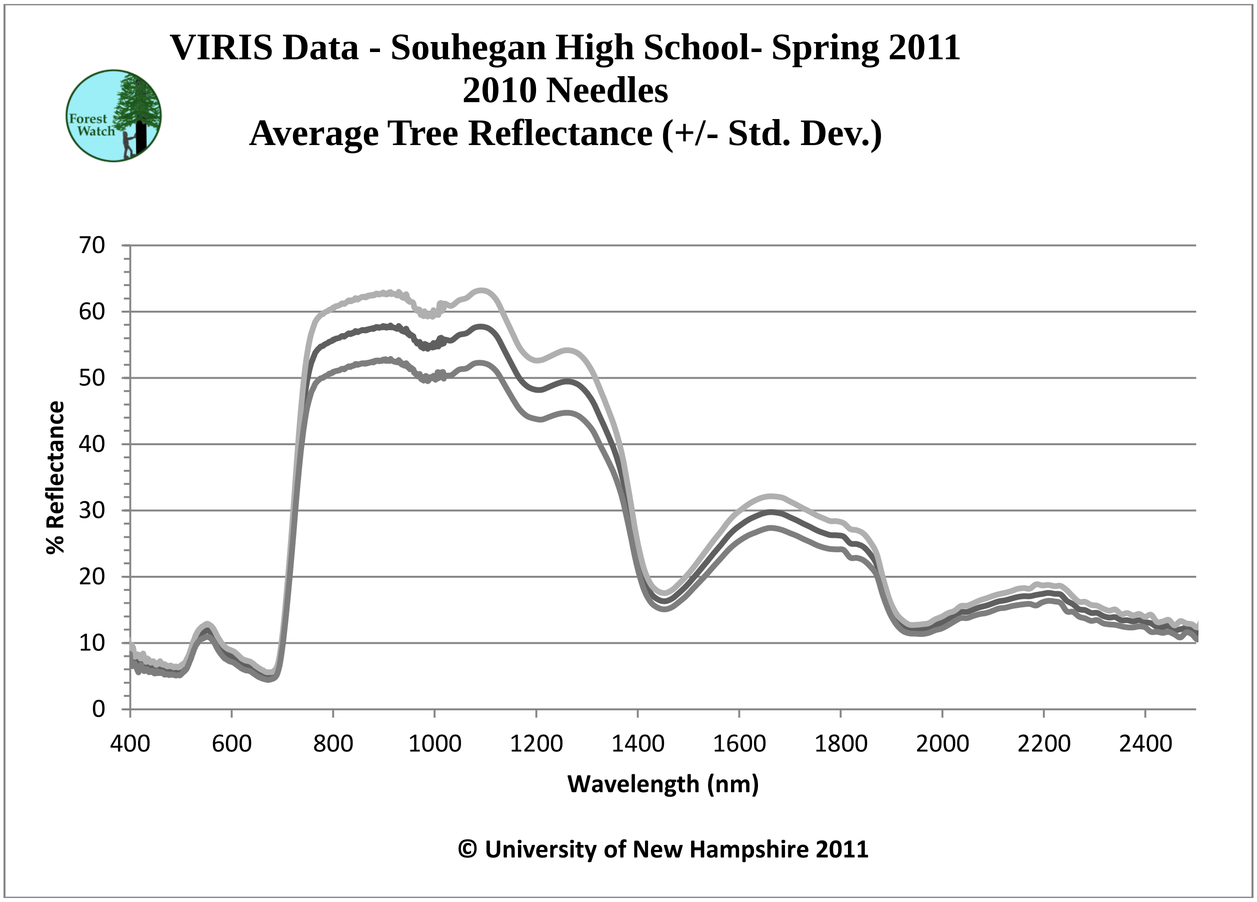
	REIP	NDVI	TM54	NIR31
100S	720.8	0.834	0.51	0.854
100W	717	0.783	0.515	0.866
96N	723.9	0.854	0.494	0.841
96S	723.9	0.839	0.498	0.833
97N	717.7	0.824	0.512	0.869
97S	723.9	0.82	0.515	0.873
98N	723.9	0.823	0.503	0.847
98S	713.1	0.811	0.472	0.832
99S	722.4	0.849	0.483	0.835
99W	723.9	0.833	0.491	0.841

NeedleYear	2010	2010	2010	2010	2010
CollectionDate	5/9/2011	5/9/2011	5/9/2011	5/9/2011	5/9/2011
TreeNumber	96	97	98	99	100
SubmittedBy	Robert Schongalla	Robert Schongalla	Robert Schongalla	Robert Schongalla	Robert Schongalla
DBH	54.5	74.7	70.4	64.3	42.5
CrownHeight	20.00	19.50	20.00	24.50	19.50
TreeHeight	22.90	20.20	22.60	26.30	21.50
N-Coll-Ht	4.50	3.50	4.50	4.50	3.00
S-Coll-Ht	3.50	4.00	3.50	3.50	4.50
N-Fas-Len	80	94	82	80	9.5
S-Fas-Len	84	82	92	74	9.5
N-Need-Ret	3	2	3	1	2
S-Need-Ret	2	3	2	1	3
N-Water	49.3	51.5	48.9	50.5	51.8
S-Water	50.9	51.6	50.1	49.2	47.8
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	74	85	82	81	94
S-AvgNeed-Len	80	80	87	75	82
N-PerTipNec	43	53	10	57	43
S-PerTipNec	33	30	27	43	39
N-PerChlMot	7	33	10	13	53
S-PerChlMot	17	7	23	7	23
N-AvgTotDamg-Len	9.2	34	0.5	6.9	11.2
S-AvgTotDamg-Len	5.8	7.5	8.3	5.3	10.4
N-PerNeedBothSymp	0	23	3	7	23
S-PerNeedBothSymp	7	0	10	0	10
N-AvgPerDamage	12.5	39.7	0.7	8.5	12
S-AvgPerDamage	7.3	9.4	9.5	7	12.4


VIRIS Data - Sant Bani School -Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
© University of New Hampshire 2011

Index	REIP	NDVI	TM54	NIR31
1761N	723.9	0.823	0.49	0.81
1761S	723.9	0.814	0.509	0.857
1762N	725.4	0.788	0.484	0.809
1762S	728.5	0.821	0.489	0.839
1763N	723.9	0.826	0.505	0.861
1763S	723.9	0.834	0.489	0.839
1764N	727	0.855	0.512	0.862
1764S	725.4	0.788	0.497	0.852
1765N	724.7	0.817	0.492	0.812
1765S	728.5	0.825	0.483	0.845

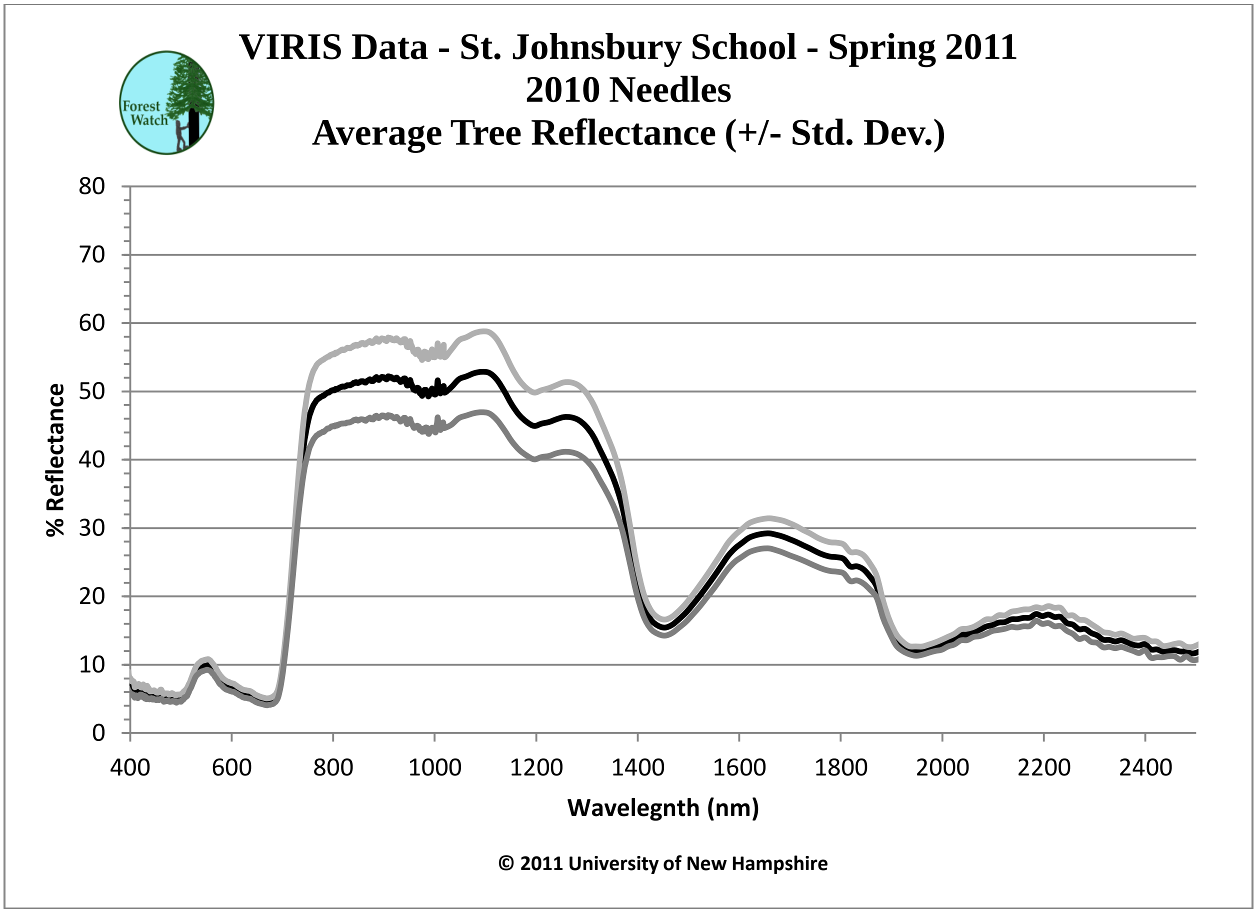
NeedleYear	2010	2010	2010	2010	2010
CollectionDate	4/-/2011	4/-/2011	4/-/2011	4/-/2011	4/-/2011
TreeNumber	1761	1762	1763	1764	1765
SubmittedBy	Melissa Chapman	Melissa Chapman	Melissa Chapman	Melissa Chapman	Melissa Chapman
DBH	11.5	14.5	30.5	32.6	29.2
CrownHeight	5.95	6.04	7.66	6.88	6.65
TreeHeight	6.95	6.61	10.92	10.47	10.90
N-Coll-Ht	3.50	3.00	6.70	5.10	5.90
S-Coll-Ht	4.00	3.90	6.40	5.30	6.00
N-Fas-Len	61	69	79	52	91
S-Fas-Len	79	69	77	75	93
N-Need-Ret	2	2	2	2	2
S-Need-Ret	2	2	2	2	2
N-Water	59	56.2	59.7	67.6	60
S-Water	58.3	58.7	56.5	56.1	59.1
N-NumNeedles	30	30	30	30	30
S-NumNeedles	30	30	30	30	30
N-AvgNeed-Len	75.6	65.5	72.2	63.5	86.9
S-AvgNeed-Len	69.7	62.5	68.9	76.8	87.7
N-PerTipNec	20	23.3	20	40	60
S-PerTipNec	6.6	36.7	23	30	63
N-PerChlMot	23	6.7	50	10	50
S-PerChlMot	16	6	46	23.3	40
N-AvgTotDamg-Len	2.5	3.2	2.4	0.7	1.4
S-AvgTotDamg-Len	1	6.1	1.9	1.3	1.3
N-PerNeedBothSymp	10	0	13	7	30
S-PerNeedBothSymp	3	23	10	7	27
N-AvgPerDamage	3	9	3	1	1.6
S-AvgPerDamage	1.3	9.7	2.9	1.6	1.5


VIRIS Data - Souhegan High School- Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
© University of New Hampshire 2011

St. Johnsbury School

2010 Needles Spectral Data VT

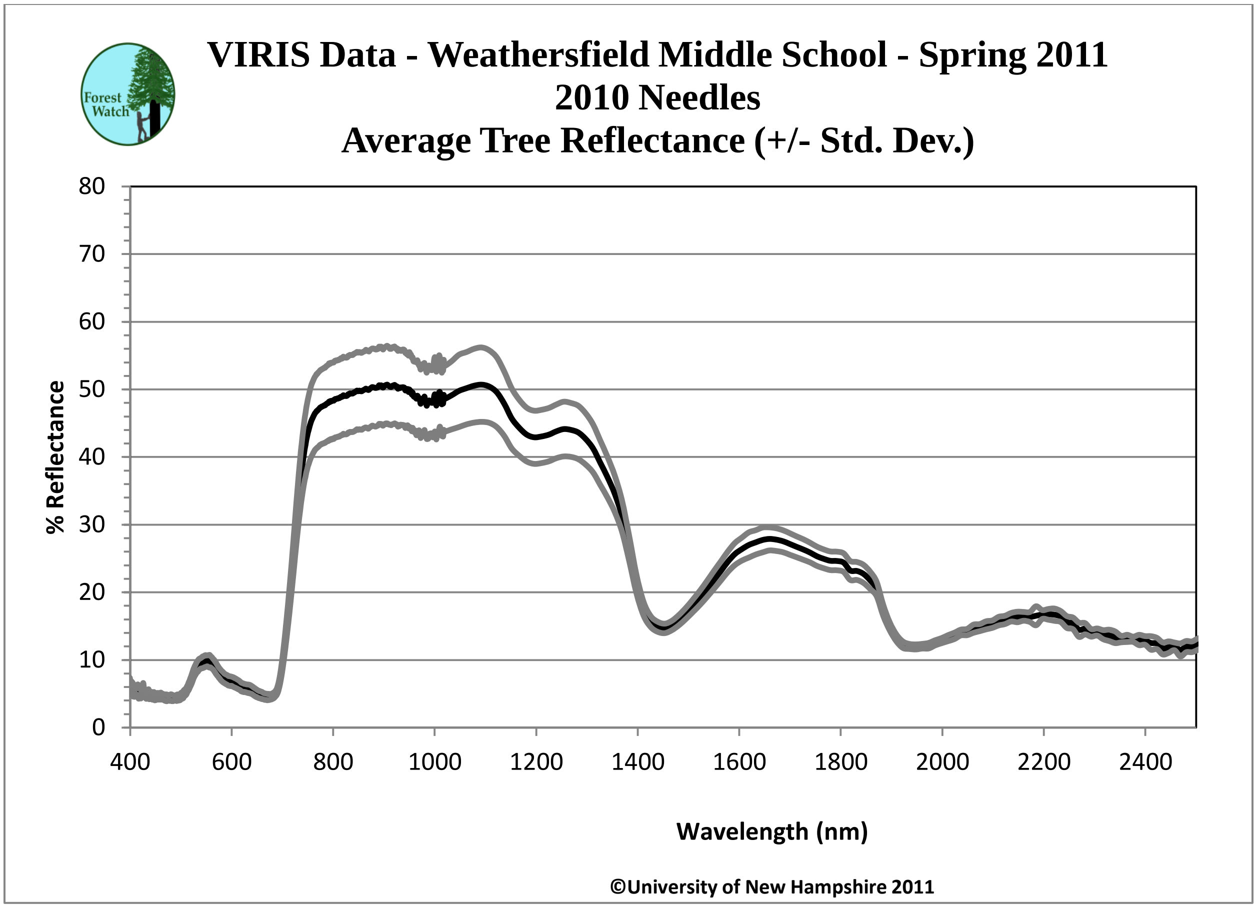
Index	REIP	NDVI	TM54	NIR31
1806N	728.5	0.838	0.52	0.888
1806S	727	0.812	0.56	0.903
1807N	723.9	0.775	0.554	0.855
1807S	725.4	0.832	0.528	0.85
1808N	725.4	0.79	0.575	0.874
1808S	723.9	0.824	0.547	0.875
1809N	723.9	0.803	0.578	0.87
1809S	723.9	0.832	0.535	0.885
1810N	728.5	0.846	0.508	0.855
1810S	727	0.838	0.532	0.877


VIRIS Data - St. Johnsbury School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
80
70
60
50
40
30
20
10
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelegnth (nm)
© 2011 University of New Hampshire

Weathersfield Middle School

2010 Needles Spectral Data VT

Index	REIP	NDVI	TM54	NIR31
1681N	717.7	0.753	0.637	0.951
1681S	724.7	0.811	0.522	0.855
1682N	720.8	0.817	0.523	0.81
1682S	723.9	0.811	0.521	0.809
1683N	725.4	0.806	0.519	0.853
1683S	720.8	0.8	0.548	0.905
1684N	725.4	0.852	0.499	0.823
1684S	726.2	0.847	0.567	0.889
1685N	722.4	0.777	0.56	0.893
1685SUB	727	0.851	0.486	0.822



VIRIS Data - Weathersfield Middle School - Spring 2011
2010 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
% Reflectance
0
10
20
30
40
50
60
70
80
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
©University of New Hampshire 2011

Chapter Eight - Avenues for New Forest Watch Research in 2012

Three interesting ideas arise from the 2010 analysis of needles (in 2011):

- Needle retention fell below 2.0 years for the first time since Forest Watch began in 1992. This year's average retention of 1.71 may be related to the PAN event and the smoke drifting south from fires in Canada in May 2010 (Figure 5.13, p. 46). We talked with FW teachers about this in December 2010 and asked them to pay special attention to this in 2011 collections. Their observations produced the new findings about needle retention. **Very clear, precise scientific questions may help guide annual collections.**

- Trees are getting too large for schools to use in research. At every school visited, the white pines selected 15 to 20 years ago are now tall stately adults that are difficult for students to sample. It is also difficult for students to measure heights of these trees when many are crowded in dense stands of other trees, canopies shaded to minimal breadth and tops far out of view. Several schools, however, have rich potential for sampling new trees. **An experiment in transitioning to new trees seems timely.**

- Research by UNH PhD candidate Tzu-ling Lai suggests that some ozone may be "falling" from the stratosphere during low pressure weather events, raising ozone levels at upper elevations. And ozone events may be occurring in spring and winter, rather than just in summertime. **Monitoring month by month and/or monitoring at different elevations may support monitoring ozone year-round and in new locations.**

Proposal: This year (and if it works, in future years), Forest Watch might involve teachers and students more in the process of asking research questions. We hope you will continue to collect needles, measure trees and examine needles just as you have in the past. But these new questions might add more Forest Watch activities to your classroom and enhance the questions students ask as they ponder Forest Watch data. If you decide to engage in asking any of these questions or in developing your own questions, please let us know. Forest Watch can work with you to develop new protocols, data forms, whatever you need from UNH to make it work.

The 2010 Forest Watch data suggests the questions on the following pages. In the next few weeks, Forest Watch will develop protocols or locate existing lab activities for each one. We will post them on our web site. Let us know if you try these new research questions.

Can we find any evidence to explain the needle retention loss?

The 2009 needles which many trees lost in 2010 would now be third-year needles in 2012 (Figure 8.1). Some trees retain a few of these weathered needles. If any are retained on our white pines, can students examine them?

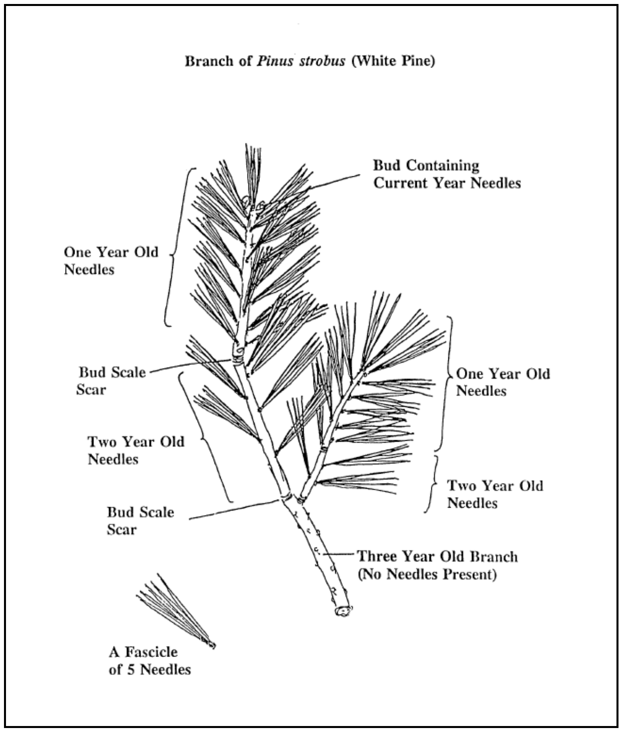


Figure 8.1: A white pine twig shows the location of first-year twigs at the distal end of the twig. Third-year twigs opened in June 2009.

University of New Hampshire Extension foresters believe the needle cast was caused by a fungus. Visit their site at http://extension.unh.edu/news/2010/06/white_pine_needles_turning_bro.html

Karen P. Bennett, Extension Forestry Professor and Specialist, told us, "We called the problem white pine needle cast. The VT folks identified two causal agents:

- Brown Spot Needle Blight caused by *Scirrhia acicola*.
- The other is a white pine needle cast caused by *Canavirgella banfieldii*. (See Figure 8.2).

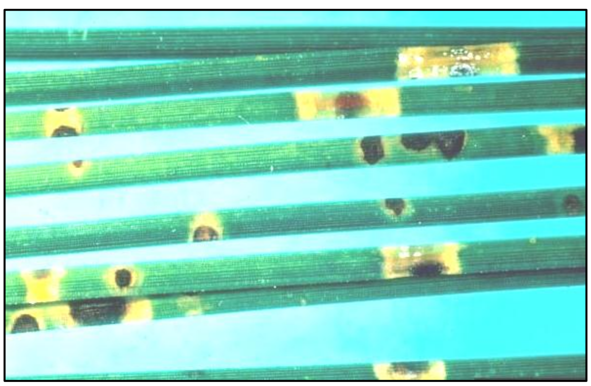


Figure 8.2: A close-up of damage caused by Scirrhia acicola shows chlorotic mottling similar to ozone damage. However, the yellow spots include a black spot, perhaps a location of fungal hyphae. At right, Canavirgella banfieldii shows browning on a white pine needle with heavy damage along the stomatal lines, different from more uniform tip necrosis caused by ozone..Scirrhia acicola from Department of Agriculture, France, mid-Pyrenees. Canavirgella banfieldii photo from Branching Out, IPM newsletter, Cornell Dept. of Plant Pathology and Cornell Cooperative Extension.

"Our pathologists seem to think that *Canavirgella* was the most common agent."

- This project might involve extensive cross-sectioning of needles as well as lessons in fungi and the signs they exhibit on a host plant. Do the needles show evidence of ozone damage? Or do they show fungal damage different from the chlorotic mottling and tip necrosis ozone causes? Figure 8.2 shows similar yellow spots and browning but distinctly different damage. Do needles with damage contain evidence of a fungus, its hyphae or fine hairs? How does ozone damage compare on first, second and third-year needles from the same branch? Is any pattern apparent? Do the needles show a different kind of damage, an overall bronzing typical of PAN?

- Regardless of the cause, what is the consequence of needle loss to the pines? Could students count the fascicle scars, the pedicels, on each branch and calculate the full potential of needle density before and after needle loss? The pedicels are visible. Each fascicle, as Forest Watch students know, contains five needles. And Forest Watch statistics show that needles average about 70 mm in length. A statistical study awaits someone.

Which Trees—Old Trees, New Trees-- Are More Sensitive to Ozone?

Before we stop sampling old trees and designate new ones, are new trees different in reflectance and ozone sensitivity from our beloved older trees? Researchers in early 1990s thought young trees would be hyper-sensitive to ozone (Bennett 1994). But that study was done at the end of several decades when ozone levels may have been very high. Young trees that have sprouted since 1998 and grown up in an atmosphere of lower ozone might be more sensitive to high ozone. The answer, whatever it is, may guide our decisions about continuing or discontinuing sampling of older trees. Can we test the question?

- Sample the sunny accessible side of five tagged older trees. Sample the foliage of five new trees of at least 10 years in age. Will one show more ozone damage? Will VIRIS indices be different? Are needle symptoms different? Is needle retention different?

- Recent studies of foliage and carbon sequestration have claimed (de Boer *et al*., 2011) that some trees can actually reduce the number of stomates they produce, limiting photosynthesis even when atmospheric carbon dioxide is enriched. The issue is being studied closely since some botanists have projected that tree growth would increase in enriched carbon dioxide. Is this visible in our white pines? Are young pine needles different from needles on older pines? Are pines in one location different from pines in another? Do the number of rows of stomata on needles change? Could students simply count the stomates? The lab is an interesting one.

New trees selected might be in one of three locations:

- Landscaped plantings right outside your classroom—students calculate how much room five trees will need by measuring canopy breadth of mature trees. Perhaps plant more than five saplings to watch their competition as they grow—thinning over the next few years. This location will require heavy management by everyone in the school community. But these trees can be visited easily by students at any time.

- Edge trees at edge of playing fields and school campus. Many of our schools are surrounded by magnificent trees. We cannot go across the fence to sample other sides. The edge provides a story of field/forest interface and these sunny trees retain lower branches, if managed as an educational resource.

- Forest succession trees—This option might start in a recently cleared area that is growing in with young new pines. It requires a class to consider that young trees that begin in a thicket of saplings will soon self-select for the tallest. And these, growing in forest, may be shaded, harvested or impacted by other forest factors. Select trees for a particular story they tell about forest succession. Plan to observe and monitor this site and its trees for several years. Lessons in succession open windows on studies of change over time, forest management, even carbon sequestration.

Can Students Advocate for Trees as Educational Resources?

If a school selects a new location for trees, could students build a management plan for their school's trees? The plan could provide for long term care and maintenance of the pines or sugar maples as an educational resource. This project would include building a plan with persuasive arguments and presenting it to school administrators and leaders. This plan might involve mapping, writing and oral presentations.

- As champions of the pines or sugar maples, students will have to ask and answer many questions. Why does a school need trees? What benefit do trees provide a school? What are the educational benefits of these trees? Will benefits outweigh the costs of management? Why are trees in your chosen location the most valuable to your research? How does the educational resource rank against playing fields, parking lots and other campus resources?

- Students might look at management of the school campus. Who manages the campus? What are their concerns? How will trees, especially growing trees, interfere with those managers' concerns? Can students do anything to allay their concerns or to help managers take care of the trees?

- Looking into the future, how will students today mark trees so that future students and campus managers will know about them and protect them?

Are ozone events happening in winter or spring?At higher elevations?

Recent research at UNH indicates that ozone events and the conditions which cause them are changing. Who would have thought elevated levels of ozone would be found at Castle Springs, Moultonboro, at 300 meters elevation? Who would think the highest levels of ozone in 2011 occurred in January? Is tree health changing at the seacoast? Farther inland? How do today's records compare with our records from 20 years ago?

- In this experiment, schools would collect white pine samples each month to send to UNH. In the classroom, students could conduct their own biometric exams for signs of chlorotic mottling, tip necrosis and any loss of 1^{st}, 2^{nd} and 3^{rd} year needles. Students might actually count the number of needles per inch or centimeter on 2^{nd} and 3^{rd} year stems.

If you decide to join us in answering any of these questions, please let us know so we can work with you to develop new protocols, data forms, whatever you need from UNH to make it work. At UNH, your Forest Watch team will spend this spring drafting some articles or papers based on your research last year. Wouldn't it be fine to see something published with the names of Forest Watch teachers listed as authors! With the research questions posed here, every Forest Watch school has an opportunity to help us address a real question in science. And every school might help us publish valuable research findings that help advance our understanding and help other teachers learn the art of teaching science. Many thanks to Forest Watch teachers and students for a job well done with the 2010 needles. You inspire us!