# FOREST WATCH DATA BOOK 2012-2013

## Published February 2014

## Research with 2012 Needles

Produced by Forest Watch



Funded by the New Hampshire Space Grant Consortium and the Forest Watch Fund

Table of Contents

# FOREST WATCH DATA BOOK 2012-2013

**Published February 2014**

**Research with 2012 Needles**

## Chapter One - Introduction

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

Forest Watch has confirmed the connection between variations in tropospheric ozone levels and white pine health. Over the past two decades, in all but a few drought years, white pine needle health during summers has declined when ozone levels were high (between 60- 80 ppb). White pine needle health has improved during summers when ozone levels were low (generally below 60 ppb). When white pine needles are damaged by ozone, they exhibit distinct and measureable tip necrosis and chlorotic mottle. Ozone damages needle mesophyll cells internally, reducing chlorophyll and cellular water concentrations (Chapter 2). 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 4).

In addition to student measurements of tree and needle biometric data (Chapter 4), each participating school sends a duplicate set of branch and needle samples from their trees to UNH for spectral analysis. Freshly-collected samples from each of five tagged trees are placed in Ziplock bags along with a wet paper towel, placed in a small picnic cooler (supplied by the program), and sent to the Forest Watch Program Coordinator by next-day mail. Once received at UNH, the first-year needles are scanned with the Visible Infrared Intelligent Spectrometer (VIRIS) to collect high-resolution reflectance spectra for each of the five trees. These spectral reflectance data are then analyzed to determine a range of needle characteristics, including chlorophyll concentrations, state of cellular health, and water content (See Chapter 3). The student biometric data are then compared with the reflectance data, resulting in an overview of the state of health of the white pines (Chapter 4).

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

**The Health of the Pines**

In 2010 and 2011, Forest Watch was alarmed to see a major loss of needles throughout New England, particularly in central Vermont, New Hampshire and Maine. For the first time in 20 years, the pines averaged less than two years of needle retention. Plant pathologists at the U.S. Forest Service and cooperating state laboratories identified three types of needle cast fungi on pines in affected areas. Forest Watch wondered if an atmospheric pollution event had stressed the pines, weakening their defenses against the fungi.

This year, the pines seem to be on the mend. We have seen little or no evidence of fungi on some 188 samples submitted from 110 trees. Needle retention rose to an average of 1.97 years, almost the 2.0 level. The early senescence we saw in 2011 needles in the Near Infrared 3/1 ratio (NIR3/1) is somewhat lower this year, an indication of younger, more robust health. The indications of water stress seen in the 2011 needles have also dropped in the 2012 needles. Both of these readings are still high and may indicate continued stress in the pines but there is improvement. Chlorophyll levels dropped a bit in 2012, as seen in the Red Edge Inflection point, a worrisome loss that suggests the stress of 2010 made a long-term impact on the tree.

On the other hand, several biometric measures suggest that the pines are meeting the challenge with their own biochemical protections. Average needle length jumped 12.5% in 2012 needles, a record. The extra cells in the 2012 needles may have helped the trees compensate for lost chlorophyll in cast-off 2010 and 2011 needles. The trees may also have enhanced their phenolic protections against stress agents such as ozone. Measurements of chlorotic mottle and tip necrosis were very low and total damage fell to 2.5 mm on average per needle, another record.

Many Forest Watch schools looked closely at the pines this year to observe and record any improvements from the 2010 needle cast event. At Monadnock Regional High School, Gerry Babonis and his students counted every needle and needle pedicel on two-year-old stems to assess needle loss precisely. At St. Johnsbury School, St. Johnsbury, VT, Otto Wurzburg and his team of co-teachers and students cored trees to look at how the 2010 event affected growth of new wood in their trees. And, for the first time, we scanned second-year needles in our Forest Watch laboratory to record foliar reflectance on older needles.

All of these measurements and data give Forest Watch a rich library of information which may help us understand the pine and its response to a serious stress event. This year's data suggests the pine is resilient.

**Highlights of Forest Watch in the 2012-2013 School Year**

This year 19 schools submitted samples and data to Forest Watch. Students in Connecticut, Maine, Massachusetts, New Hampshire and Vermont sampled 110 trees. The program involved an estimated 854 students in middle and high school. In addition, teachers in six new schools--Biddeford High School, Bonny Eagle High School and Westbrook High School in Maine and Groveton Middle and Groveton High School in Groveton, NH, and Winnacunnet Middle School in Hampton, NH—have taken Forest Watch training and are starting to use our protocols.

We are very proud of this growing number of schools and students. More and more teachers see our program as an interdisciplinary blend of sciences, one that can support new Common Core learning standards and lessons in 21st century technology.

The Third Forest Watch Student Convention was a huge success last May. Some 100 students, teachers and chaperones visited the Institute for the Study of Earth, Oceans and Space. Students presented their research in a poster session that many University of New Hampshire scientists visited. Then students visited UNH laboratories. Meridian Academy students learned about solar plasma with Dr. Mark Popecki. Gilmanton students looked at fungi grown on their own needles in Dr. Kirk Broder's lab and learned how pine weevils eat the tips of young pines with Dr. Cheryl Smith. Another group explored microscopic soil organisms with Mel Knorr and Sarah Andrews in James Hall and looked at insects on their maple foliage with graduate student Betsey Holland.

A full house of teachers attended a Teacher Enrichment day in August. The workshop reviewed basic field protocols such as coring a pine tree and introduced teachers to the new Landsat 8 satellite. Forest Watch will be offering more workshops in remote sensing as Landsat 8 provides more and more high resolution images of our forests.

Most recently this past year, the Governors of eight New England and Mid-Atlantic states have petitioned the Environmental Protection Agency to help them in reducing ozone levels. We explain this major policy action in Chapter 2. Dr. Jeffrey Underhill of the New Hampshire Department of Environmental Services has provided us with a detailed report on how this state is addressing EPA requirements.  Dr. Underhill's report opens the door to countless research projects which Forest Watch students might want to undertake.

The Forest Watch Fund has received new support for the program this past year and we are exploring new sources of funding.  New Hampshire Space Grant, our NASA partner for 22 years, is excited about the prospect of new partners and plans to continue support for Forest Watch.  A first corporate gift was made to the Fund by ReVision Energy, a Portland, ME, solar installation company.  We look forward to growing funds for teacher training and school support.

Last, in this year's news, Martha Carlson, our Forest Watch coordinator, completed her doctoral studies on November 15, 2013.

The 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 |
| Dr. Martha Carlson | Coordinator, Forest Watch | martha.carlson@unh.edu |

Email Forest Watch at forestwatch@ unh.edu

## Schools Participating in the 2012-2013 Studies of 2012 Needles

| **State** | Town | In Forest Watch Since… | # Trees Reporting |
|---|---|---|---|
| RHAM High School<br>Frank Schmidt | Hebron, Andover,<br>Marlborough CT | 1997 | 10 |
| Tolland High School<br>Fred Szezciul | Tolland, CT | 2009 | 5 |
| Morse High School<br>George Schaab | Bath, ME | 2008 | 5 |
| Hanson Middle School<br>Wes Blauss | Hanson, MA | 1996 | 5 |
| Meridian Academy<br>Stephanie Kinkel | Watertown, MA | 2006 | 5 |
| Springfield Central High<br>Naomi Volain | Springfield, MA | 2007 | 5 |
| Alvirne High School<br>Michael Gagnon | Hollis, NH | 2012 | 10 |
| Dublin School<br>Katri Jackson | Dublin, NH | 2012 | 5 |
| French Pond School<br>Bill Emerson | Woodsville, NH | 2012 | 5 |
| Gilmanton Middle<br>School<br>Mary Fougere | Gilmanton, NH | 1993 | 5 |
| Keene High School<br>Marshall Davenson | Keene, NH | 2012 | 5 |
| Lyme School<br>Skip Pendleton | Lyme, NH | 1994 | 5 |
| Monadnock Regional<br>High School<br>Gerald Babonis | Swanzey, NH | 2001 | 5 |
| New Hampton School<br>Jon Shackett | New Hampton, NH | 2007 | 5 |
| Prospect Mt. High<br>School<br>Sarah Thorne | Alton, NH | 2012 | 5 |
| Salem High School<br>Norma Bursaw | Salem, NH | 1994 | 5 |
| Sant Bani School<br>Robert Schongalla | Sanbornton, NH | 1992 | 5 |
| Windham High School<br>Christy Johnson | Windham, NH | 2012 | 5 |
| St. Johnsbury School<br>Otto Wurzburg | St. Johnsbury, VT | 1997 | 10 |
| 19 SCHOOLS | | | 110 TREES |

# Chapter Two – Ozone Basics and Atmospheric Conditions, 2012-2013

## The Basics

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

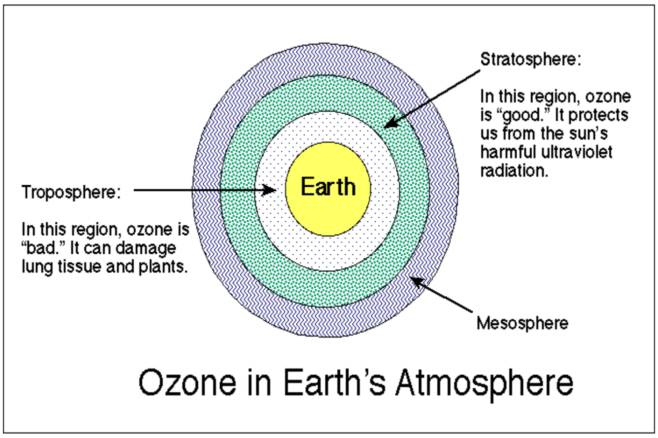



*Figure 2.1: Ozone occurs in both the troposphere and the stratosphere. The Earth’s entire atmosphere is about 80 km thick. The troposphere is 10 to 15 km from the surface of the Earth. The next atmospheric layer is the stratosphere, 15 to 30 km thick. Beyond the stratosphere, are the mesosphere and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

## What Is Ozone?

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

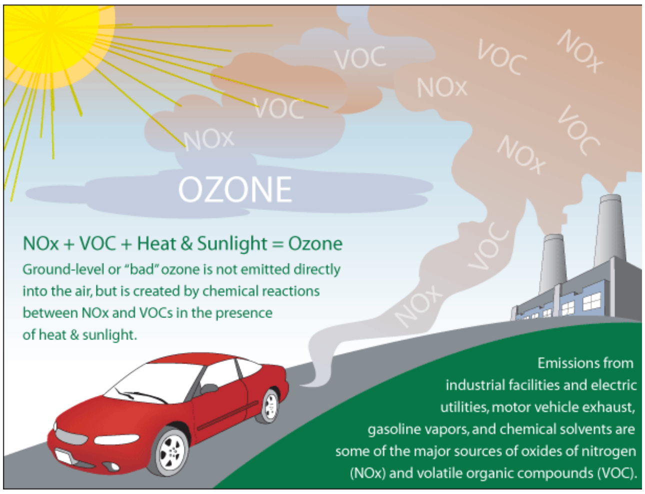



*Figure 2.2: Tropospheric ozone is formed when high temperatures and bright sunlight allow NOx and VOCs to react. Image adapted from EPA 2010.*

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 nitrogen oxides include nitrogen oxide (NO), nitrogen dioxide $NO_2$), and many other molecules based on nitrogen, so numerous we call them $NO_x$. VOCs and $NO_x$ combine photolytically, in light and heat. Historically, the highest ozone levels in the troposphere occur when the temperature reaches 90°F or more, when there is bright sun, and when both VOCs and NOx are readily available. Figures 2.2 and 2.3 illustrate the sources and formation of ozone.

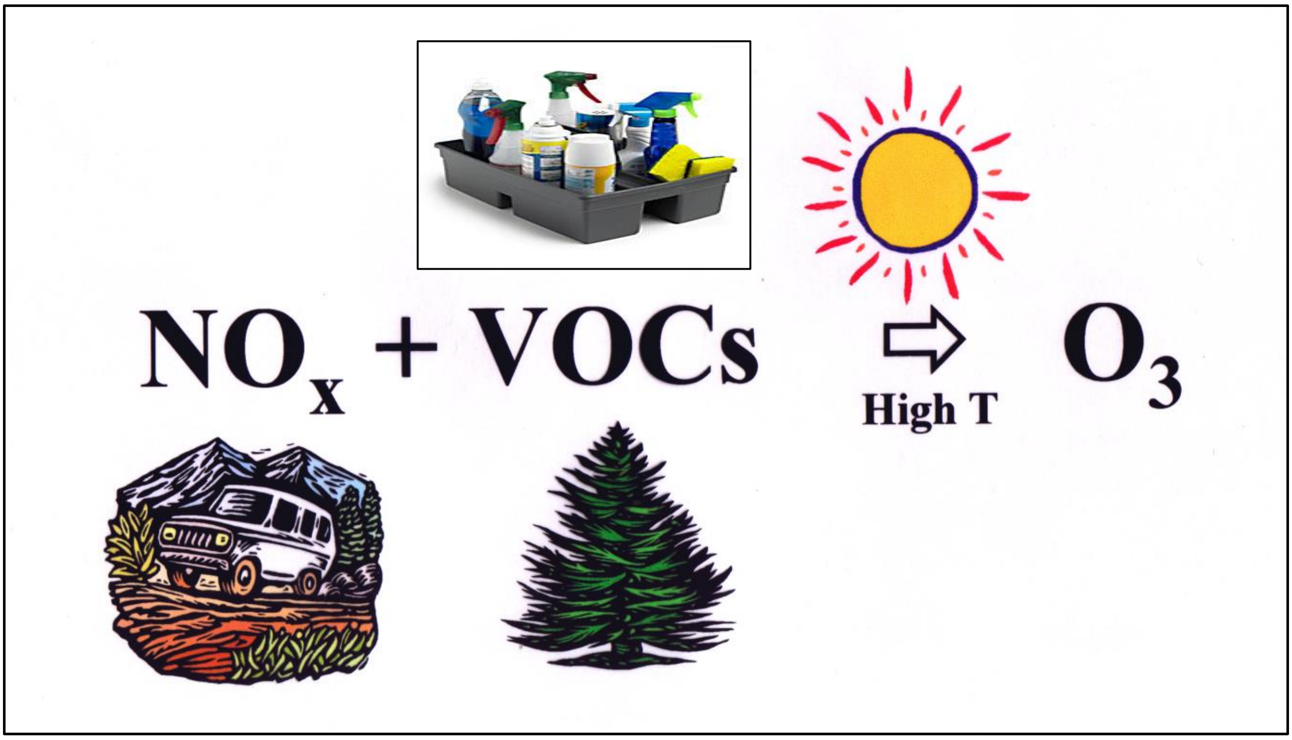



*Figure 2.3. Ozone is a secondary pollutant formed in the atmosphere when reactive nitrogen gases meet and react with volatile organic gases. The reaction requires high heat and bright sunlight.*

**Volatile Organics (VOCS)**

Volatile organics are chemical gases emitted by plants and many human-made products. 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.

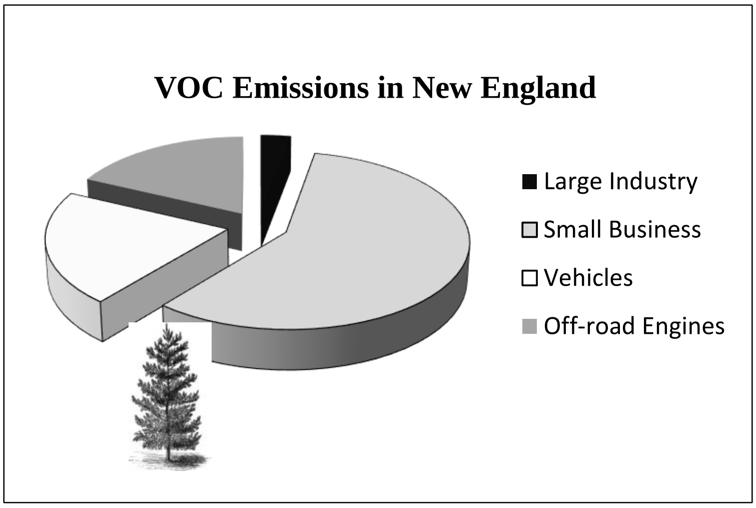



*Figure 2.4: VOCs in New England come primarily from small business. Large amounts are produced by chemical plants in the mid-west. Homes also release VOCs. The New England forest also releases substantial amounts of VOCs. Graph built using EPA Region 1 data, http://www.epa.gov/region1/airquality/piechart.html.*

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. As Figure 2.4 shows, the largest producers of VOCs are small businesses—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. In fact, VOCs inside our homes can be concentrated and harmful.

There are a number of good web sites which explain the presence of VOCs in household products. We found this one informative: http://www.critical-environment.com/blog/know-the-air-you%E2%80%99re-breathing-volatile-organic-compound-2-of-4/

**Reactive Nitrogen Gases (NOx)**

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 2.5 shows, in New England, the major producers of $NO_x$ are automobiles and trucks.

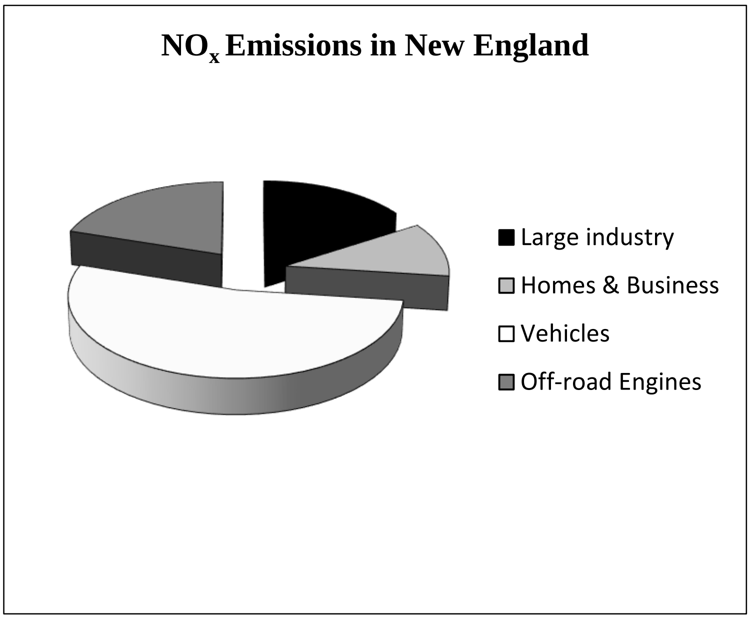



*Figure 2.5: $NO_x$ in New England is created primarily on the hot surface of automotive engines—cars and trucks in the densely populated urban corridor. Graph built using EPA Region 1 data, http://www.epa.gov/region1/airquality/piechart.html.*

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

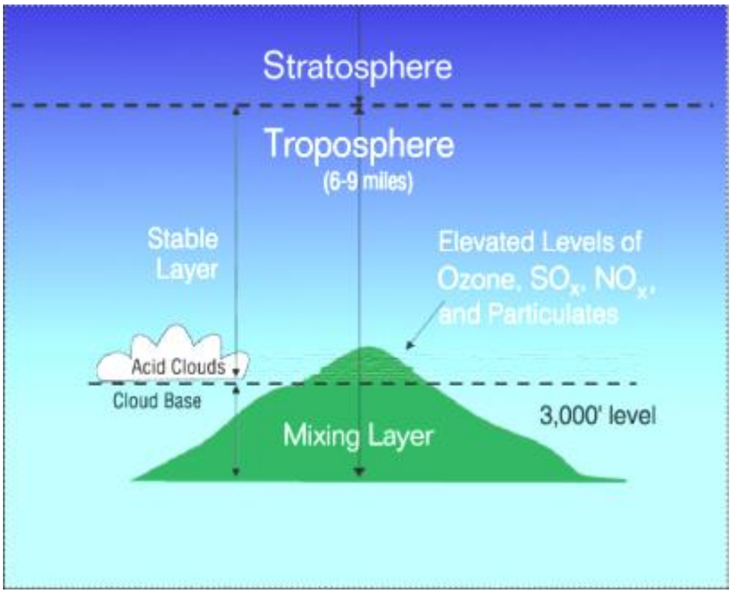



*Figure 2.6: Ozone levels are often highest at about 3,000 feet, mountain trail elevations that can make breathing hard for hikers.*

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

**Major Storm Patterns for the U.S.**

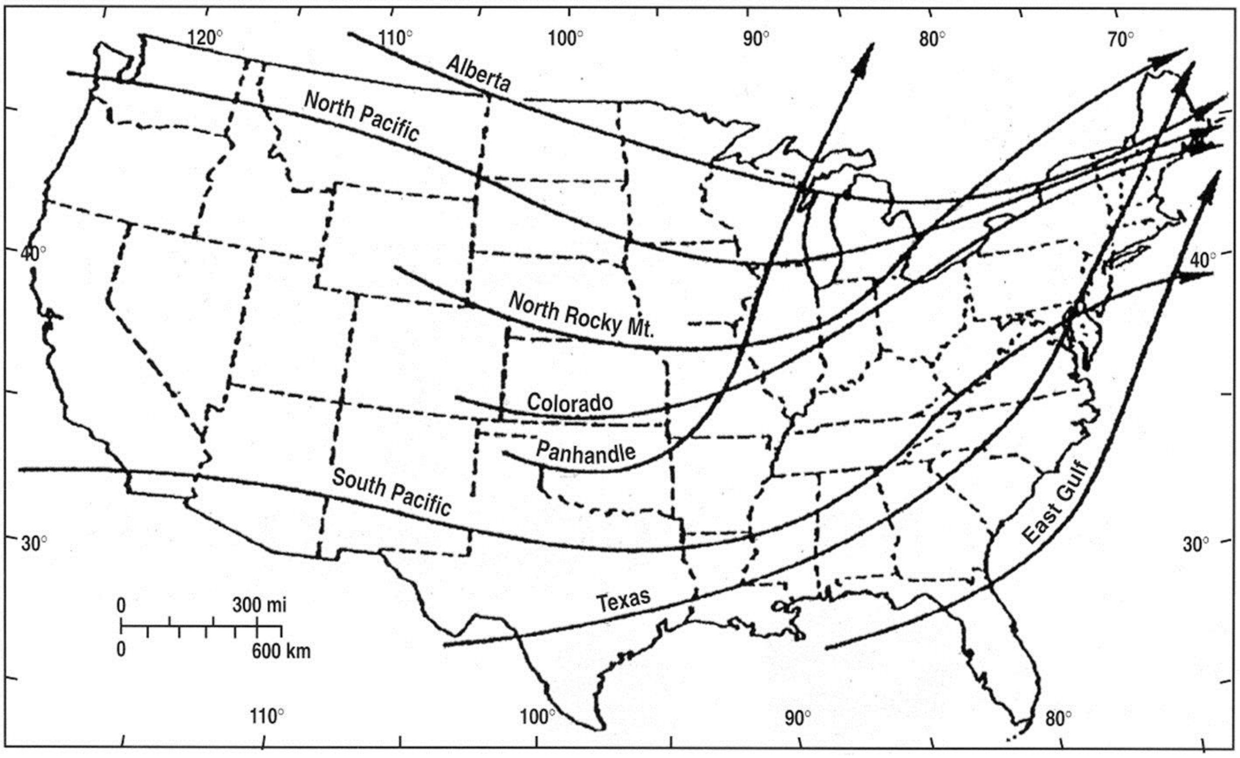



*Figure 2.7: Westerly and southwesterly winds bring air pollutants from every part of the nation to New England..(NERA 2001).*

transported high into the stratosphere where it becomes a helpful shield around the Earth.

### Tail Pipe of the Nation

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 (Figure 2.7). 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 indistinct spots of chlorotic mottling. When cells of the needle tips die, needles may exhibit brown tip necrosis. Figure 2.8 shows yellow spots and smears on either side of stomata, chlorotic mottle.  Tip necrosis is visible as a brown and dry section at the outer or distal tips of needles. These cells are necrotic or dead. These particular types of damage are unique to ozone.

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

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

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

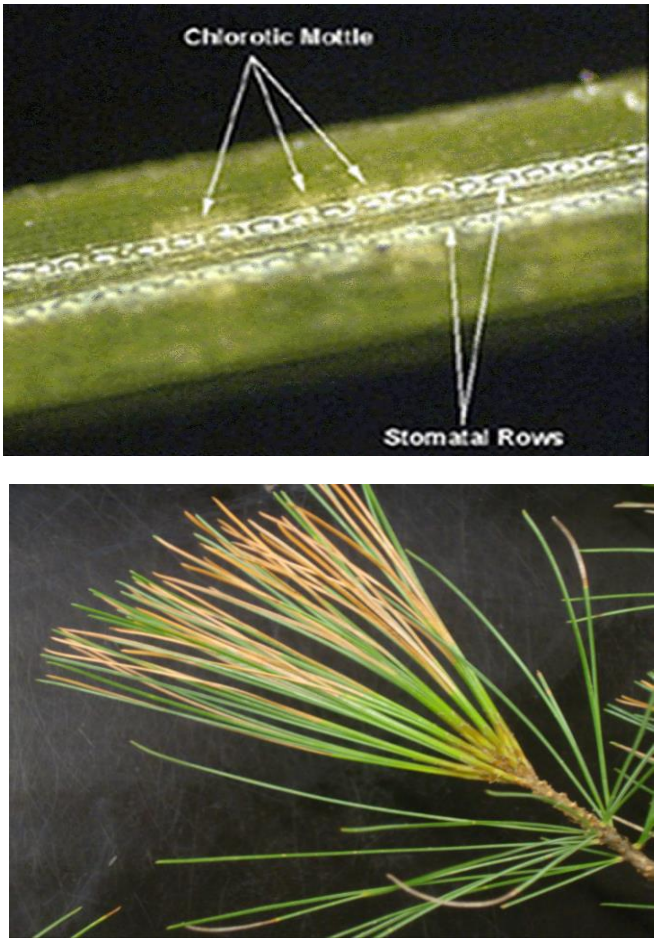



*Figure 2.8: Chlorotic mottle at top and tip necrosis below are key indicators of ozone damage. Students measure both.*

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 2.9. Today health officials and many weather stations make regular announcements of high ozone levels to help guide citizens who may have asthma or other health conditions that can be influenced by ozone. As the chart in Figure 2.7 shows, levels under 100 parts per billion (ppb) are considered only moderately concerning. Levels above 100 ppb are considered to be unhealthy. During the early 1990s, levels in the low 100-150 ppb area were measured frequently on hot summer days. In 1990, the EPA set 85 ppb as the maximum allowed level. This was a goal which the EPA and environmental advocates hoped would drive auto designers and industry to reduce production of NOx and VOCs. Slowly, ozone levels have fallen.

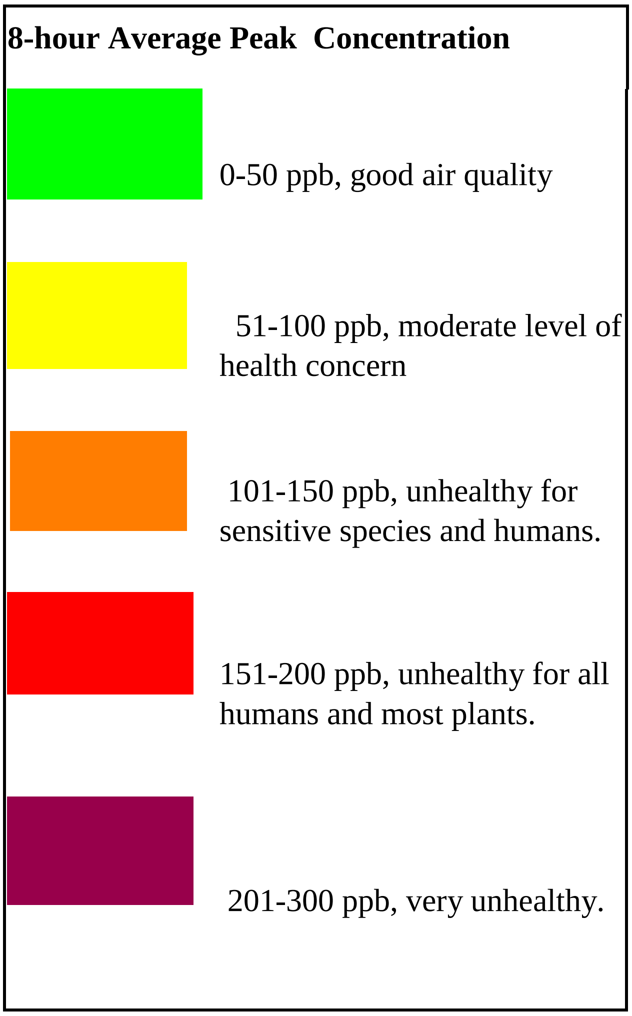



*Figure 2.9: Ozone levels at peak concentrations on December 12, 2011. Source: www.epa.gov/airnow/2011.*

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

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

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

**Ozone Conditions in the 2012-2013 School Year**

A warm 2012 increased the number of days on which numerous monitoring sites in New England registered ozone at above the 8-hour standard of 75 ppb. There were 29 such days in 2012 compared with only 16 in 2011. The highest concentrations ranged from 82 ppb in Massachusetts and Rhode Island to a lower high of 67 ppb in Vermont.

Wild fire smoke continued to cause many of the ozone events in the 2012-2013 school year. One of the highest air quality index day (a combined measurement of particulate matter

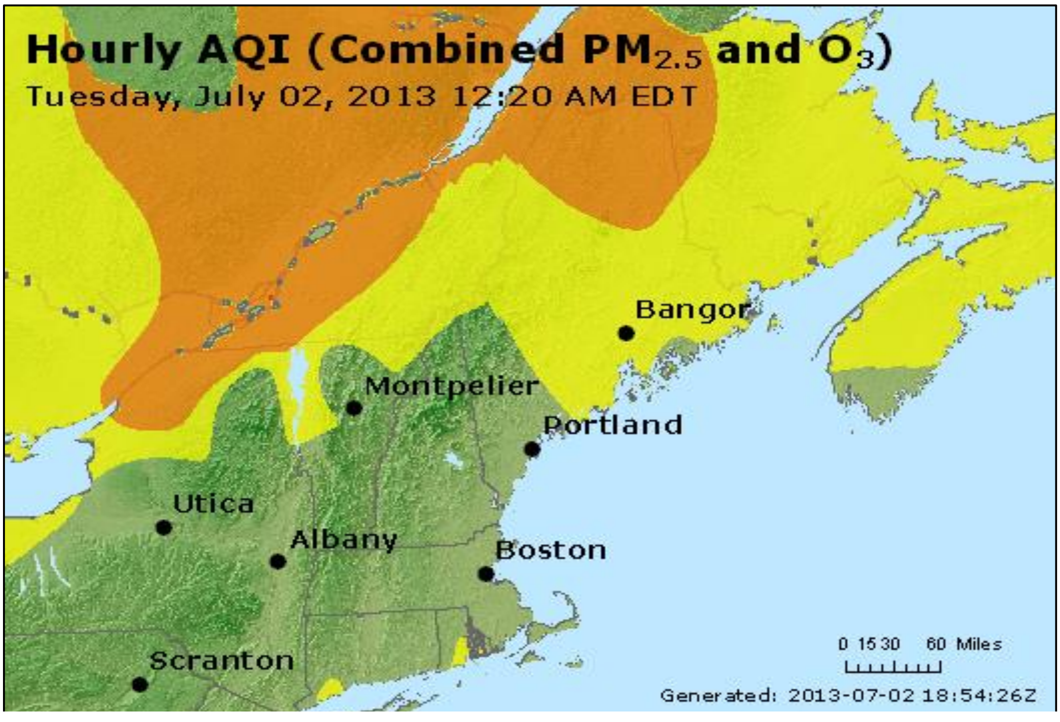



*Figure 2.9: Unhealthy air quality was recorded by the EPA in northern New England on July 2, 2013. Many of the primary pollutants which formed the ozone were attributed to wild fires in western and northern Canada. EPA AirNOW and The Smog Blog archives.*

and ozone) occurred on July 2, 2013 when wildfires in northern Quebec swept smog southeast into New England. Another moderately high day of ozone occurred on February 11, 2013 when a temperature inversion following a two-foot snowfall held pollution close to the ground. Luckily, there were very few incidents of code orange, red or purple in our region last year.

We invite Forest Watch schools to explore the imagery of atmospheric conditions. The EPA AIRNOW site produces daily reports on air quality. Local information is also available at the EPA Region One site. Another great site is the SMOG Blog produced by the University of Maryland's Baltimore County Lidar Group. The Smog Blog is a U.S. Air Quality (USAQ) program. It gathers maps, models, satellite images and weather reports from every source in North America and often from around the world. (http://alg.umbc.edu/usaq).

As Figure 2.10 shows, the trend in declining ozone exceedance days continues. Connecticut continued last year to record the most exceedance days among the New England states, with Massachusetts second. Vermont had no exceedance days in 2012 or 2013.

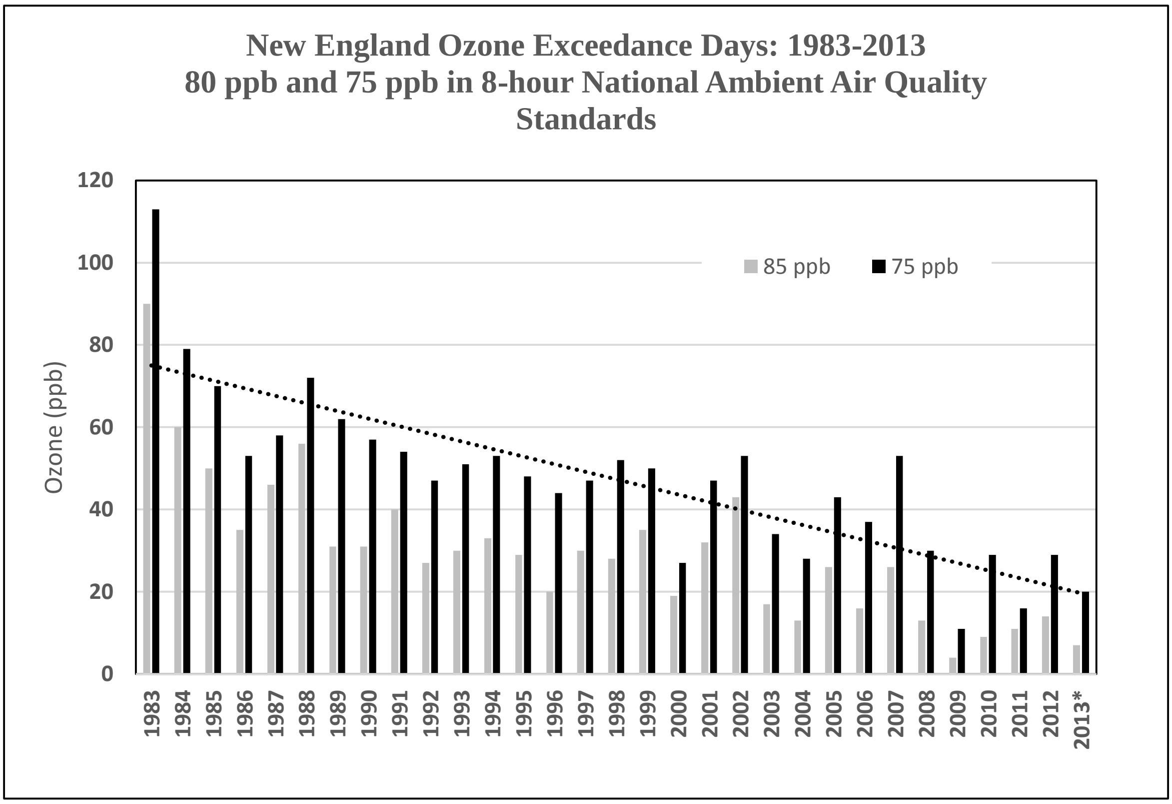



*Figure 2.10. New England air quality shows improvement in measurements of ozone as compared with National Ambient Air Quality Standards. The levels of ozone and the number of exceedances has continued to fall since 1983.*

Table 2.2 provides the State by State details. Connecticut, Massachusetts and Rhode Island had significantly more exceedances in 2012 than they had in 2011. But the trend is downward.

| | Historical Exceedance Days in New England | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | New Eng. | | CT | | ME | | MA | | NH | | RI | | VT | |
| | # days > | | # days > | | # days > | | # days > | | # days > | | # days > | | # days > | |
| Year | 85 | 75 | 85 | 75 | 85 | 75 | 85 | 75 | 85 | 75 | 85 | 75 | 85 | 75 |
| 1983 | 90 | 113 | 84 | 103 | 21 | 36 | 62 | 84 | 10 | 18 | 24 | 34 | 4 | 7 |
| 1984 | 60 | 79 | 54 | 63 | 25 | 34 | 44 | 65 | 10 | 20 | 28 | 42 | 4 | 10 |
| 1985 | 50 | 70 | 41 | 58 | 21 | 35 | 38 | 53 | 8 | 16 | 16 | 27 | 6 | 9 |
| 1986 | 35 | 53 | 28 | 41 | 9 | 17 | 24 | 32 | 9 | 16 | 12 | 22 | 1 | 6 |
| 1987 | 46 | 58 | 37 | 44 | 10 | 20 | 23 | 35 | 13 | 28 | 18 | 27 | 3 | 11 |
| 1988 | 56 | 72 | 50 | 62 | 35 | 40 | 43 | 63 | 27 | 37 | 19 | 29 | 14 | 26 |
| 1989 | 31 | 62 | 26 | 41 | 16 | 21 | 21 | 43 | 11 | 16 | 9 | 14 | 2 | 5 |
| 1990 | 31 | 57 | 24 | 44 | 15 | 21 | 22 | 37 | 9 | 20 | 13 | 18 | 5 | 8 |
| 1991 | 40 | 54 | 34 | 46 | 17 | 26 | 26 | 45 | 13 | 22 | 20 | 28 | 10 | 16 |
| 1992 | 27 | 47 | 19 | 29 | 12 | 22 | 20 | 36 | 8 | 18 | 5 | 12 | 6 | 11 |
| 1993 | 30 | 51 | 27 | 39 | 14 | 20 | 23 | 40 | 8 | 17 | 7 | 11 | 4 | 9 |
| 1994 | 33 | 53 | 28 | 39 | 10 | 22 | 20 | 39 | 9 | 19 | 8 | 21 | 2 | 13 |
| 1995 | 29 | 48 | 24 | 35 | 14 | 20 | 20 | 39 | 9 | 19 | 11 | 18 | 3 | 13 |
| 1996 | 20 | 44 | 16 | 33 | 5 | 20 | 15 | 28 | 6 | 14 | 4 | 12 | 3 | 4 |
| 1997 | 30 | 47 | 27 | 34 | 11 | 16 | 24 | 38 | 10 | 16 | 11 | 19 | 2 | 11 |
| 1998 | 28 | 52 | 25 | 44 | 11 | 16 | 12 | 36 | 7 | 14 | 5 | 11 | 0 | 5 |
| 1999 | 35 | 50 | 33 | 43 | 10 | 21 | 22 | 36 | 10 | 19 | 13 | 16 | 3 | 11 |
| 2000 | 19 | 27 | 13 | 23 | 3 | 5 | 5 | 16 | 1 | 5 | 8 | 14 | 1 | 2 |
| 2001 | 32 | 47 | 26 | 39 | 15 | 22 | 27 | 37 | 11 | 22 | 15 | 26 | 2 | 9 |
| 2002 | 43 | 53 | 36 | 49 | 17 | 28 | 30 | 43 | 13 | 23 | 17 | 33 | 5 | 13 |
| 2003 | 17 | 34 | 14 | 26 | 5 | 15 | 11 | 27 | 1 | 10 | 10 | 13 | 0 | 4 |
| 2004 | 13 | 28 | 6 | 20 | 1 | 11 | 8 | 16 | 5 | 10 | 4 | 5 | 2 | 4 |
| 2005 | 26 | 43 | 20 | 30 | 5 | 15 | 17 | 31 | 4 | 17 | 8 | 17 | 0 | 4 |
| 2006 | 16 | 37 | 13 | 29 | 2 | 10 | 12 | 26 | 2 | 10 | 3 | 13 | 0 | 0 |
| 2007 | 26 | 53 | 17 | 42 | 8 | 14 | 20 | 38 | 8 | 22 | 8 | 18 | 1 | 5 |
| 2008 | 13 | 30 | 8 | 22 | 0 | 4 | 9 | 18 | 2 | 10 | 4 | 6 | 0 | 3 |
| 2009 | 4 | 11 | 1 | 6 | 2 | 3 | 1 | 8 | 0 | 2 | 0 | 1 | 0 | 0 |
| 2010 | 9 | 29 | 5 | 24 | 2 | 8 | 4 | 14 | 0 | 8 | 1 | 6 | 0 | 0 |
| 2011 | 11 | 16 | 10 | 14 | 2 | 3 | 5 | 10 | 1 | 2 | 0 | 6 | 0 | 1 |
| 2012 | 14 | 29 | 13 | 27 | 0 | 4 | 6 | 17 | 1 | 4 | 3 | 12 | 0 | 0 |
| 2013* | 7 | 20 | 7 | 17 | 1 | 5 | 0 | 6 | 0 | 3 | 0 | 7 | 0 | 0 |
| *** 2013 data preliminary and subject to change.** | | | | | | | | | | | | | | |
| Download a copy of the 2012 Annual Report at: | | | | | | | | | | | | | | |
| **http://www.epa.gov/region1/oeme/AnnualReport2012.pdf** | | | | | | | | | | | | | | |

How does this decline in ozone compare with the health of white pines? Each year Forest Watch publishes a chart, Figure 2.11, comparing the difference using just our New Hampshire white pines and ozone records from New Hampshire monitoring stations. Figure 2.11 shows the dramatic inverse correlation: As ozone levels have dropped in the last decade, white pine health has increased as shown in spectral measurements of chlorophyll abundance, a test we call the Red Edge Inflection Point (REIP). Scans of 116 samples from New Hampshire trees had an average REIP of 722.0. All samples from around New England averaged 722.5 during the 2012-2013 school year.

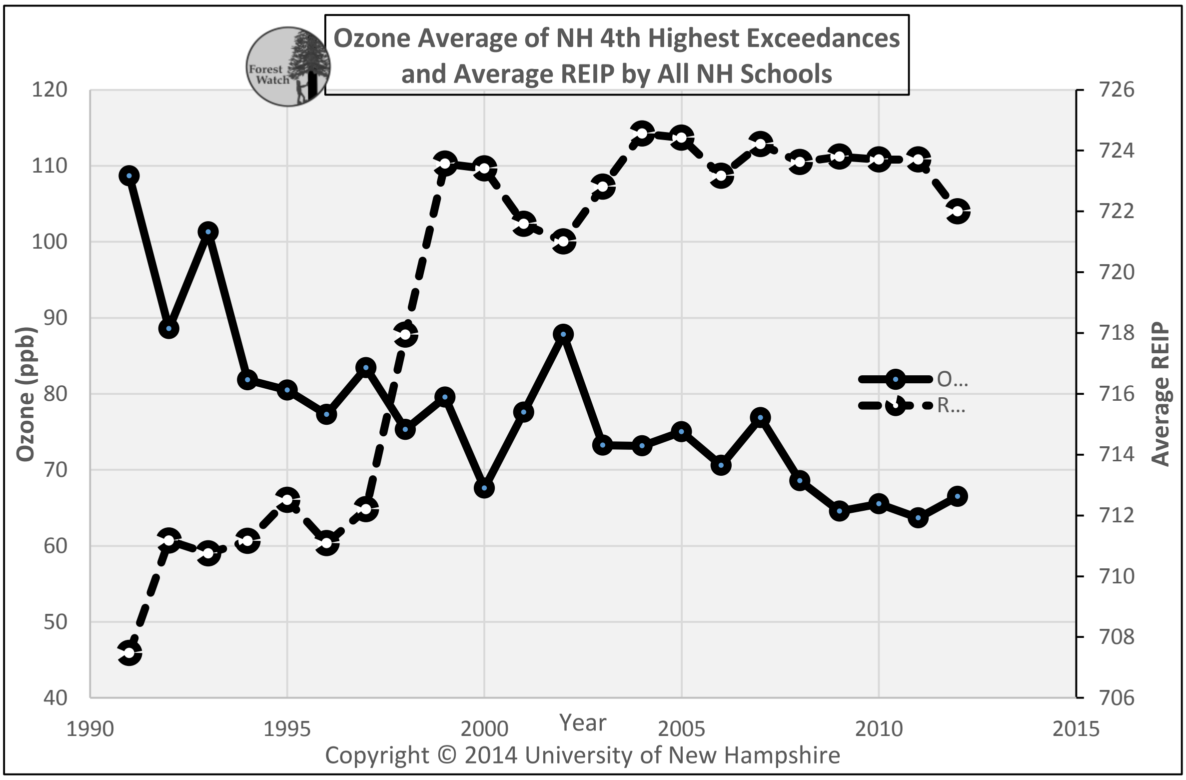



*Figure 2.11. Ozone levels have fallen as white pine health has ridden in Forest Watch documents in New Hampshire.*

This year we update this chart to use what the EPA calls a "standard summary statistic" for high levels of ozone. Ozone levels in summer may average 45 ppb on sunny days. Higher levels vary depending on weather, sunshine, and winds from outside the region. Very high levels of ozone are becoming unusual. When ozone exceeds federal levels for 8-hours or longer on one day, the monitoring station and its neighborhood are said to be "in exceedance."

Rather than simply average the highest levels of ozone or all of the exceedance days measured each year, the EPA selects the fourth highest exceedance of its standards. That day, not the highest or worst day, gives a fairly good idea of what air pollution or smog looks like in any one area, the EPA statisticians have decided. The use of the fourth highest day of ozone levels which are above 75 ppb is a "convention." It is used by the EPA to identify states and areas within states that are non-compliant with the Clean Air Act. And it is used by states to set goals for improving air quality.  Forest Watch will use this day of data from now on.  The four highest days are reported annually by state in the EPA's Annual Report, **http://www.epa.gov/region1/aqi/index.html**.

**Ozone Politics**

Since 2009, five years ago, the EPA, state and federal leaders and environmentalists have been calling for stricter standards on ozone and emissions of the chemicals that cause ozone.

Despite the improvement in air quality over the past two decades, scientists and environmentalists believe our national ambient air quality standards (NAAQS) 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.  Advocates expected the limit would drop to 65 ppb but 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.

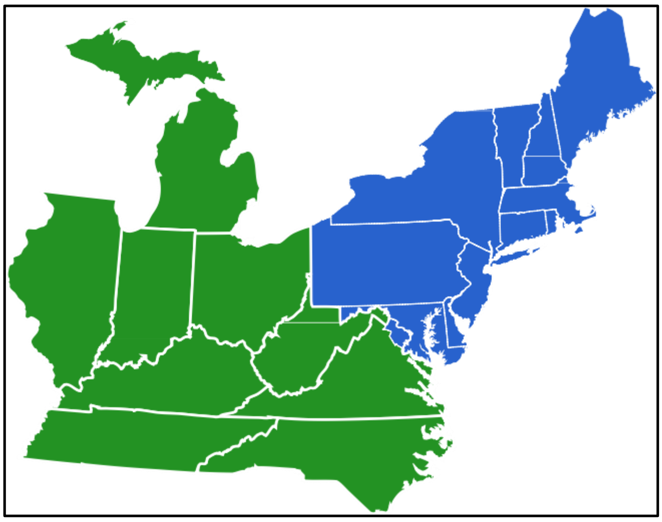


*Figure 2.12. The present Ozone Transport Region is shown in dark grey.  The Midwest states proposed for addition to the OTR are in lighter grey.*

Most recently, the governors of eight New England and Mid-Atlantic states have petitioned the EPA to add nine Mid-West states to the Ozone Transport Region (the OTR). Eleven states from Maryland and Delaware north to New Hampshire and Maine were designated as OTR states by the Clean Air Act Amendments of 1990.  Ozone in our region regularly exceeded EPA standards.  The OTR states were required to enact laws and regulations that would reduce NOx and VOCs with the best "reasonably available control technologies (RACTs)."

Last December, 20 years after the OTR states began working to meet the EPA's requirements, 8 of the 11 want upwind states added to the OTR.  These governors, all Democrats, claim that they have used all of the affordable and "reasonably available control technology" (RACT) options yet their states will still see exceedances of the ozone limits. Most of the pollution causing those exceedances is coming from the upwind Mid-West states, the governors claim.  Three governors, all Republicans, of Maine, Pennsylvania and New Jersey, did not join the petition.

The Midwest states on the list include Michigan, Illinois, Indiana, Ohio, West Virginia, Virginia, Kentucky, Tennessee, and North Carolina, See Figure 2.12.  Adding these states and requiring them to restrict their emissions will yield health benefits of $2 to $17 billion, the governors claimed last December when they submitted their petition. Asthma treatment is a major part of the benefit but ozone also causes other human health problems and damages many agricultural crops, the governors claim. A portion of a statement issued by Governor Maggie Hassan, New Hampshire, is at right.

**Governor** Maggie Hassan, Statement, December 19, 2013

Millions of dollars of pollution control efforts and decades of hard work to improve air quality in the Northeast and Mid-Atlantic could all be wasted if the EPA doesn't decide to help.

While we've spent years working to improve our air quality, upwind states further west have not, and their pollution is blowing into our states and impeding our best efforts…

There are days in New Hampshire when over 95% of our air pollution is blowing in from these upwind states.

**Ozone Technology**

How do the Eastern governors know that air pollution is coming from the Midwest?

Forest Watch students might know the answer. Last year we examined the amazing work being done to trace air pollution at the University of Baltimore in Maryland.  We introduced their Smog Blog and invited students to visit the website frequently to see where our daily air pollution comes from.  The Governors are using the same technology for their decision making as Forest Watch!

These remarkable air quality reports are being gathered from every available source by U.S. Air Quality (USAQ), a daily diary and analysis provided by the University of Maryland, Baltimore County Atmospheric Lidar Group.  USAQ obtains permission to use the many different satellite, weather and ground-based maps and models it presents.  And new satellites provide better data about small particulates in the troposphere. Daily reports are presented by the U.S. Air Quality Smog Blog (http://alg.umbc.edu/usaq).

If you haven't visited the Smog Blog, please add it to your ozone readings.  The maps are beautiful and highly informative.  Smog Blog writers not only explain the daily news in air quality but frequently give general lessons in a particular pollutant.

**Ozone Clean-Up**

Another fascinating feature of the Governors' petition is a technical report which details how one state, New York, has addressed the OTR requirements.  The example details millions of dollars in public tax funds for ozone reductions and how the State of New York and its citizens have been reducing both NOx and VOCs.

In 1994, New York began implementing its OTR plan with the following programs:

- Motor vehicle emission controls
- Enhanced motor vehicle emissions inspections
- Reformulated gasoline
- A commuter options program
- Limits on consumer solvents and architectural coatings
- Clean fuel for heavy duty vehicles
- A New York City natural gas taxi cab program
- Restrictions on diesel vehicles
- Restrictions on federal non-road hardware and fuels

But New York continued to have exceedance days over the EPA's limits for ozone. In 2007 more programs and tighter regulations were aimed at:

- Gasoline stations and gasoline hauling trucks
- Reformulated gas
- Solvent metal cleaning and surface coatings
- Storage and transfer of petroleum and volatile organic liquids
- Pharmaceuticals and cosmetic manufacturing
- Graphic arts shops and industries
- Paint and consumer products
- Architectural and industrial maintenance coatings
- Landfills and waste combustion sites
- Personal watercraft
- Cement, glass and asphalt paving production
- Fossil fuel boilers
- Ultra low sulfur heating oil

Lastly New York set a NOx budget for the State at 46,959 tons per ozone season. The State declared it would reduce NOx by 46.6% by 2020 and reduce VOCs by 25% by 2020.

Despite this multitude of efforts, New York expects it will continue to have exceedance days in 2015. Much of the pollution will come, however, from the states upwind, the governors claimed. The Smog Blog has traced air in Maryland on high ozone days and has attributed as much as 82% to air from Ohio, the governors Technical Report said. Since the Mid-West states are not in the OTR, they are not currently required to enact such regulations. Indiana produces four times more ozone and contributing NOx and VOCs than New York State does, the governors claim.

**What's Being Done in Your State**

Forest Watch students might want to inquire about what your state is doing to reduce ozone and the pollutants which cause it. Petitioning governors in Vermont, Massachusetts and Connecticut may well welcome your questions.

Forest Watch called Governor Hassan's office to ask what New Hampshire has done since 1990 to reduce NOx and VOCs here. They put us in touch with the Air Quality Bureau of the New Hampshire Department of Environmental Services. Dr. Jeffrey Underhill and his DES team spent several weeks preparing a wonderful report for Forest Watch. See Chapter II – The New Hampshire Story.

**What Are Political Interest Groups Advocating?**

Opposition to the eastern Governors' request began immediately. In North Carolina, for instance, attorneys for the Department of Environment and Natural Resources began working on arguments to prove that their state contributes very little to downwind states' pollution. The attorneys are also examining the states rights issue raised by the petition: how can eastern states impose stricter regulations on North Carolina than the people of North Carolina would impose on themselves? http://www.martindale.com/natural-resources-law/article_Troutman-Sanders-LLP_2041806.htm

The Conservation Law Foundation, a regional group in New England, is advocating a Clean Fuels Standard. The CFS would reduce high carbon fuels and promote development of more efficient cars and trucks.

Advocates for a CFS say they also will ask for Smart Growth, less sprawl and more concentration of growth around existing urban areas and transportation systems. In New Hampshire, the CLF is working to close the Merrimack Station in Bow, a coal burning electricity plant that is New Hampshire's largest contributor to greenhouse pollution. This organization also reports that suburban sprawl and new poorly planned highways in the Seacoast area have increased commuting and related auto emissions. http://www.clf.org/blog/clean-energy-climate-change/air-quality-alerts-what-you-can-do-about-them/

The debate about smog appears to be joining with concerns about high sulfur coal, tar sands oil, fracking and other fossil fuels. The governors' ozone petition is likely to spark a long and lively debate.

What will the fossil fuels industry say about the governors' petition? What do the governors of Maine, New Jersey and Pennsylvania say about the petition? What are their reasons for declining to sign the petition?

**What Can Students Do?**

The tightening of standards on NOx and VOCs will prompt strong opinions for and against. Forest Watch has explored a few questions in this report. The issue offers numerous avenues for learning about civics and how we resolve controversial issues in our States and in federal agencies such as the EPA.  Such an issue also can introduce students to intriguing discussions about how science and policy merge or collide.  We suggest a few lines of inquiry:

- Have every student write down one or two questions about the OTR petition.
- Discuss the questions as a group.  Can you separate or classify the questions into any categories:  science, politics, economic, pro, con, other?
- Divide questions and students into groups.
- Within each group, consider how you can answer these questions. Who are reliable resources on this topic?  How can we contact those sources?

Before you go too far, discuss as a class what is the difference between studying civic action and policy and advocating one point of view or another.  What position does the class have as an educational group?  Can you be impartial?  Or do some students feel they are being pressured to adopt a position they might not support?  How does a school foster open inquiry?  What is the role of science in the political arena?

## Chapter Two-Part Two
## The Ozone Story in New Hampshire

As we discussed in Part One of this chapter, Governor Maggie Hassan's petition to the EPA, with seven other governors, sparked our interest in what our state has done to reduce ozone and the primary pollutants which form ozone.

We are very grateful to Dr. Jeffrey Underhill, Chief Scientist, Air Resources Division, for the New Hampshire Department of Environmental Services for responding to our inquiries about ozone actions in New Hampshire. The following is an abridged version of Dr. Underhill's answers to our questions. We will post the entire document and its many appendices on the Forest Watch website. We encourage young researchers to explore this amazing information and to ask questions of other states in which you and your white pines are living.

Martha Carlson, Ph.D.
University of New Hampshire
Natural Resources and Earth Systems Science
Room 466, 39 College Road, Morse Hall
Durham, NH 03824-3535

Dr. Carlson,

Thank you for your recent inquiries regarding air pollution control requirements, emissions trends, and ambient ozone trends in New Hampshire. Attached you will find responses to your questions along with supporting graphics and links to additional information. I'd like to thank you for bringing our attention to the need for posting this information on our website. We will be working on that in the near future.

It was a pleasure pulling this information together for you. If you have any further questions, please feel free to email of call me.

Sincerely,
Jeffrey Underhill, Ph.D.
Chief Scientist, Air Resources Division
Department of Environmental Services
603-271-1102

**Dr. Underhill's Response to Forest Watch Questions**

1. The Technical Report for the Governors' petition includes a wonderful section about New York State and what they have done to reduce NOx and VOCs. Can you please provide similar information about NH?

New York and Maryland were specifically targeted in the petition because they have the most severe nonattainment of the 2008 ozone national ambient air quality standard. Maryland is designated as moderate nonattainment and New York will likely change its status from marginal nonattainment to moderate.

Comparatively, New Hampshire is currently meeting the 2008 standard, so there has been less focus on our state. While we have taken many similar actions in the past when areas of New Hampshire were designated nonattainment for prior ozone standards, this information was contained in various submittals to EPA and not summarized in a readily convenient form. Thanks in part to your request, we plan to add this information to our website in the near future. More detail is provided in the Attachments.

2. Why are NH and Vermont not included in the Technical Report regarding exceedances caused by upwind emissions. Is it just that we have so few exceedance days? Or we lack back trajectory technology or staffing?

Similar to answer #1, New Hampshire and Vermont are currently meeting the ozone standard, and while exceedances do happen in our states, they don't carry the same legal meaning as for states with designated nonattainment areas. For this reason, NH and VT were not the focus of the technical report.

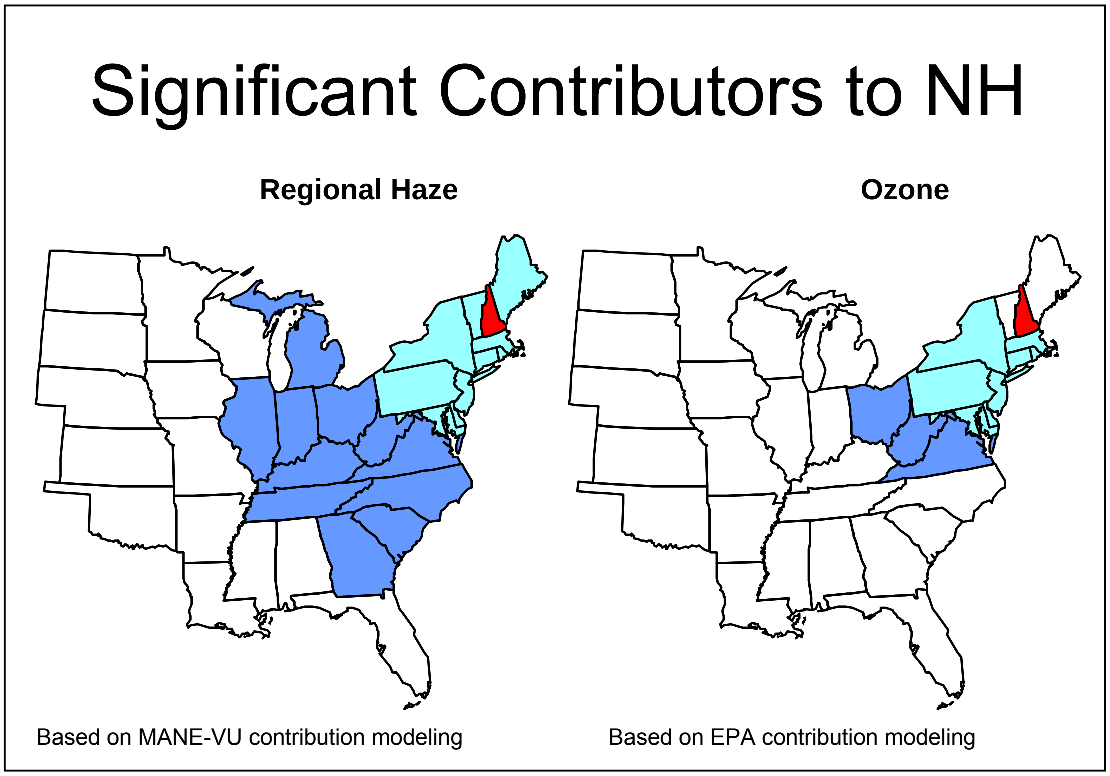
3. If NH has few incidents of pollution provable from upwind sources, why did NH and Governor Hassan join the other states in this petition?

There are many instances that support the governor's decision to join the petition... A report on the DES website documents that in 2004, over 90% of the air pollution in NH on bad air days came from out-of-state sources. Further, while New Hampshire is now meeting the conditions of the current ozone standard, this standard is under review and will likely become more protective in the next year or two. It is quite possible that New Hampshire could fall back into ozone nonattainment and would need the remedies that this petition seeks.

Air Pollution Transport and How it Affects New Hampshire

Further, modeling efforts have identified states significantly contributing to ozone and regional haze as follows:

**FIGURE 2.13: Significantly Contributing States to New Hampshire Ozone and Regional Haze**




4. We know New Hampshire has done things also-such as requiring auto emission checkups. Is there a list of such actions and regulations anywhere?

You are correct that New Hampshire has an inspection and on-board diagnostic computer check requirement. See these sites for more information on that requirement.
http://des.nh.gov/organization/divisions/air/tsb/tps/msp/onboard.htm
http://des.nh.gov/organization/divisions/air/tsb/tps/msp/index.htm

In addition, we have listed other emission reduction actions and regulations in Attachment A.

(A Forest Watch list of Attachment A items includes: gasoline vapor recovery regulations; a clean fuel fleets rule, reformulated gasoline, diesel opacity testing, low emitting vehicles rules, portable fuel container rules and many regulations regarding automobile fluids and cleansers.)

5. Could you tell us how much NH has spent on reducing ozone since it was very high in 1988 or 1990 when the Clean Air Act was passed? We know ozone has gone down. Forest Watch students would like a history lesson on their State's ozone history.

As you stated, ozone levels in New Hampshire have improved over the years, thanks to the efforts conducted in New Hampshire and similar efforts in upwind states. While ozone concentrations in New Hampshire have declined for over 20 years, the ozone standard has also been lowered. As required by the Clean Air Act, ozone standards are reviewed every 5 years to ensure that they are adequately protective of public health. More recent health studies have demonstrated the need to lower the ozone standards, which has kept our state near the edge of compliance.

**FIGURE 2.14: New Hampshire Ozone Design Value Trends, 1982-2012**

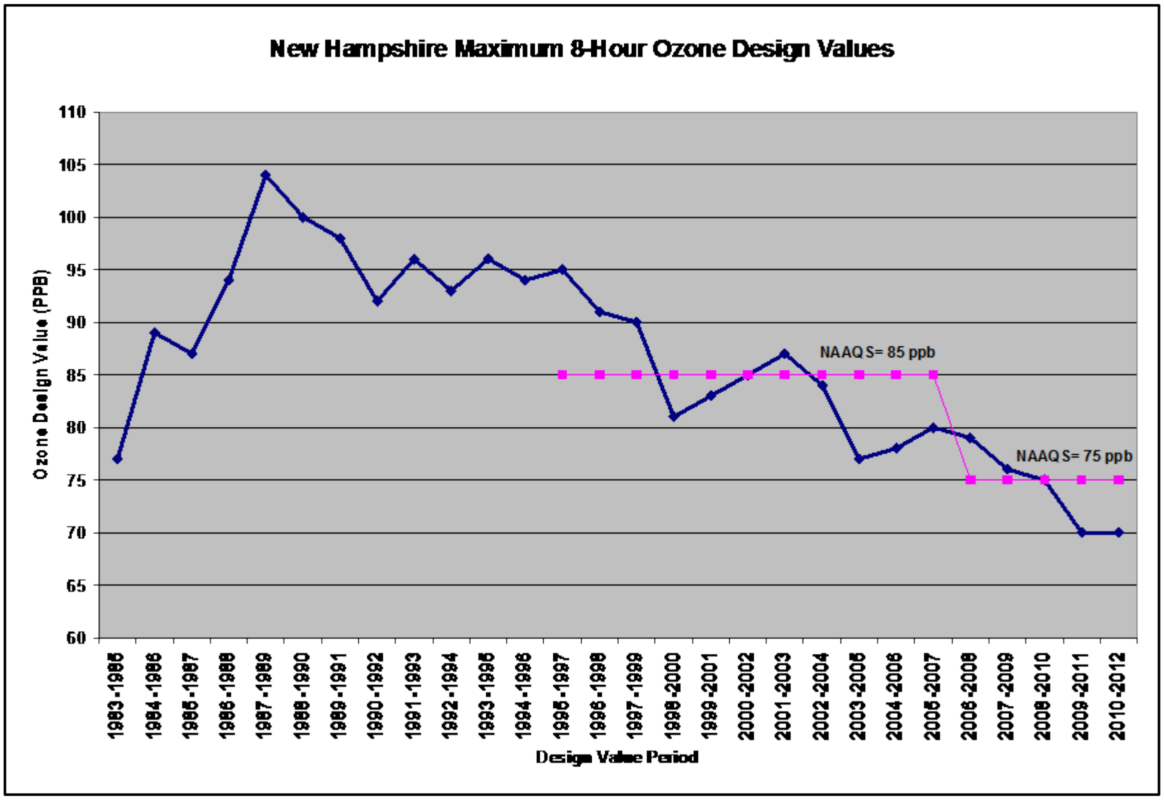



Figure 2.14 demonstrates Dr. Underhill's point: While ozone has dropped in New Hampshire, so have regulations. The State continues to have a few exceedances. Dr. Underhill added a note to explain "design values," the title of this chart:

A design value is simply monitored data put into the form of the ambient air quality standard, which for ozone is the 3-year average of the 4th maximum yearly ozone concentration at each monitor. To violate the standard, the design value must exceed the NAAQS of 0.075ppm. What this essentially means is that there can be several days where ozone exceeds the NAAQS threshold but is not considered a violation. Therefore, we track the design value, yearly peak ozone, and number of days exceeding the threshold, but only the design value has real legal context.

Costs are a very complex matter and not easily quantified. There are costs for pollution controls (installation and operation), cleaner fuels, regulations to change chemical formulas of products or materials used, costs of energy, jobs lost, etc. These would be offset by the benefits of less pollution, such as improved public health and associated lower expenses, jobs gained, and increased tourism. Much of this information is difficult to obtain. EPA does assess the costs and benefits whenever it issues a major new rule, including any revision of a NAAQS, and has previously shown net economic benefits for lower ozone standards.

Below are some notes from the Technical Report for reducing NOx and VOCs -this is the kind of detail Forest Watch likes to put on our website for middle and high school student researchers.

a. Does NH have a similar detailed plan of action? What is it?

It is contained within our 1998 ozone state implementation plan (SIP) and subsequent modifications (I&M, emission inventory reformulated gasoline, RACT) adopted in DES rules. Additional adjustments to the SIP were made in accordance with the 2012 DES ozone redesignation request.

http://des.nh.gov/organization/divisions/air/do/sip/documents/o3-redes-request-1997.pdf

http://des.nh.gov/organization/divisions/air/do/sip/sip-revisions.htm#o3

b. What companies and manufacturers or consumer goods does it apply to?

Applicability is specified by rule. For example, consumer products are regulated by Env-A 4100 (see http://des.nh.gov/organization/commissioner/legal/rules/documents/env-a4100.pdf), and specific types of manufacturing and processing are regulated by Env-A 1200 and Env-A 1300 (see http://des.nh.gov/organization/commissioner/legal/rules/documents/env-a1200.pdf and http://des.nh.gov/organization/commissioner/legal/rules/documents/env-a1300.pdf.)

See Attachment B for listing of products regulated under Env-A 4100.

(A Forest Watch list of Attachment B consumer goods includes adhesive sprays, air fresheners, antiperspirants, automotive brake cleaners, rubbing and polishing compounds, wax and polishes, windshield washer fluids, bathroom and tile cleaners, bug and tar remover, carburetor intake cleaners, carpet cleaners, charcoal lighter materials, cooking sprays, deodorants, dusting aids, engine degreasers, fabric protectants, floor polishes, floor wax strippers, furniture maintenance products, general purpose cleaners, glass cleaners, degreasers, hair mousses, sprays and styling gels, heavy-duty cleansers, insecticides, laundry prewash and starches, metal polishes, lubricants, nail polish remover, herbicide, oven cleaners, paint remover, penetrants, rubber and vinyl protectants, sealants, shaving creams, silicone-based lubricants, spot removers, tire sealants, undercoatings.)

c. How much has this cost?

As mentioned before, total implementation costs are very difficult to calculate, but cost effectiveness is typically considered by EPA in their rulemaking. In general, to be considered for adoption an air pollution control's expected benefits must exceed its costs.

d. How much has this reduced ozone in NH?

Below is a summary of ozone trends throughout New Hampshire along with recent and projected NOx and VOC emission reductions in NH.

These reductions, along with those of upwind states, have reduced New Hampshire's highest ozone concentrations by over 35%.

**FIGURE 2.15: New Hampshire City Ozone Design Value Trends (1990-2011)**

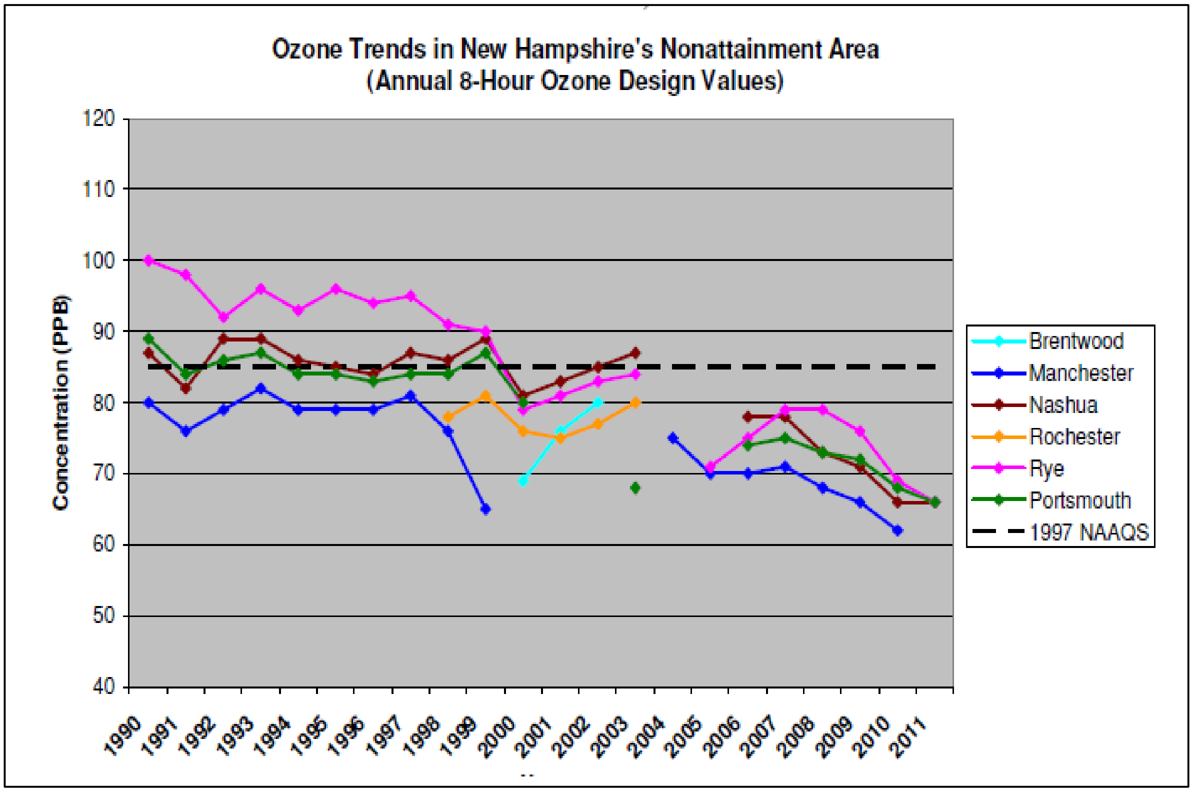
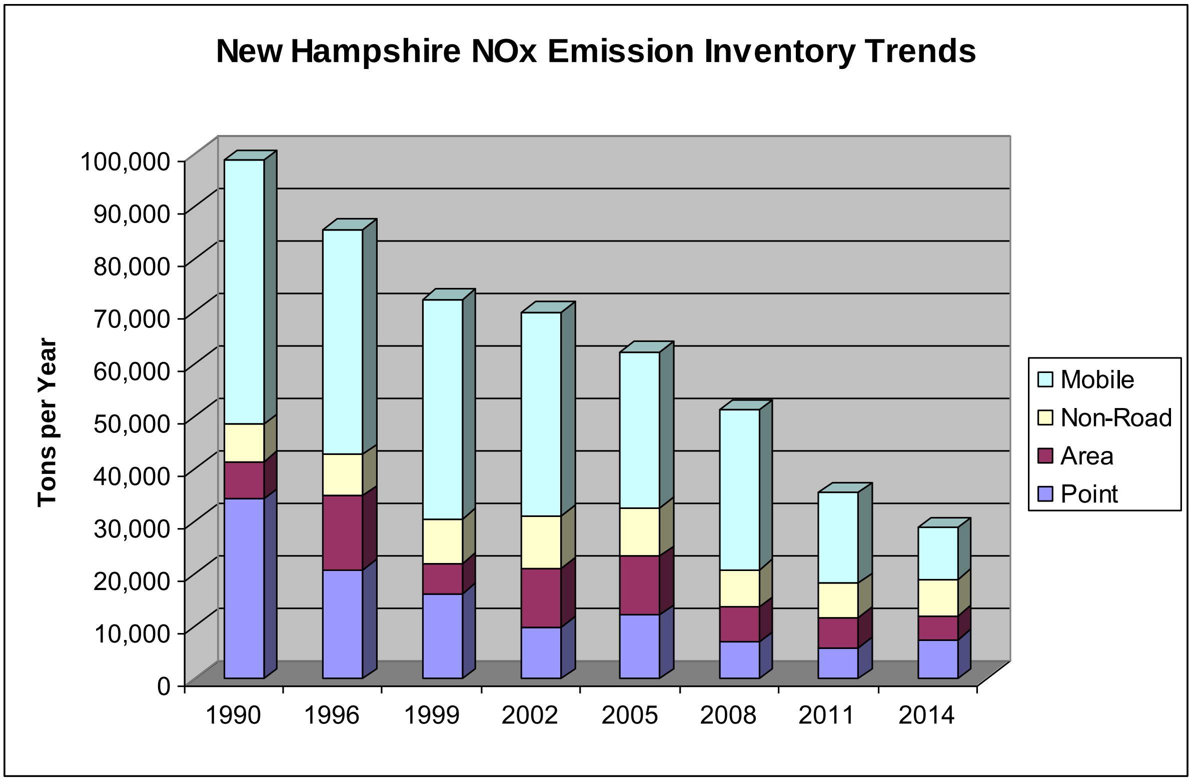



**TABLE 1: New Hampshire NOx Emissions (tons per year)**

| Category | 1990 National Emissions Inventory | 1996 National Emissions Inventory | 1999 National Emissions Inventory | 2002 National Emissions Inventory | 2005 National Emissions Inventory | 2008 National Emissions Inventory | 2011 National Emissions Inventory |
|---|---|---|---|---|---|---|---|
| Point | 34,179 | 20,690 | 16,170 | 9,786 | 12,068 | 6,969 | 5,887 |
| Area | 7,188 | 14,089 | 5,724 | 11,259 | 11,259 | 6,680 | 5,739 |
| Non-Road | 7,056 | 7,928 | 8,547 | 10,015 | 9,246 | 7,116 | 6,532 |
| Mobile | 50,422 | 42,970 | 41,873 | 38,799 | 29,750 | 30,377 | 17,243 |
| **Total** | **98,845** | **85,676** | **72,314** | **69,859** | **62,323** | **51,142** | **35,402** |

*Note: A revised methodology (EPA's residential wood combustion too) was used in the 2008 inventory for residential wood combustion; this resulted in substantially lower estimates of NOx and VOC for area sources.*

**FIGURE 3: New Hampshire Nitrogen Oxide (NOx) Emissions Trends (1990-2014)**



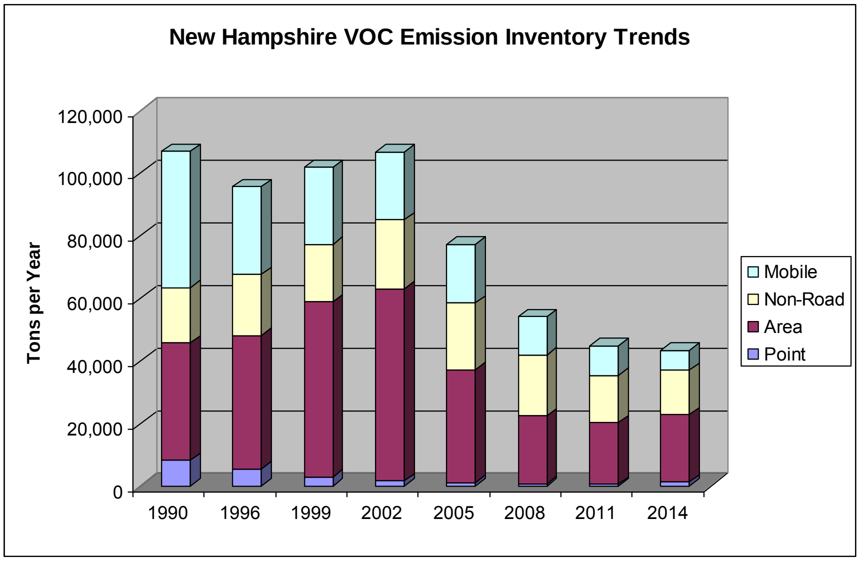

*Note: 2014 values are estimates*

**TABLE 2: New Hampshire VOC Emissions (tons per year)**

| Category | 1990 National Emissions Inventory | 1996 National Emissions Inventory | 1999 National Emissions Inventory | 2002 National Emissions Inventory | 2005 National Emissions Inventory | 2008 National Emissions Inventory | 2011 National Emissions Inventory |
|---|---|---|---|---|---|---|---|
| Point | 8,311 | 5,421 | 2,991 | 1,599 | 1,104 | 783 | 652 |
| Area | 37,452 | 42,700 | 55,921 | 61,554 | 36,105 | 21,701 | 19,686 |
| Non-Road | 17,690 | 19,523 | 18,468 | 21,950 | 21,255 | 19,415 | 15,094 |
| Mobile | 43,604 | 28,069 | 24,511 | 21,681 | 18,927 | 12,333 | 9,417 |
| **Total** | **107,056** | **95,713** | **101,891** | **106,784** | **77,391** | **54,232** | **44,849** |

*Note: A revised methodology (EPA's residential wood combustion too) was used in the 2008 inventory for residential wood combustion; this resulted in substantially lower estimates of NOx and VOC for area sources.*

**FIGURE 4: New Hampshire Volatile Organic Compound (VOC) Emissions Trends (1990-2014)**




*Note: 2014 values are estimates*

e. And, what is our 2015 outlook for exceedances?

Emissions trends are expected to continue downward in response to regulations already on the books or proposed. Also, emission reductions will result from the proliferation of natural gas used in place of dirtier fuels. While these factors would suggest that NH ozone levels will also continue trending downward, it is impossible to say what the actual ozone levels will be in any future year because of the variability of weather patterns from one year to the next. In recent years, weather patterns have not been conducive to bringing ozone into NH from the usual upwind sources. We do not know whether this pattern will continue or shift into a pattern that is more conducive to transport of higher ozone concentrations, or whether climate change is causing shifts in historic patterns.

**Questions for Forest Watch Students**

Forest Watch students might now take this report a step further. Who do you know in your town or city who has been affected by these regulations? Why not interview that person and find out exactly how the New Hampshire regulations work.

Does this report make sense to you? Can you write a paragraph explaining just one interesting chart?

Are there any peculiar words in this report that are new to you? Reading that section again, can you define the word from its context? Can you Google a clearer definition? Now what does that word mean in this context?

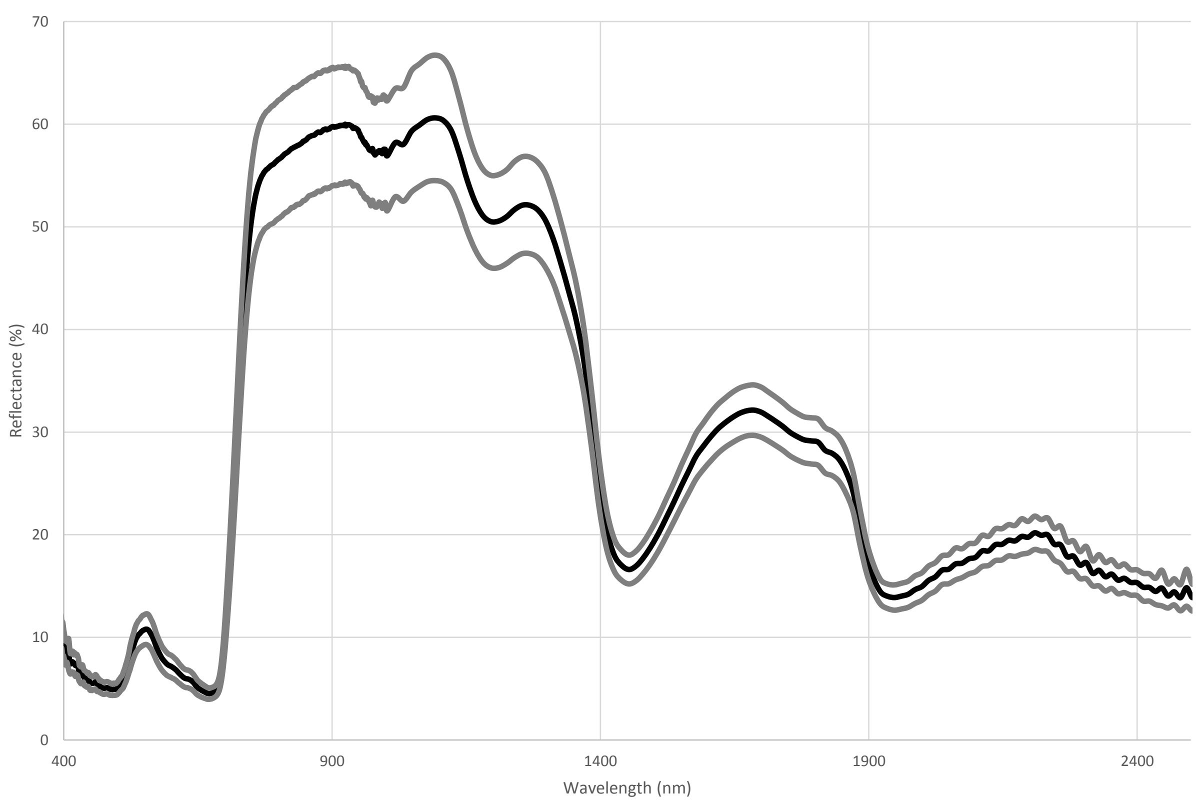
## Chapter Three
## Spectral Measures of 2012 Needles

### Reading Light

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

Over the past thirty-five years, Forest Watch scientists and other plant physiologists have deciphered the messages contained in a plant's spectral reflectance properties. "Reading light," (Figure 3.1) we can learn how much chlorophyll the needles contain, whether the needles contain adequate amounts of water, and how healthy the needle mesophyll cells are. Those messages of reflectance and absorption give us a clear picture of a white pine's health.

Figure 3.1. Reflectance Data - 106 Trees, 2012-2013
Mean and Standard Deviations (+/-)



Each year Forest Watch schools provide our labs at UNH with a supply of fresh needles from their white pine trees for spectral measurements. When they collect samples for their own classroom and laboratory study, Forest Watch teachers and their students carefully collect a duplicate set of needles, store them in labeled Ziploc bags and ship them overnight to UNH. Usually, we select from these needle samples only first-year needles (in this case, 2012 needles). This year, because of our concerns about a major needle cast event in 2010 and 2011, we have also scanned some 2011 needles.

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

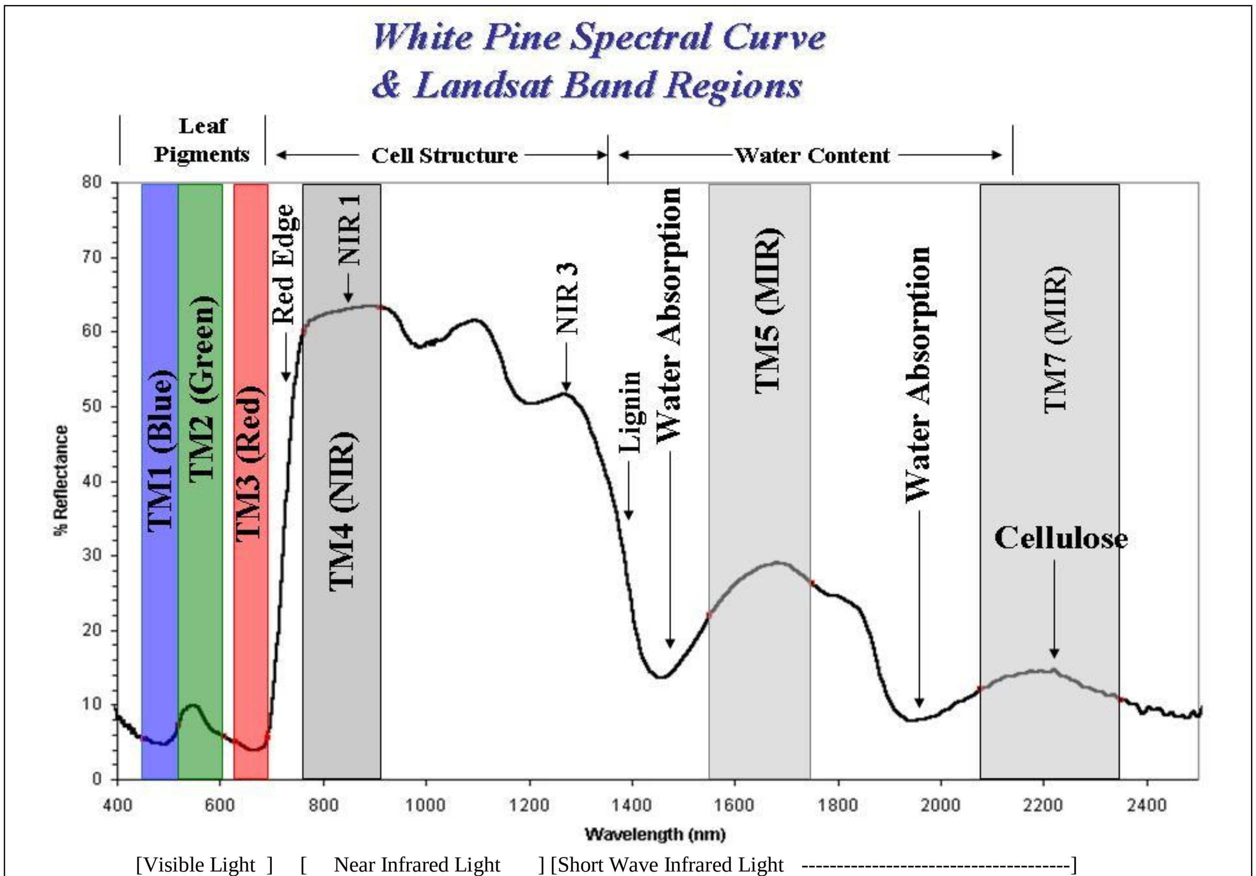



Figure 3.2: From left to right, the VIRIS measures visible light, near infrared and short wave infrared light. TM bands are identified by number as they are in Landsat imagery sets as well as by the information they provide as to plant conditions.

On the left side of the spectrum, visible light shown in Figure 3.2, 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.

**The Red Edge Inflection Point**

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 3.2). The red edge inflection point (REIP) is the first derivative, the tipping point, on the steep slope between absorption in TM 3 and reflectance in TM4. With the VIRIS, we can detect to within a nanometer of light where that point, the REIP, is. Higher REIP numbers indicate rich chlorophyll in a deep broad well of red visible light absorption. This is the part of the spectrum in which chlorophyll a and chlorophyll b

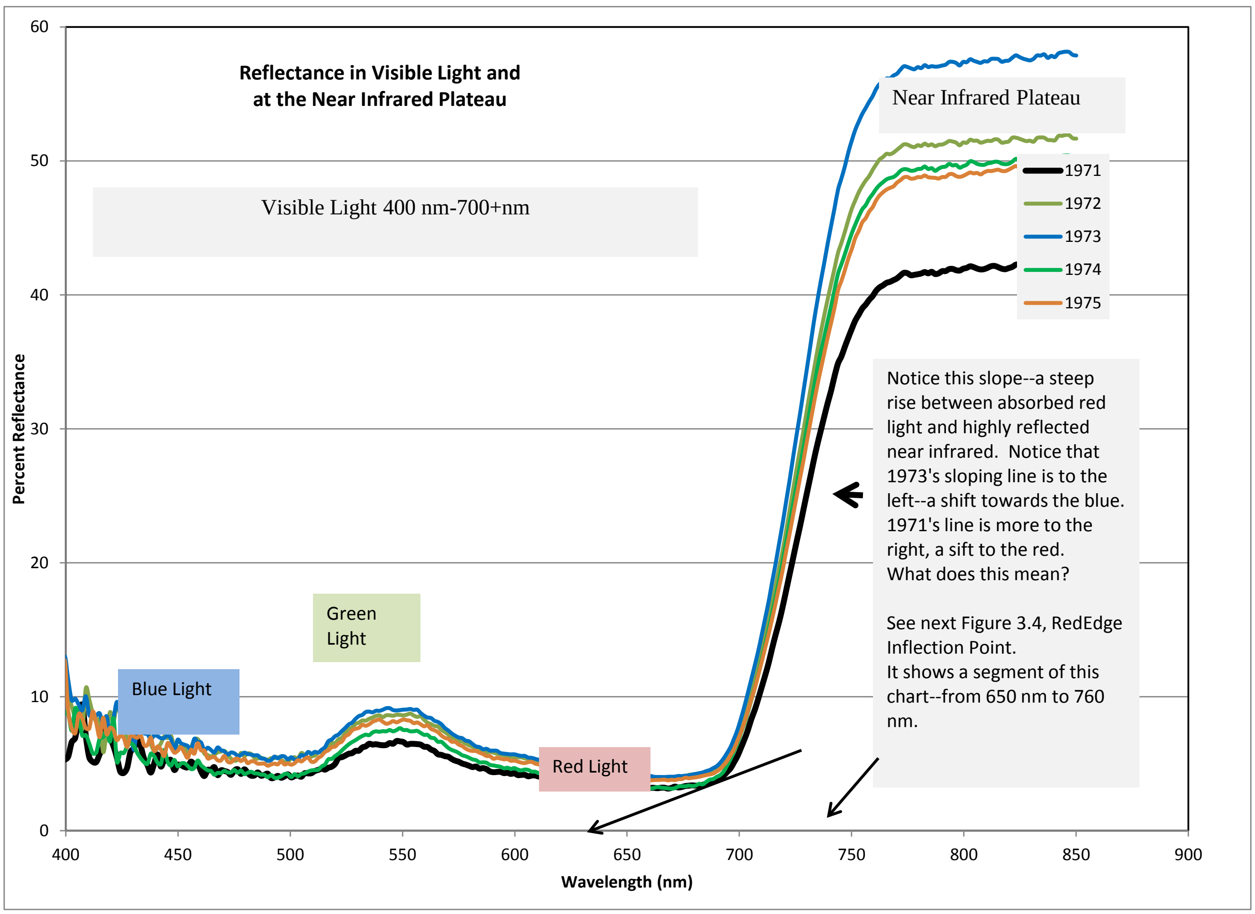



*Figure 3.3. A close-up view of visible light and the edge of the near infrared plateau help to explain the Red Edge Inflection Point. Notice that the reflectance curve for Tree 1971 is deeper in visible red, showing more chlorophyll and farther to the right on the slope. It has more chlorophyll.*

absorb most efficiently. Lower REIPs indicate less chlorophyll in stressed or aging leaves or needles.

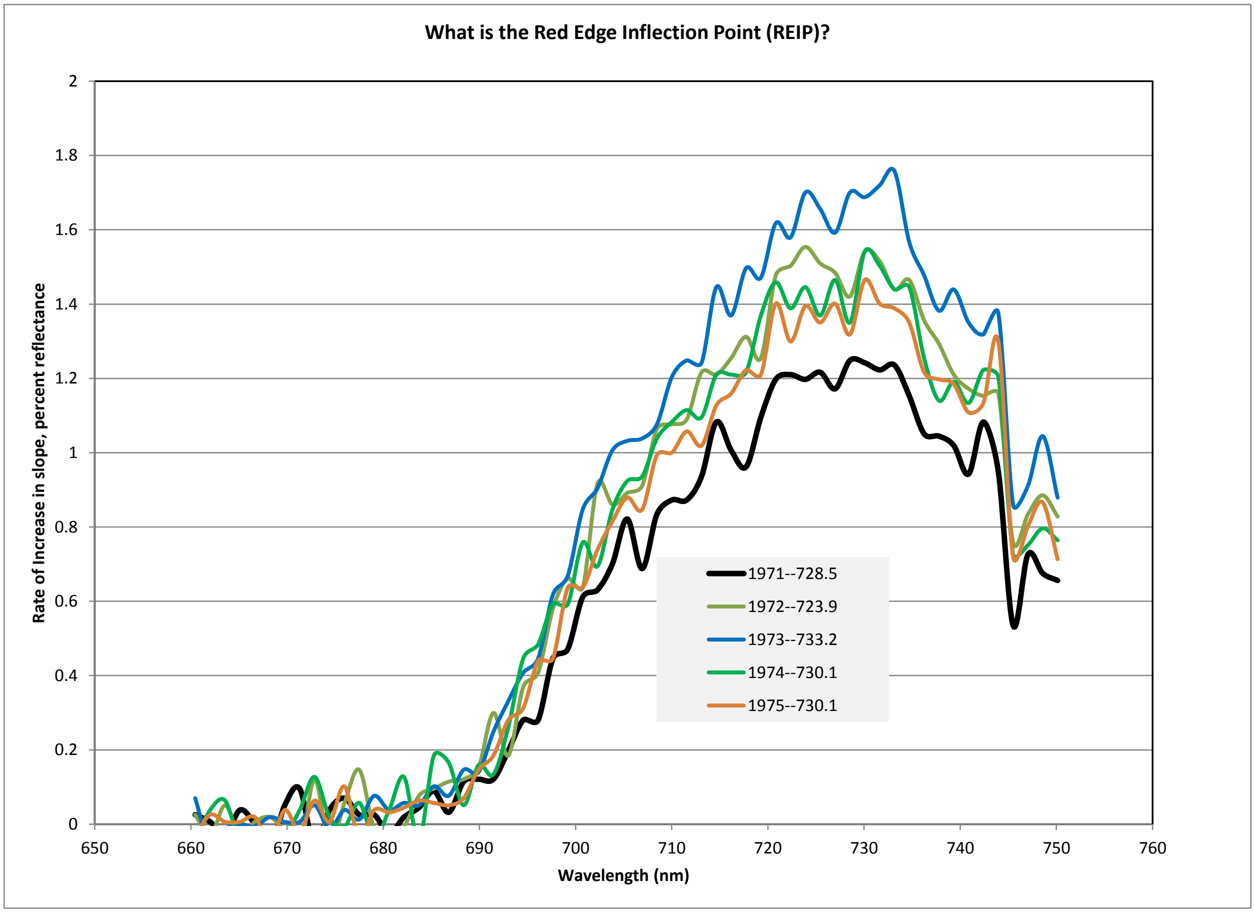



*Figure 3.4. A close-up of the change in slope from visible red light to the top of the Near infrared plateau. The high point shows the point, the point at which change slows and drops off—even as the slope continues up—the Red Edge Inflection Point.*

In Algebra class, many students learn how to calculate the slope of the line. The REIP is a study of the slope of white pine's reflectance, the slope between visible light's strong absorption and the high reflectance in the near infrared plateau. How steeply does the slope rise? At what point does the rate of increase in that slope's steepness slow down? Imagine a stair case in which steps are high at first and then become shorter near the top of the staircase. The point at which increases in the slope get shorter is called the 'first derivative." This point is the Red Edge Inflection Point, as shown in Figure 3.4.

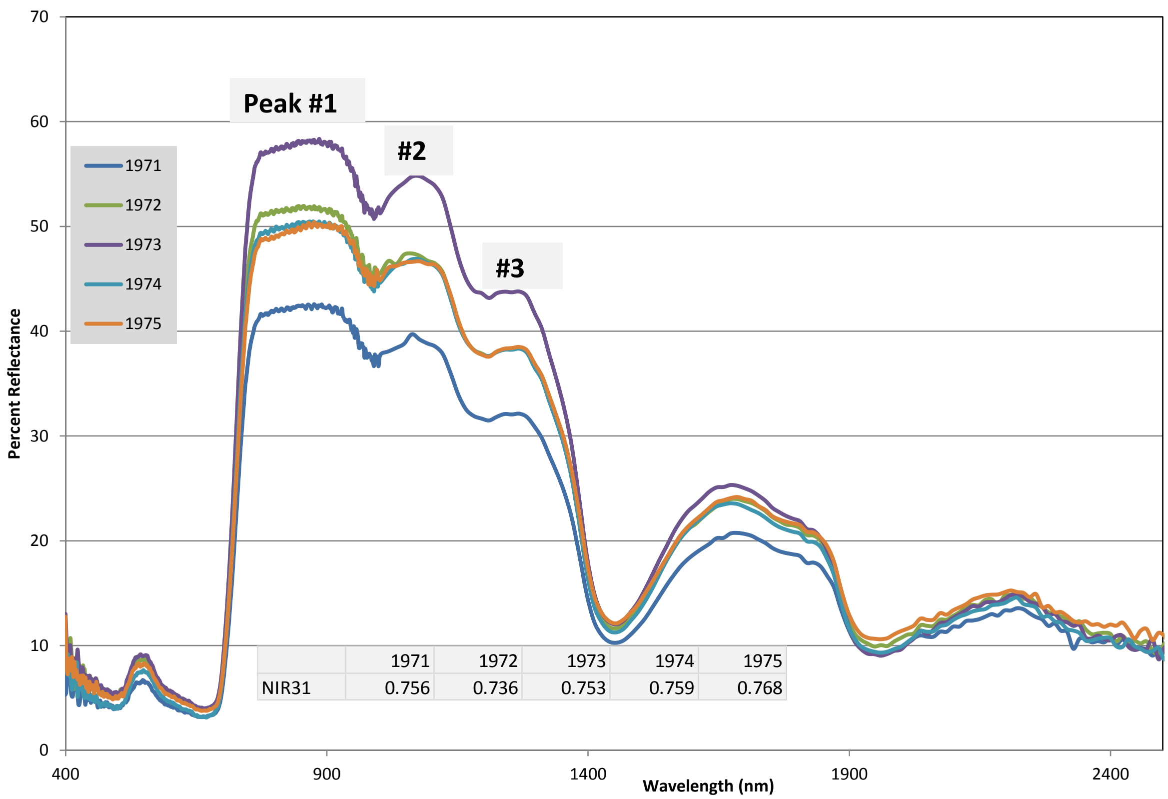
In this chart, we've cut out the data between 660 nm and 750 nm and laid it on its side. The increase is clear. The first derivative is the highest point on each line. Using Excel charts of their trees, students in Forest Watch can touch the computer screen and bring up point data for that high point. It matches the REIP shown in their tree's data indices.

Dr. Barrett Rock, founder of Forest Watch, thinks the REIP is the most sensitive measurement of chlorophyll. If the peak occurs above 720 nm, the tree has abundant pigments for photosynthesis. If the peak occurs between 710 and 720 nm, chlorophyll is less abundant—the tree may be stressed. If the REIP is below 710, the tree is certainly stressed and lacks chlorophyll.

### The Near Infrared 3/1 Ratio

Figure 3.5 shows the three peaks of the NIR plateau (NIR1, NIR2 and NIR3). A ratio of NIR 3 over NIR1, the percent of reflectance for each peak, gives scientists an accurate measure of the cellular maturity of needles—how many cells, cell walls and water they contain compared to the amount of intracellular space. Lower ratios indicate young vigorously growing needles. High ratios over 0.90 indicate aging, damaged or senescing needles.

**Figure 3.5. VIRIS Data - The Near Infrared 3/1 Ratio**

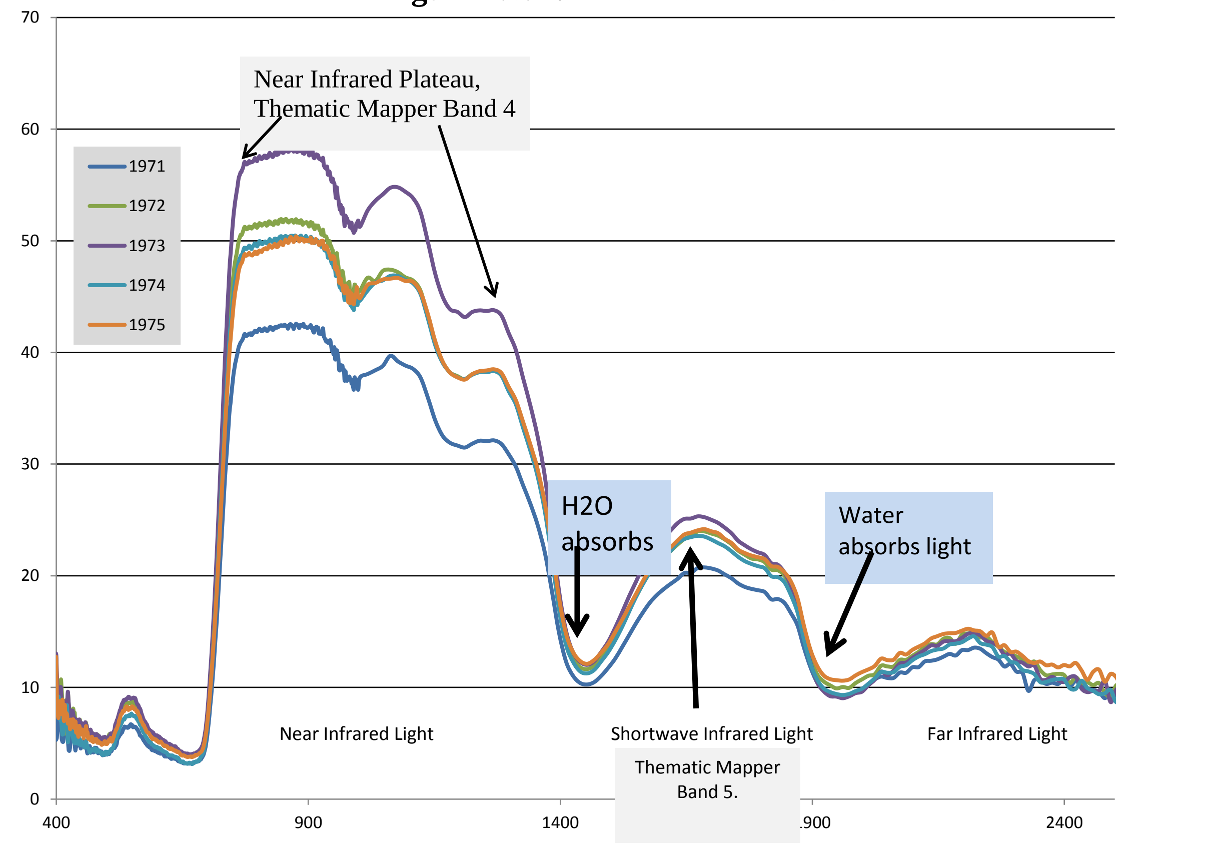



| | 1971 | 1972 | 1973 | 1974 | 1975 |
|---|---|---|---|---|---|
| NIR31 | 0.756 | 0.736 | 0.753 | 0.759 | 0.768 |

The TM5/4 Ratio

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 are good; they indicate that a plant cells are flush with water. Ratios of percentages of 60% or more indicate water stress and a plant that will have trouble photosynthesizing.

**Figure 3.6. VIRIS Index - TM 5/4**




The Thematic Mapper aboard a Landsat satellite  reads light reflected from Earth in 7 bands.

- Band 1 is an average of blue light.
- Band 2 is an average of all green light.
- Band 3 is an average of red light.
- Band 4 is an average of the entire NIR plateau.
- Band 5 is an average of the Shortwave or Mid-Infrared Plateau.

A ratio of Band 5 over Band 4 tells us if foliage has good water content or poor water content.

< 0.55 means foliage has ample water.
0.50-0.55 indicates initial water stress.
>0.55 indicates a lack of water and plant stress.
How do the ratios looks in Figure 3.6?

Forest Watch teachers know that the indices discussed above may change slightly as we begin to use Landsat 8. The new satellite adds several new bands. Our TM5/4 ratio will soon become a 6/5 ratio—but our VIRIS in the Forest Watch lab continues to use the familiar TM5/4.

Table 3.1 shows the three major indices of reflectance and plant health which we use in Forest Watch. The 106 trees monitored in the past year average REIPS of 722.5 nm. This agrees with other average REIPs measured in the last decade, a sign of abundant chlorophyll. The average TM5/4 ratio is 52.8, a healthy percentage of water after a dry TM5/4 in 2011. NIR 3/1 ratios are also falling back to average levels after a high in 2011.

| Table 3.1. Reflectance Indices | |
|---|---|
| All Needles from 106 trees, 2012 | |
| Red Edge Inflection Point (REIP) | 722.5 |
| TM Band 5/TM Band 4 Ratio (TM5/4) | 52.8 |
| Near Infrared Band 3/Band1 Ratio (NIR3/1) | 86.8 |

In Table 3.2, some schools in the needle cast area—Sant Bani School and St. Johnsbury School—show low REIPs but on the whole, the average has returned to historic averages.

The REIP data shown in Table 3.2 shows healthy chlorophyll levels in every state. Exceptionally high levels might indicate excellent sites, young vigorous trees and supportive care by tree owners. Springfield High School's pines live in a city park where lawns may be fertilized and where trees are pruned to give each pine full light. French Pond School's trees, on the edge of a ball field, might also have special lawn care. Gilmanton School's trees have high REIPs probably because they are young and vigorous with plenty of space and light.

| | | | | | |
|---|---|---|---|---|---|
| | | **Table 3.2: REIP Summary by State** | | | |
| | **2012 Needles - Fall and Spring Samplings, 2012-2013** | | | | |
| | | | | | |
| **State: CT** | | | **Avg. REIP** | **Std. Dev.** | **# Trees** |
| RHAM High School | | | 725.03 | 2.3 | 10 |
| Tolland High School | | | 722.65 | 3.5 | 5 |
| | | **State Average** | **723.84** | **2.9** | |
| **State: ME** | | | | | |
| Morse High School | | | 724.2 | 3.75 | 5 |
| | | **State Average** | **724.2** | **3.75** | |
| **State: MA** | | | | | |
| Hanson Middle School | | | 722.88 | 3.17 | 5 |
| Meridian Academy | | | 729.16 | 3.4 | 5 |
| Springfield Central School | | | 728.15 | 2.46 | 5 |
| | | **State Average** | **726.73** | **3.01** | |
| **State: NH** | | | | | |
| Alvirne High School | | | 720.08 | 2.44 | 10 |
| Dublin School | | | 722.08 | 4.2 | 5 |
| French Pond School | | | 727.26 | 4.5 | 5 |
| Gilmanton Middle School | | | 727.77 | 5.78 | 5 |
| Keene High School | | | 719.43 | 2.6 | 5 |
| Lyme School | | | 724.61 | 3.05 | 5 |
| Monadnock Regional High School | | | 720.36 | 4.24 | 5 |
| New Hampton School | | | 722.21 | 4.62 | 5 |
| Salem High School | | | 722.37 | 2.16 | 5 |
| Sant Bani School | | | 716.8 | 5.42 | 5 |
| | | **State Average** | **722.30** | **3.90** | |
| **State: VT** | | | | | |
| St. Johnsbury School | | | 718.43 | 4.8 | 5 |
| | | **State Average** | **718.43** | **4.8** | |
| **New England Regional Average** | | | **723.10** | **3.67** | |
| **Number of Trees** | | | | | **95** |

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 3.7 shows. As the Red Edge Inflection Point rises, moving to longer wavelengths in the spectrum of light, Moss and Rock found more chlorophyll in the spruce samples. The r2 value of 0.87 means that 87% of the data points exhibit this correlation.

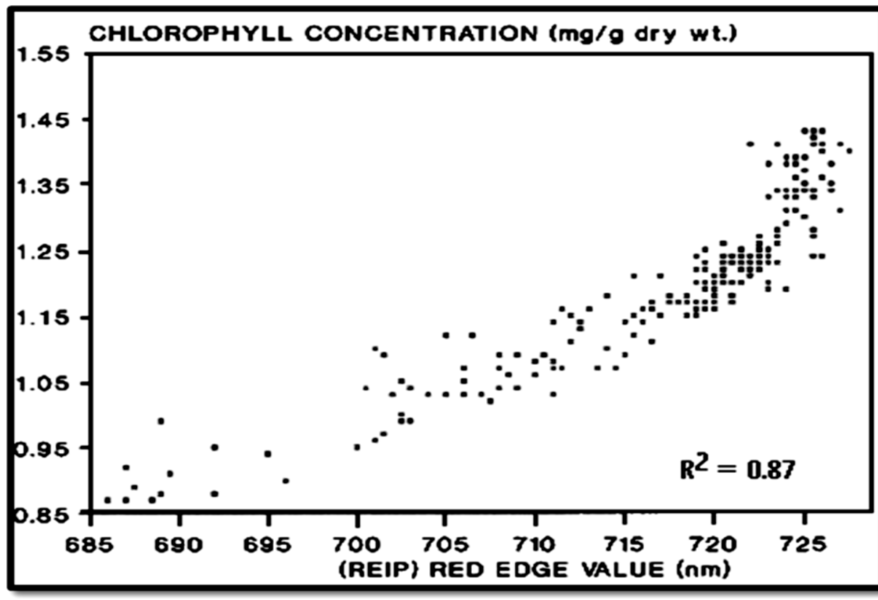


Figure 3.7: A positive correlation between chlorophyll and REIP (Moss & Rock, 1991.)*

This past fall, Michael Gagnon, our former Forest Watch coordinator, now a teacher at Alvirne High School, in Hudson, NH, examined this correlation closely in his Masters of Science thesis. We look forward to interesting new perspectives on chlorophyll and the REIP when Mike publishes his work. The correlation holds and gets more interesting, thanks to Mike's work.

TM5/4 ratios can be correlated with water content in foliage. Many schools mass needles when they are fresh and then dry them for a few days. The difference in weight should correlate with our laboratory findings about water content.

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

## Comparing 2012 Needles with 2011 Needles

This year, for the first time, we scanned 2011 needles on as many samples as we could. We wanted to understand why needles in 2010 and 2011 lost their second and third-year-old needles. We wanted to see how two-year-old needles were aging in the 2012-2013 year. As Figure 3.8 shows, differences between senescing or aging needles and young vibrant needles are easy to see in a VIRIS scan. Aging needles have lower REIPs and shallow V-shaped chlorophyll wells. The NIR plateau's three peaks become almost flat and yield NIR3/1 ratios close to 1.0. The needles generally become dry, with higher TM5/4 ratios.

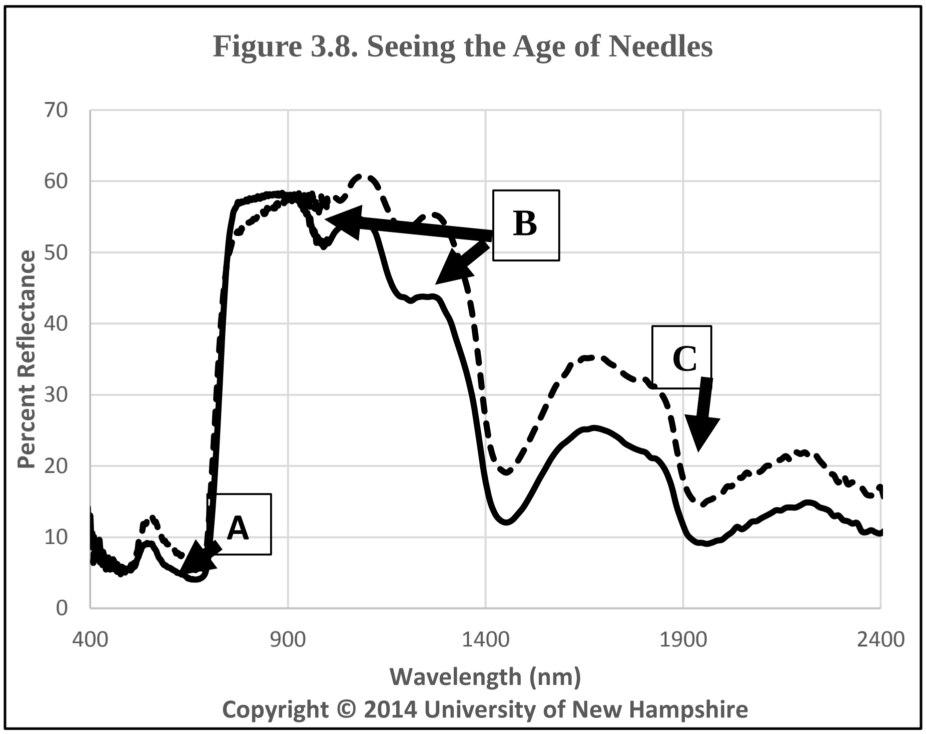



*Figure 3.8. Chlorophyll amounts change with age as seen at A.*

*The dotted line of the older needle (B) is slanted as it arrives at the Near Infrared Plateau and crosses Peak 1, 2 and 3. The solid line of younger needles is slanted.*

*Older needles have shallower wells (C) on either side of the mid-infrared plateau because they have less water, which absorbs light.*

Forest Watch scanned 45 sets of second year needles this year. As our Biometric data will show in Chapter 4, needle retention is back to an average of more than 2 years. Only a few trees had only one year of needles. Others had scanty groups of second year needles and needles that showed high NIR3/1 ratios, strong evidence of aging. We could not see any pattern in the aging of needles—by location or any other attributes. In Salem, NH, for instance, one tree showed advanced senescence of second-year needles while a nearby tree maintained abundant chlorophyll and ample water content in second year needles.

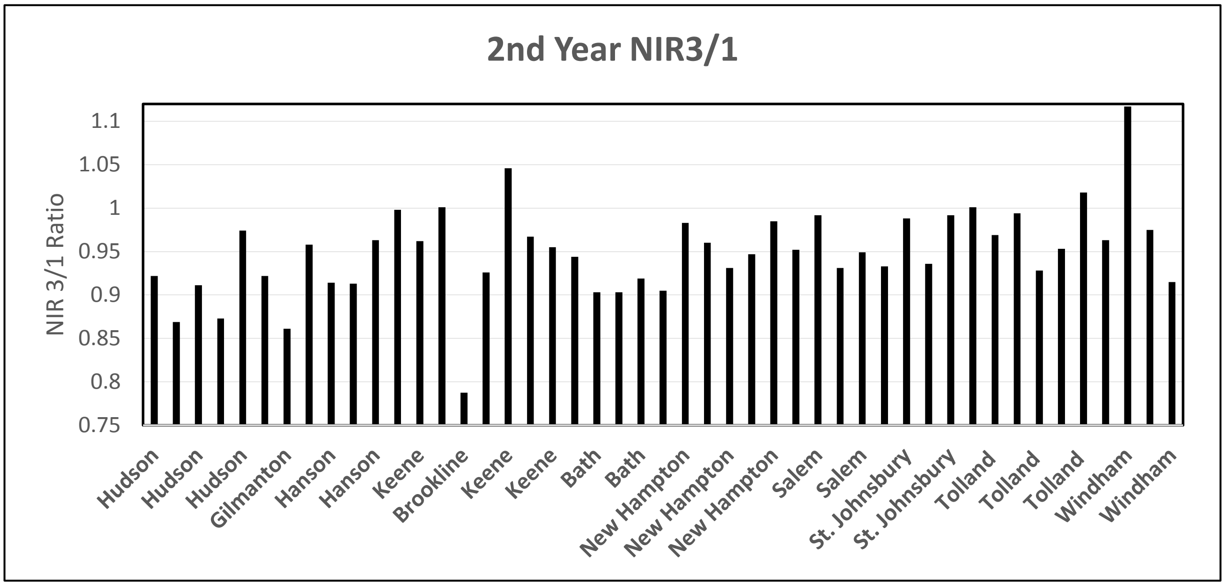



*Figure 3.9. Most 2nd –year needles show some senescence with NIR3/1 ratios averaging 0.949. One tree in Keene and one in Windham showed needle death with NIR3/1 ratios of 1.0 or more. Many needles, especially in Bath, Maine, and Hanson, MA, are robust.*

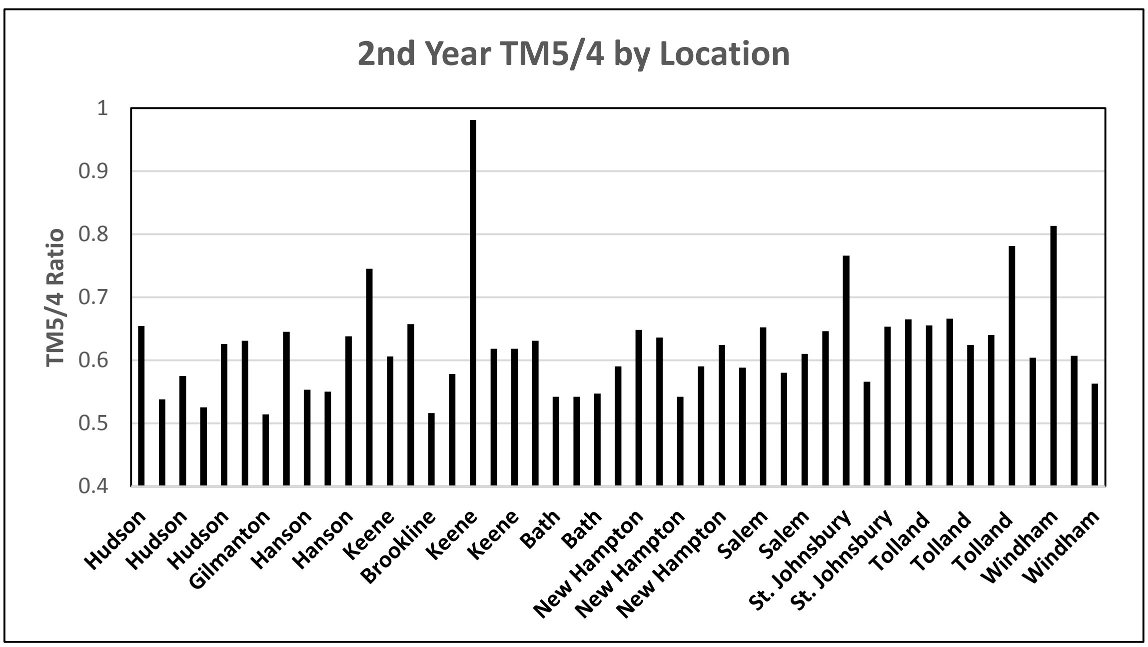



*Figure 3.10. Most trees show stress with TM5/4 ratios that averaged 0.624, an indication of water stress, but many 2011 needles are still healthy and have ample water as shown with TM5/4 ratios below 0.55.*

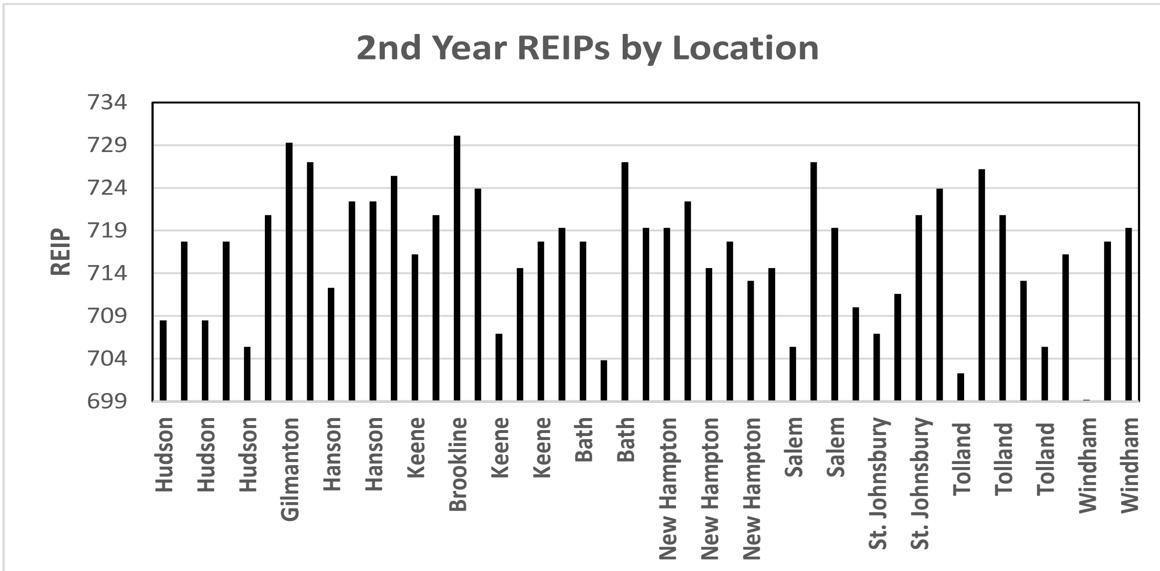



*Figure 3.11. 2011 needles averaged 716.6 nm in the REIP but at least one-third of the 45 samples had chlorophyll levels on a par with 2012 needles.*

In each case where second year needles could be scanned, we returned curves and data to the sending school for their analysis. An example of what students can see in their data can be seen in spectral indices for Morse High School's first year 2012 needles and second year 2011 needles.

| | Morse 2012 Spectral Data | | | |
|---|---|---|---|---|
| | REIP | NDVI | TM54 | NIR31 |
| 1741N | 723.9 | 0.839 | 0.509 | 0.848 |
| 1741S | 727 | 0.844 | 0.508 | 0.85 |
| 1742N | 720.8 | 0.878 | 0.51 | 0.851 |
| 1742S | 716.2 | 0.826 | 0.517 | 0.865 |
| 1743N | 725.4 | 0.847 | 0.516 | 0.856 |
| 1743s | 725.4 | 0.826 | 0.516 | 0.866 |
| 1744n | 723.9 | 0.845 | 0.533 | 0.858 |
| 1744s | 722.4 | 0.836 | 0.514 | 0.858 |
| 1745n | 728.5 | 0.869 | 0.479 | 0.834 |
| 1745s | 728.5 | 0.879 | 0.505 | 0.861 |
| Mean | 724.2 | 0.8489 | 0.5107 | 0.8547 |

| | Morse 2011 Spectral Data | | | |
|---|---|---|---|---|
| Tree ID | REIP | NDVI | TM54 | NIR31 |
| 1741-2 | 719.3 | 0.836 | 0.631 | 0.944 |
| 1742-2 | 717.7 | 0.864 | 0.542 | 0.903 |
| 1743-2 | 703.8 | 0.838 | 0.542 | 0.903 |
| 1744-2 | 727 | 0.855 | 0.547 | 0.919 |
| 1745-2 | 719.3 | 0.87 | 0.59 | 0.905 |
| Mean | **717.42** | **0.8526** | **0.5704** | **0.9148** |

*Figure 3.12. A table of 2012 data indices at left can be compared with the table at right of 2011 needles.*

As the two tables in Figure 3.12 show, Morse 2012 needles are beautiful, with ample chlorophyll, equal to historic averages. The 2011 needles are also generally good. The average REIP of 717 indicates some loss in chlorophyll. One tree, 1743, shows significant near-total loss of chlorophyll.

NDVI measures indicate we had ample samples for accurate measurements.

TM5/4 measures water stress. The 2012 Morse needles show no water stress. In the 2011 second year needles, one tree, 1741 shows water stress and drying of needles. Another tree, 1745, shows initial water stress. The others have ample water.

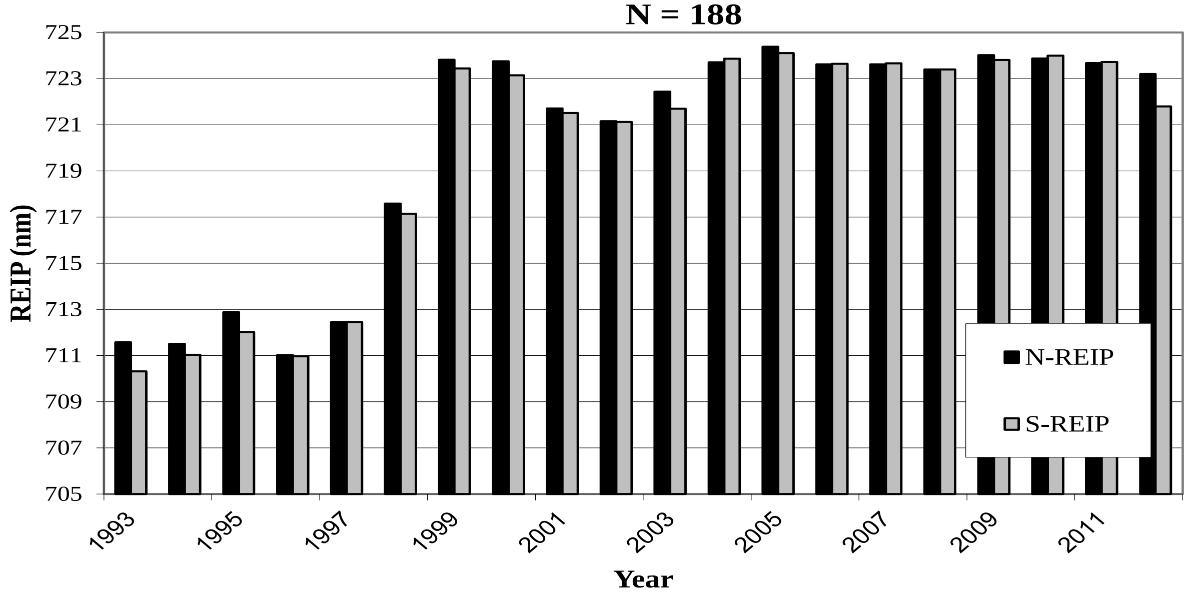
The NIR 3/1 index shows maturity of needles. The 2012 needles are young and robust, even though they were sampled in May 2013, nearly one year after they emerged from the bud in 2012. The 2011 needles, a full two years in age, show some senescence but not severe aging. They appear capable of surviving and photosynthesizing sugar another year.

Such comparisons, whether made with the VIRIS or with other simple classroom measurements of water content, appearance, color and chlorophyll content, may give students valuable information about the health of different trees at their schools.

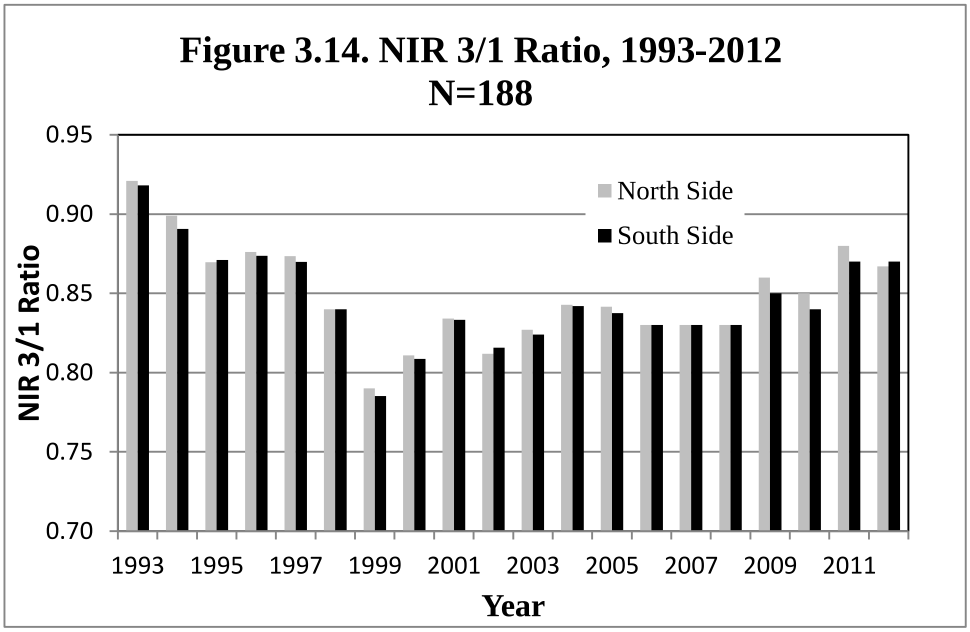
**Long-Term Spectral Comparisons**

One more perspective on the light reflected by the pine foliage comes with comparisons over time. The Forest Watch data library now contains 20 years of data. The 2012 average

**Figure 3. 13. REIP Values 1993-2012**
**N = 188**



REIP of 722.4 shows a slight drop from the previous years but still very high, especially compared with the high ozone years of the early 1990s.




As needles showed in 2011, the 2012 needles still show advanced senescence and greater aging than we have seen in recent years. The drop to 0.87 is a slight improvement from 2011.

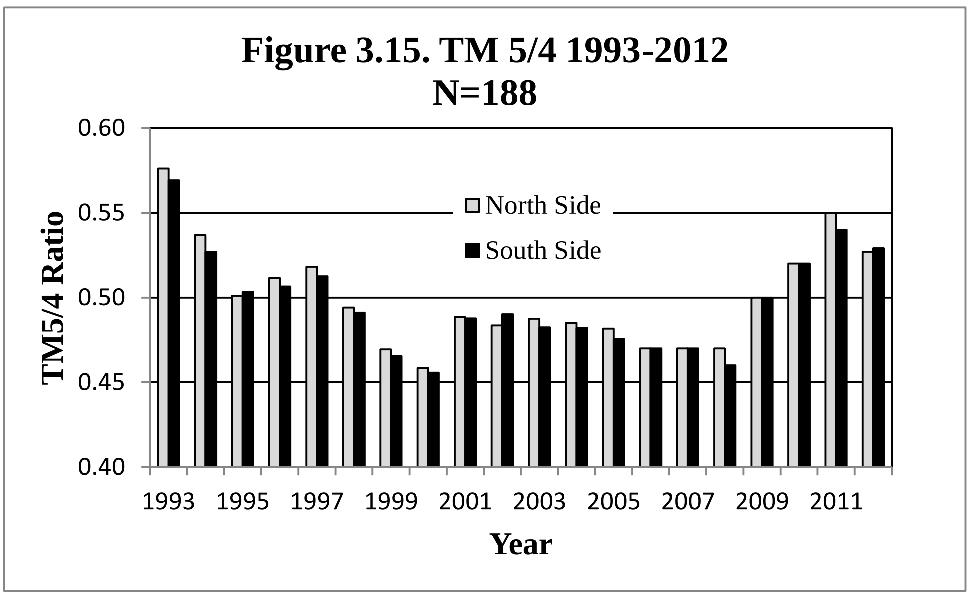



Figure 3.15 shows even better improvement in water content in the 2012 needles. The average dropped from a TM5/4 indication of initial water stress (0.55) in 2011 to a healthier 0.53. This chart shows that water content dropped in 2009 following a very dry year in 2008. Climate change and changing precipitation patterns may continue to cause water stress in the pines.

# Chapter Four

## Forest Watch Biometric Data Analysis

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

The Forest Watch Data Book examines the data for 2012 and compares this year's biometrics with measures from past years. Students measured 7,600 needles in the 2012-2013 school year. Actually, we think an additional 2,500 needles were measured by students in other schools which forgot to report their tabulations to Forest Watch. We urge teachers to send their data to us—it can add significantly to our long term data analysis and its accuracy.

### Long Term Data Analysis

White pines across the region are retaining second-year needles once again. The widespread needle cast which Forest Watch documented in 2010 needles appears to be a past problem. Many trees in our region, particularly those in southern New England, retained three

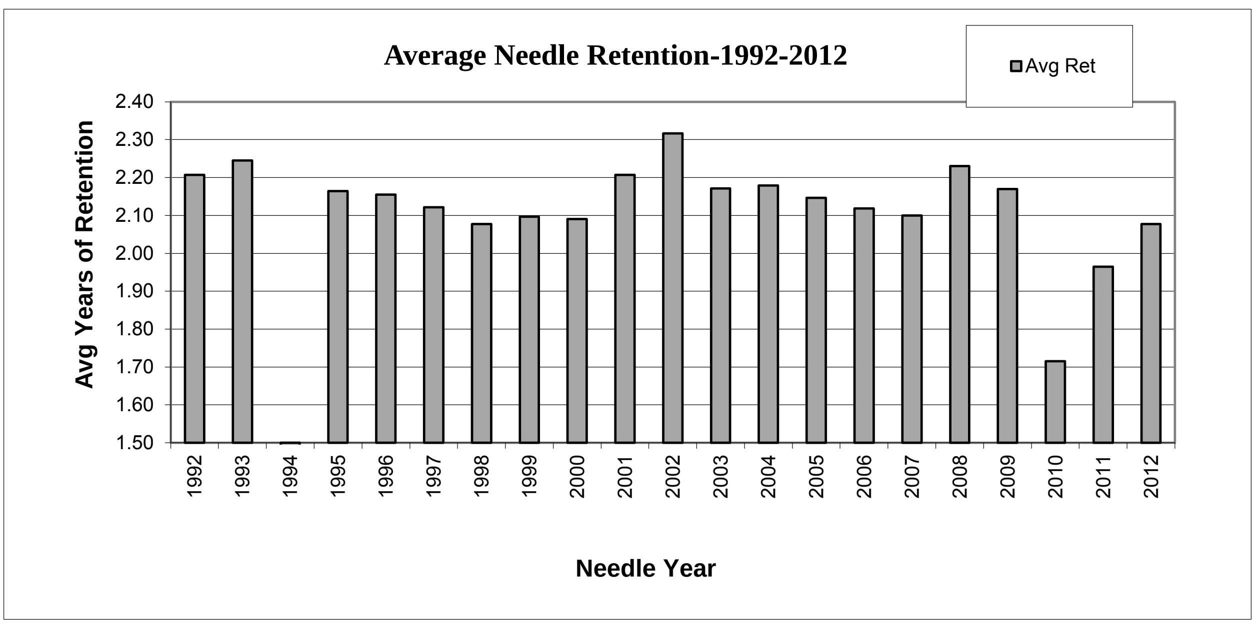



*Figure 4.1. Needle retention returned to 2.08 years in 2012-2013, a strong indication that the white pines are recovering from the stress of 2010.*

years of needles. Even in northern areas where needle cast problems were most severe in 2010 and 2011, trees retained two years of needles. As Figure 4.1 shows, average retention is back up over 2.0.

| Tree | North | South |
|---:|---:|---:|
| 1266 | 2.94 | 0.94 |
| 1267 | 1.20 | 1.18 |
| 1268 | 1.73 | 1.25 |
| 1269 | 1.52 | 1.2 |
| 1270 | 1.52 | 1.85 |

*Table 4.1. Actual percentages of needles retained on Monadnock Regional High School pines in Swanzey, NH.*

At Monadnock Regional High School, Gerald Babonis and his 10th grade Biology students counted pedicels and two-year-old needles to record a precise percentage of needles on each sample. As Table 4.1 shows, one south side sample on Tree 1266 really did retain only one year of needles. The rest had 18 to 85% of their second-year 2011 needles. Tree 1266 retained 94% of its third year 2010 needles.

The needle cast problem may not be completely resolved and some trees may continue to show stress from whatever caused the 2010 needle cast. Some trees continue to be infected by needle cast fungi. So, some trees, particularly in heavily infected areas, continue to show relatively few needles in the two-year-old class and almost none of three year age. Needle cast was widely observed in the region in June 2013 when 2011 and 2012 needles were cast and again in the fall when needle


*Figure 4.2. Needles from Monadnock Regional High School, collected on May 2, 2013, and from Windham High School, on June 5, 2013, retain both 2011 and 2012 needles. The 2011 needles show some browning but no fungal wounds as we saw the previous year.*

cast fungi frequently cause major casts. This winter, after a particularly sticky snowfall around the holidays, the snowy streets were littered with dead pine needles.

Observations of needle cast fungi on the needles we received were few. The needles appear to be generally free of the three fungi which the U.S. Forest Service identified in its study of 2011 needles.

**Resilience in the Needles**

Last year, Forest Watch wondered what would be the impact of the 2010 needle loss on white pine health. How would the trees respond?

This year's needle measurements may provide part of the answer: the white pines appear to have put extra oomph into their 2012 needles. In every biometric measure of this year's needles, the pines are breaking records—fascicle length and needle length are at record highs, indicating that our needles have greater photosynthetic power than on average, a compensation for those lost needles perhaps. Needles are 12.5% longer in 2012-2013 than our average needle length in the past 16 years, Figure 4.3.

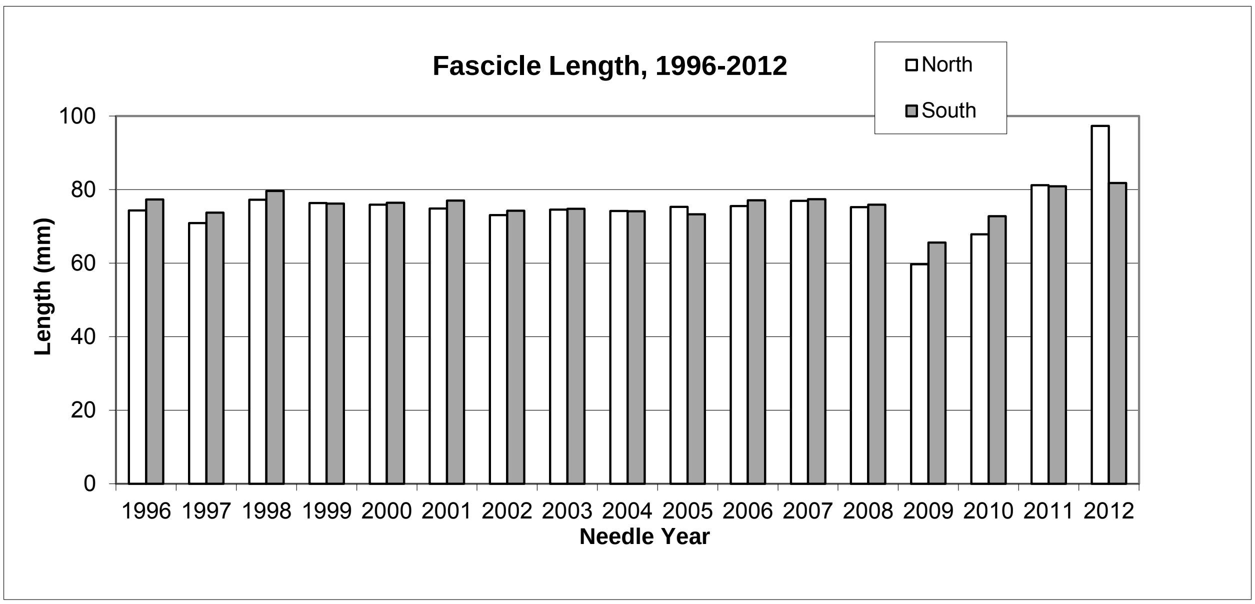



*Figure 4.3. Fascicle length jumped to record levels in 2012. Are the trees compensating for lost needles?*

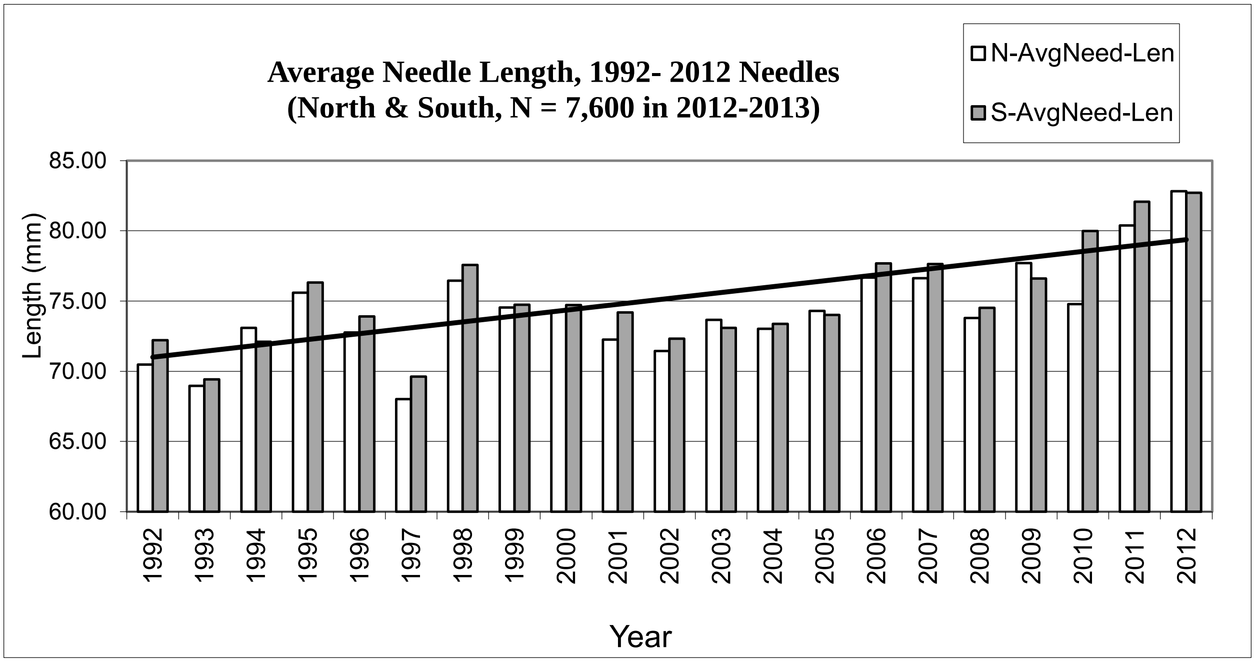



*Figure 4.4. Needles were, on average, 12.5% longer in 2012 than in any previous year, another indication trees are rebounding from the 2010 shock and perhaps compensating for lost older needles.*

Water content was at one of the highest levels measured over the past 20 years. Even as some older needles continued to show browning and early loss, the 2012 needles were robust and fit.

These long juicy needles appear to have been packed full of protective phenolics. The 2012 needles, like their 2011 predecessors, had the lowest tip necrosis and chlorotic mottling in our records. And, when damage is measured by length, we saw less than ever before, an average of 2.5 mm of damage or less on needles that showed damage or less than 3% on all needles counted. The low damage might be attributed to falling ozone levels but they may also point to heightened defense mechanisms in the pines, a phenomenon triggered by the 2010 stress.

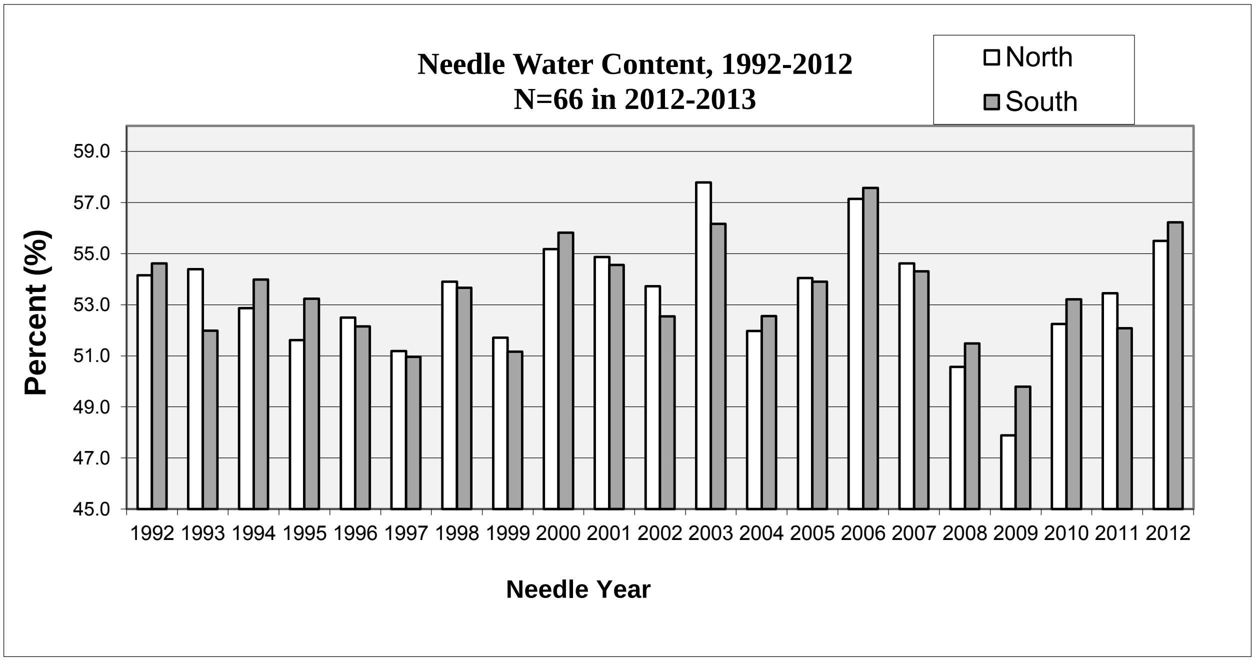



*Figure 4.5. Water content returned to record high levels in 2012 needles.*

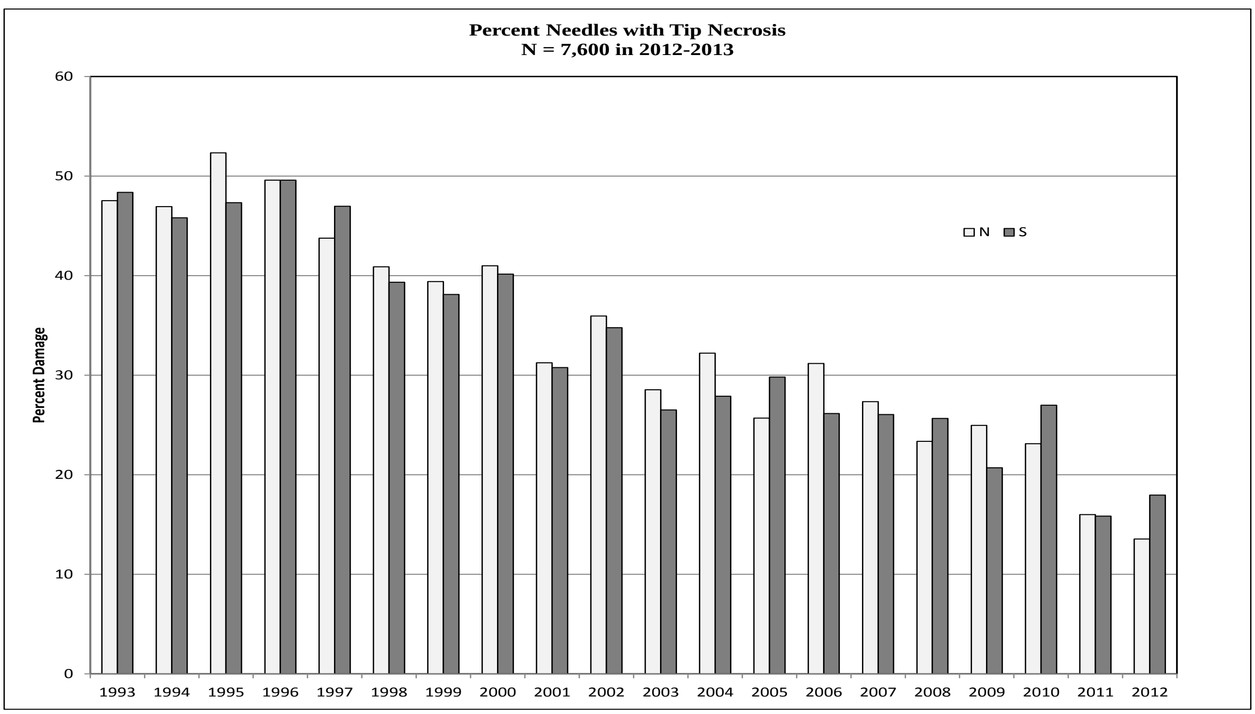



*Figure 4.6. Tip necrosis fell to the lowest average on record, 15.75% for both North and South needles.*

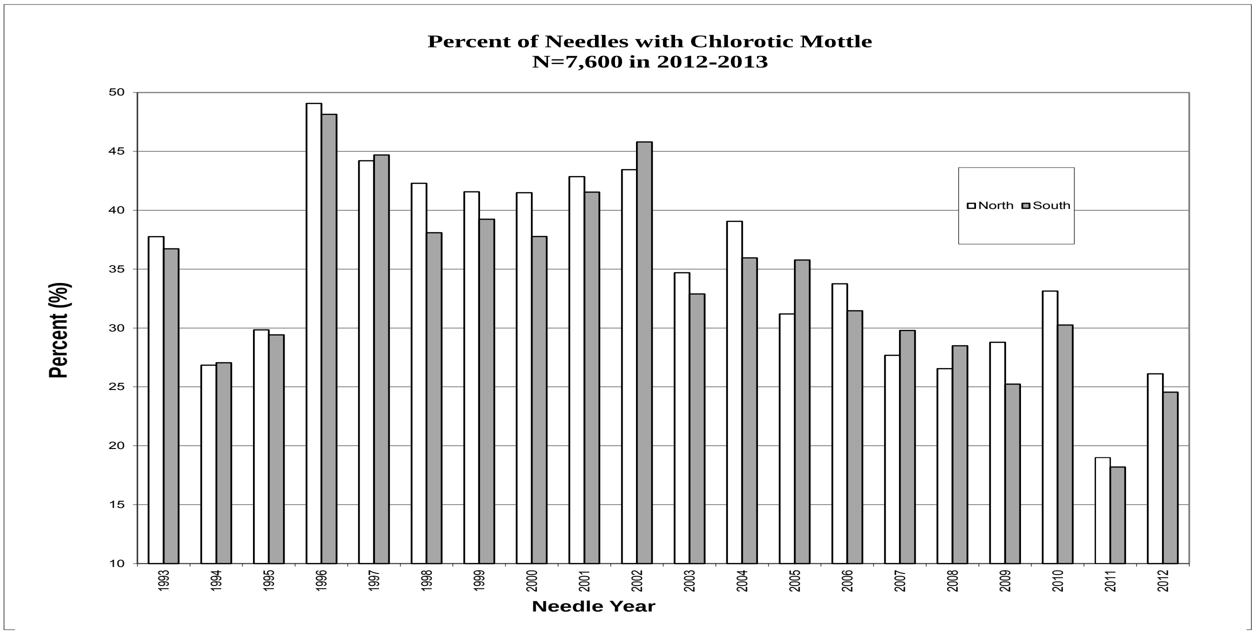



*Figure 4.7. Chlorotic mottle, the yellow spots and smears which ozone causes, was found on 25.3% of needles.*

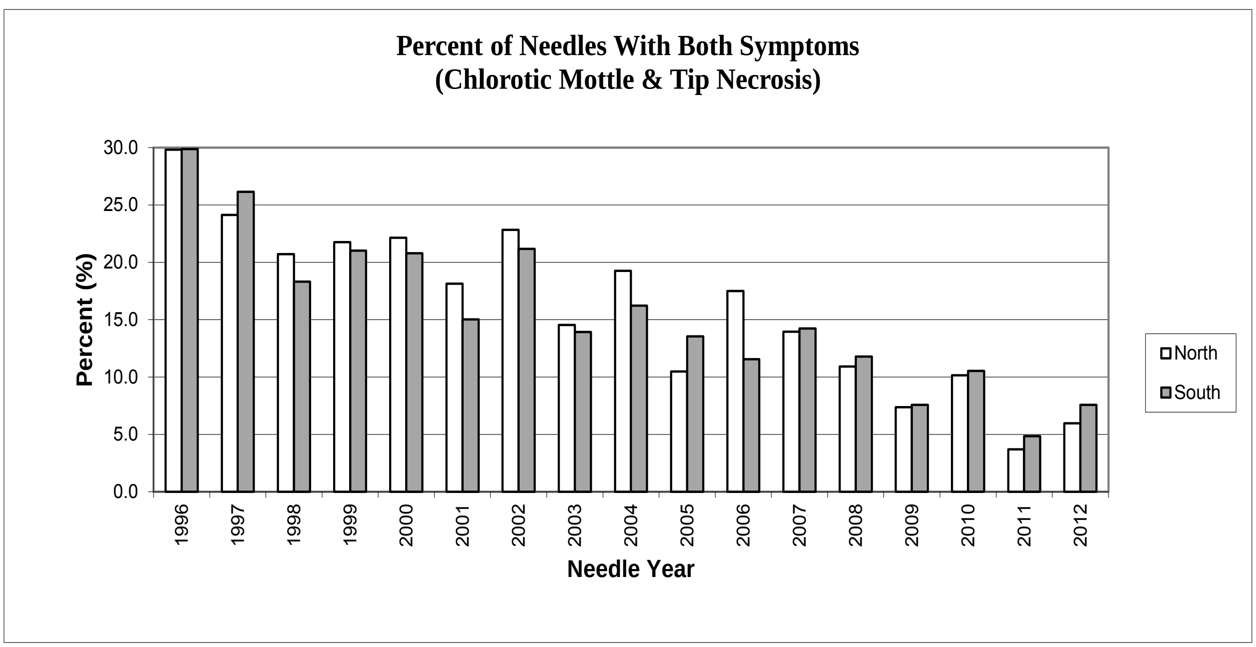



*Figure 4.8. Not quite as low as in 2011 needles, the percent of needles showing both symptoms of ozone damage was still a very low 6% on North trees and 7.6% on South trees.*

The white pine is a resilient species. The powerful stresses of 2010, wild fire smoke and accompanying air pollutants, and fungi caused serious loss of foliage to the trees. But they are rebounding. Forest Watch records clearly record the trees' long term good health and strength

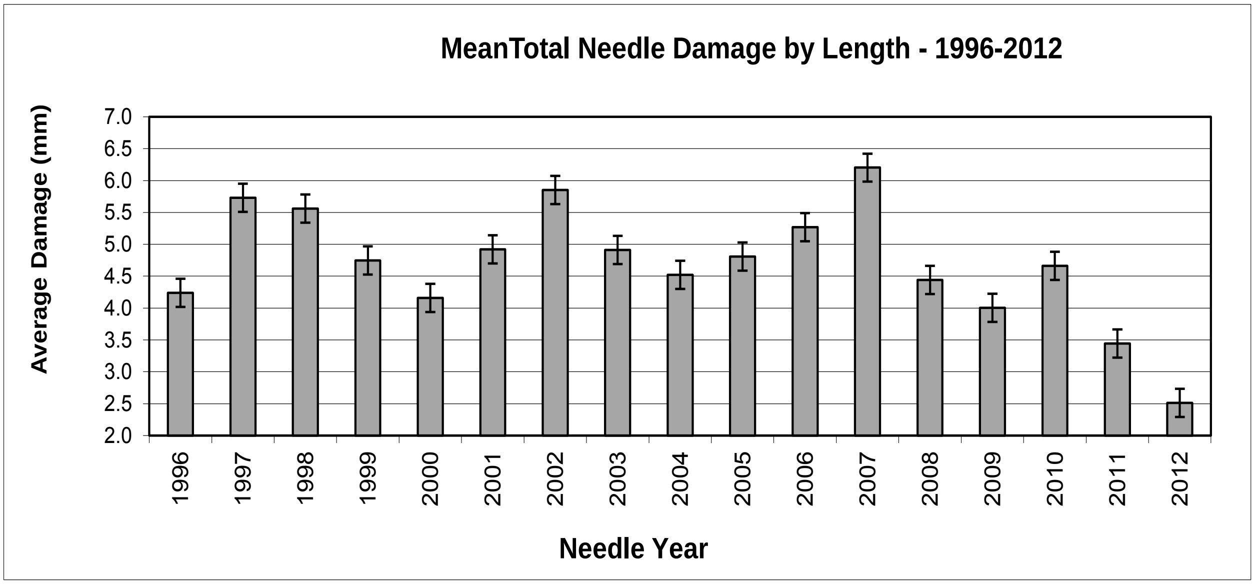



*Figure 4.9. The average length of damaged tissue on needles fell to a record 2.5 mm in 2012 needles.*

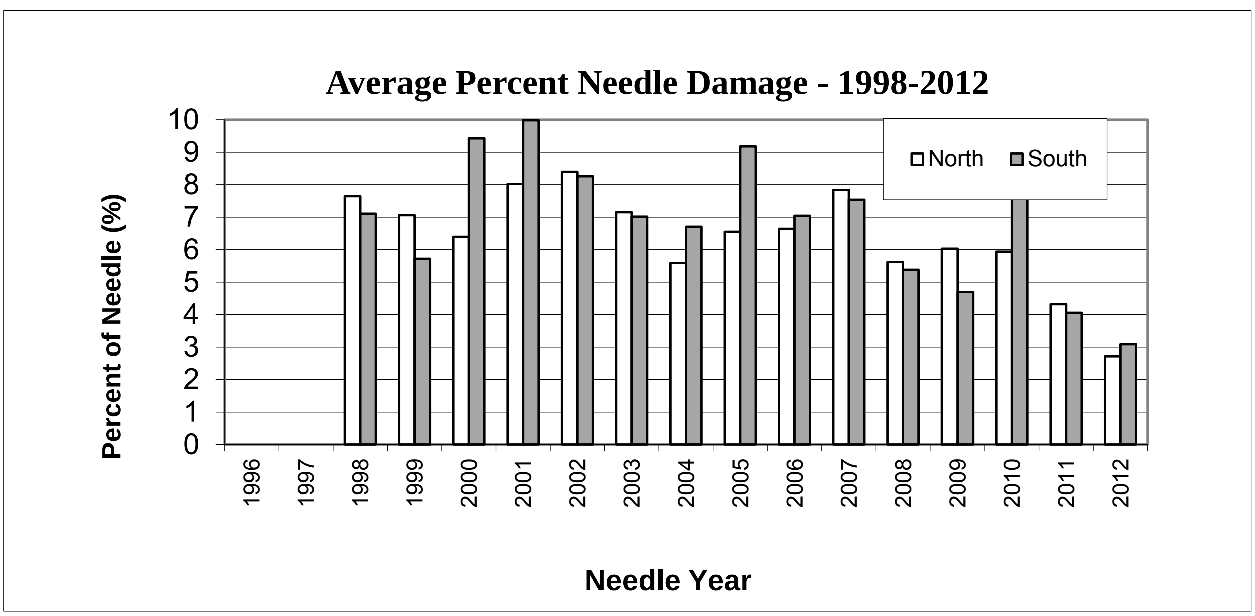



*Figure 4.10. The average percent of damage (length of damage/length of needles) was also a record, 2.9% of the needles' lengths.*

## Histograms of 2012 Trees and Needles

Each year we create histograms of the data. At a glance, histograms display the "frequency" of how data is distributed. Histograms are a great tool for introducing students to statistics and to the mathematics of analysis. We provide each reporting school with their biometric data in Chapter 5. We encourage teachers and students to build their own histograms and to compare their trees over time and with trees from other schools.

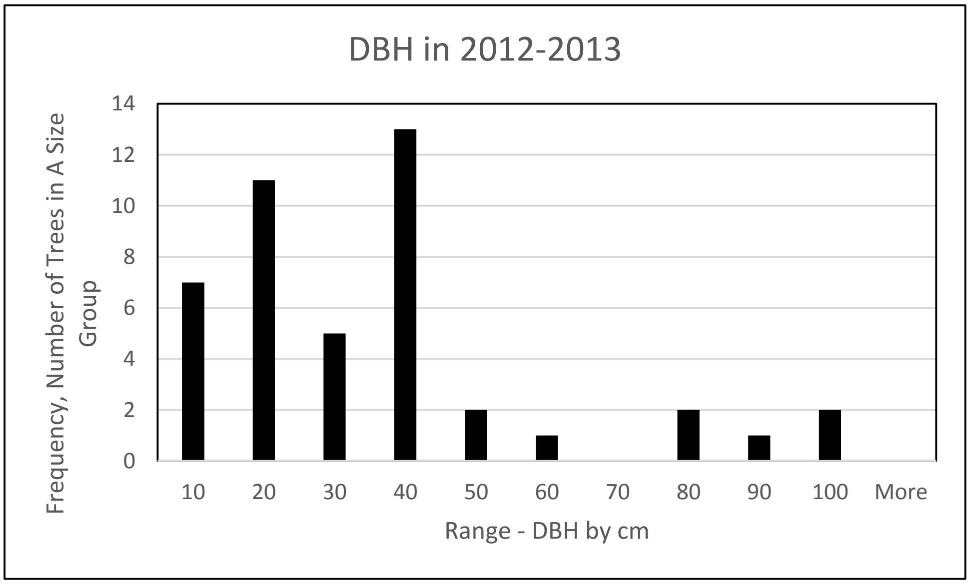



Figure 4.11. Diameter at Breast Height (DBH) shows the mode at 40 cm

Diameter at breast height is the first measurement students and teachers learn. At last summer's Enrichment Workshop, teachers clearly agreed that metric is the measurement they use in their classrooms. Despite the continued practice by foresters and timber industry to use English measures, feet and yards, our school children are learning to measure in centimeters and meters. We introduced teachers to the Biltmore stick anyway.

The DBH measurement offers many mathematical opportunities to teachers of any age group. Younger children might use a string to encircle the tree and discuss the meaning of pi and the differences between circumference and diameter. Older students might use their DBH measurements to calculate stand density. That finding can be used to assess the health of a forest stand and its future productivity. The same measurements can also be used to calculate carbon sequestration by the trees in a stand or by all the trees in an acre of similar forest. Look for these activities on our website.

The histogram in Figure 4.11 indicates that most of our current trees are young. Many of our older trees have been retired since their branches are now too high to sample. The new trees they have added are still of good size, 20 to 40 cm in diameter. Where are your trees in this histogram? The mean for this year's group of trees is 30.7 cm. Where is the Mode?

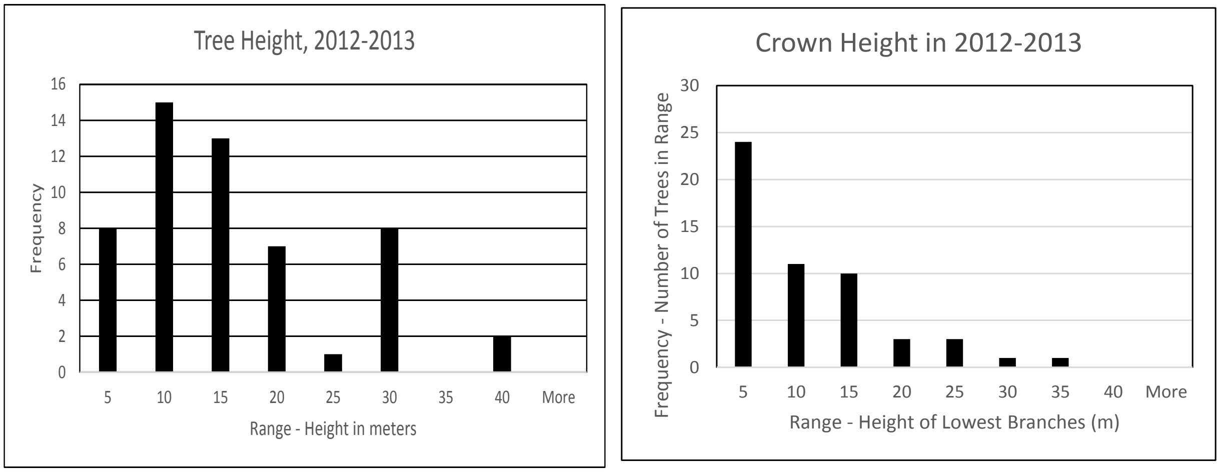



*Figure 4.12. From the top of the tree to the lowest branches of the crown, these two measurements give us an idea of how large a canopy our trees have. Large canopies mean a tree has plenty of light, lots of room to grow into, and a large photosynthetic mass of foliage.*

Forest Watch schools are paying attention to our suggestions: They are selecting trees that are of modest height so that students can see the whole tree and easily sample foliage in the mid-canopy. The mid-canopy is best—it has a bit less intense light than the upper canopy foliage may have. And its leaves are far enough above the ground to avoid dust, insects and fungi. We want low crown height measurements, the height at which students find the lowest thick healthy needles. If crown height is low and tree height is high, the difference is the depth of the canopy. Deeper canopies give trees more foliage for making sugar.

How do your crown heights compare with your tree heights. If the crown height is almost as tall as the tree itself, your tree may be too crowded by other trees to grow much more and the canopy may be too small for healthy photosynthesis. Maybe it's time to select a new tree out in the open with low branches and a deep canopy.

Histograms of needle conditions and features present some interesting information. Almost all trees had needles between 70 and 90 mm. The average this year was a record 82.3 mm.

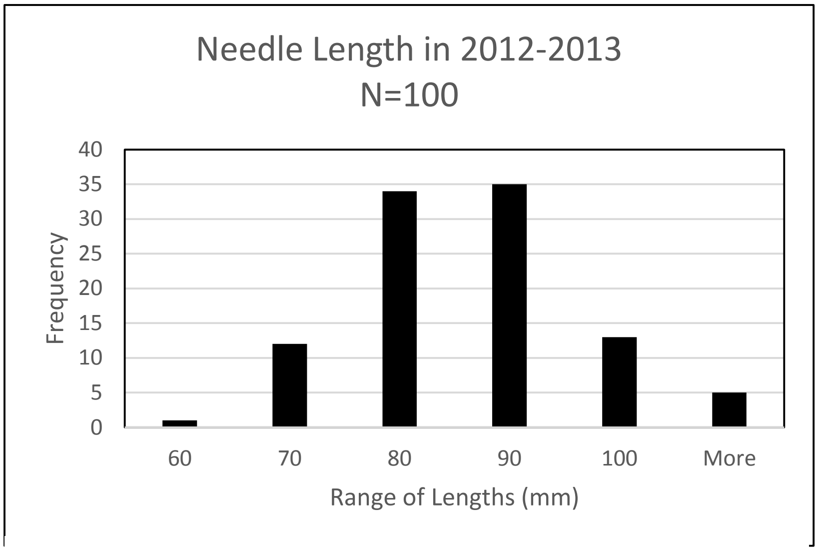



*Figure 4.13. Needle length shows most trees had long needles near the average of 82 mm.*

A look at our data shows that 10 trees at RHAM High School, Hebron, CT, exceeded the means with their own average lengths of 88.8. Even longer needles were found on trees at the Lyme School in Lyme, NH. Those needles averaged 92 mm in length.

Lyme trees showed significant damage last year and in 2010. The town lies in the area of northern and central New Hampshire, Vermont and Maine where needle cast fungi were found and where needle cast was high. Where do your trees lie on the histogram? Are all of your trees similar? Are there differences? What would cause differences between trees?

Average tip necrosis fell to a mean of 15.75 percent of needles having any tip necrosis, a bit lower than the 2011-2012 levels of 18.7%. Again a look at locations is informative. RHAM, located in Hebron, CT, right in the middle of major interstate highways—I-95, I-84 and I-395 -- has the least tip necrosis. Just 4.7% of the needles on its 10 trees show tip necrosis. In Lyme, the needle cast damage area, 25.2% of the needles show tip necrosis.

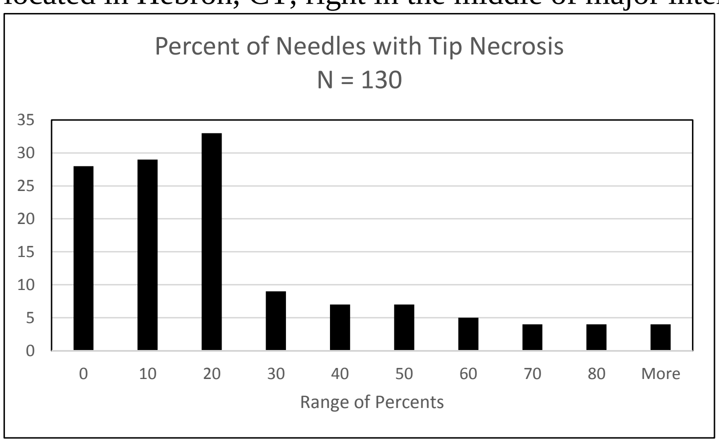



*Figure 4.14. What percent of the 7,600 needles examined showed tip necrosis? In analyses of 130 trees, the average is 15.75%.*

Where are the schools with very high percentages? Along the Connecticut River Valley in Springfield, MA, and near Keene, NH, at Monadnock Regional High School and the Dublin School. As Forest Watch noticed many years ago, this river and highway corridor have a unique geography which appears to capture and hold ozone.

Every histogram provides unique information. When we look at what percent of the 7,600 needles had any chlorotic mottle, the histogram gives widely differing Mean and Mode. This is a difficult concept for students to grasp. So these statistics might be helpful in explaining how a set of data can have a mean in one place and a mode in a very different place.

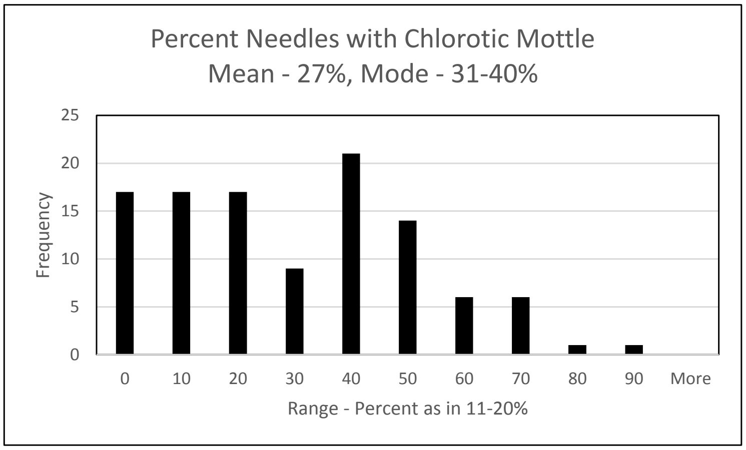
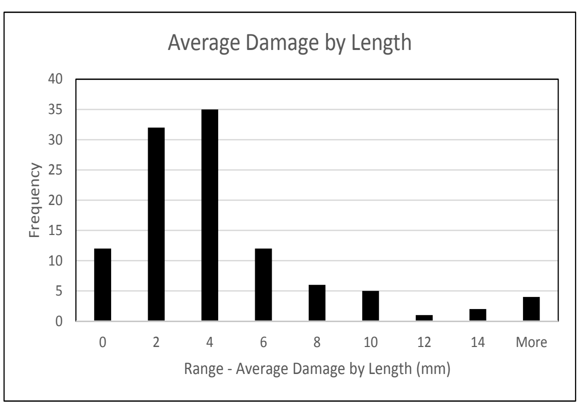



*Figure 4.15. The percent of needles with some chlorotic mottle.*

In this year's case. The answer is a healthy one—lots of trees had zero chlorotic mottling, bringing the average down. The three big columns of low damage, 0 damage, 1-10% damage and 11-30% damage outweigh on average the 21 samples that have 40%. The mode is simply the highest point on the histogram.

This study also shows that the highest damage was again in the Connecticut River corridor. But high levels of chlorotic damage, the clearest signs of ozone, were also seen at Lyme—where trees may not have had the strength to close their stomata. High levels were also seen in Hanson, MA (sorry, Wes Blauss). Was there a coastal ozone event that damaged those pines?

Histograms are fun and easy to build and they tell us a lot about what's going on in the forest. Your students can probably think of a dozen other ways to use, compare and contrast data with Forest Watch data.



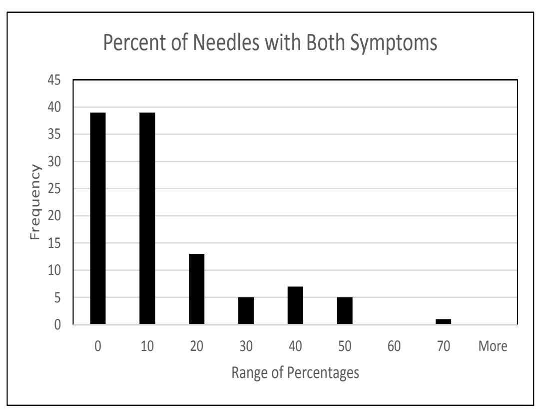




*Figure 4.16. Students complete their biometric measurements with math calculations of average damage by length in mm (at left) and percent of needles with both symptoms.*

Measuring 30 needles, recording findings and calculating percentages takes time and patience. Too often, the class bell can ring before students have time to finish or to consider what their findings mean. Histograms give students a graphic illustration of their findings and grounds for discussion of what the data may indicate.

This year we add a new tool to our website: Excel sheets on Google Docs for classroom biometric counts and discussion. Our thanks to Robert Schongalla of the Sant Bani School, Sanbornton, NH, for this helpful tool.

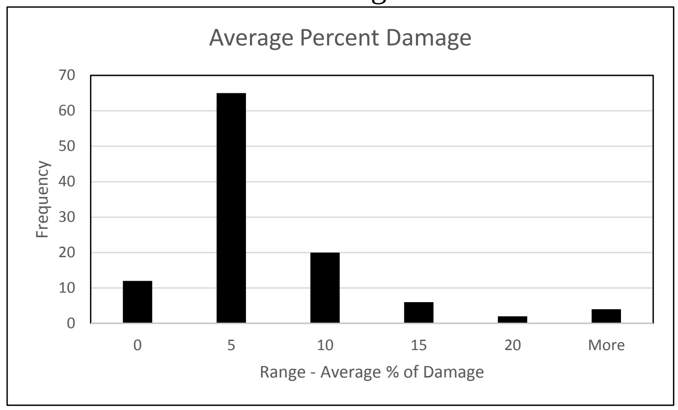



*Figure 4.17. A final calculation of the average mm of damage/average needle length gives students an average percent of damage.*

Robert and his 6th graders use the Excel sheets as they count needles. They enter data directly into a group document that is projected for the whole classroom. As one team of students studies the North side of Tree 100, another might be counting the South side of Tree 97. Keen eyes can see at a glance if students make the common mistake of recording cm rather than mm for needle length. If one tree has an unusually high percentage of tip necrosis, everyone can examine those needles and question why damage is heavy on that sample. As students attempt the final calculations of percentage, the class can discuss where the decimal goes and whether the answer is 12% or 0.12%. We invite you and your students to try Robert's documents. Thanks, Robert!

# CHAPTER 5 – SCHOOL DATA

## RHAM High School

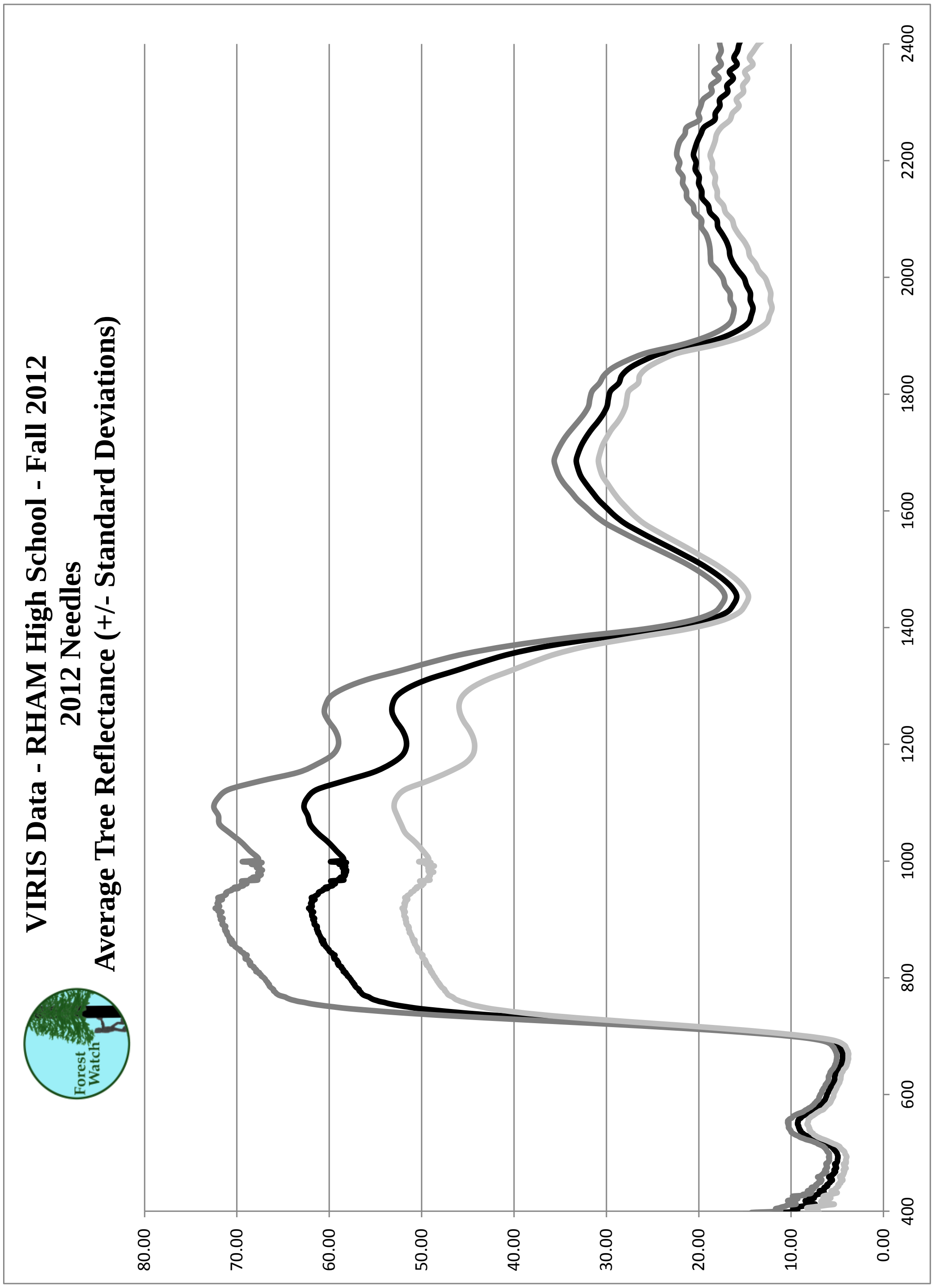
## Biometric Data, Trees 1321-1325

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 10/18/2012 | | | | |
| Submitted by | Frank Schmidt | | | | |
| **TreeNumber** | **1321** | **1322** | **1323** | **1324** | **1325** |
| DBH (cm) | 6.1 | 12.2 | 18.2 | 14.2 | 24.3 |
| CrownHeight (m) | 2.5 | 2.6 | 4.5 | 4.5 | 2.0 |
| TreeHeight (m) | 3.6 | 7.0 | 8.4 | 10.1 | 6.1 |
| N-Coll-Ht (m) | 3 | 3.0 | 5 | 4.5 | 3.2 |
| S-Coll-Ht (m) | 3 | 3.0 | 5 | 4.5 | 3.0 |
| N-Fas-Len (mm) | 808 | 73.0 | 84 | 78 | 131.0 |
| S-Fas-Len (mm) | 83 | 73.0 | 90 | 113 | 105.0 |
| N-Need-Ret (year) | 3 | 2.0 | 3 | 3 | 1.0 |
| S-Need-Ret (year) | 2 | 2.0 | 3 | 2 | 2.0 |
| N-Water (%) | 63.3 | 60.0 | 55 | 62.8 | 54.1 |
| S-Water (%) | 64.3 | 60.6 | 62 | 66.6 | 51.9 |
| N-NumNeedles | 30 | 30.0 | 30 | 30 | 30.0 |
| S-NumNeedles | 30 | 30.0 | 30 | 30 | 30.0 |
| N-AvgNeed-Len (mm) | 87 | 80.0 | 85 | 66 | 122.0 |
| S-AvgNeed-Len (mm) | 96 | 74.0 | 88 | 99 | 106.0 |
| N-PerTipNec | 1 | 0.0 | 0 | 0 | 7.0 |
| S-PerTipNec | 2 | 0.0 | 0 | 0 | 3.0 |
| N-PerChlMot | 3 | 0.0 | 0 | 0 | 0.0 |
| S-PerChlMot | 0 | 0.0 | 0 | 0 | 0.0 |
| N-AvgTotDamg-Len | 0.8 | 0.0 | 0 | 0 | 2.3 |
| S-AvgTotDamg-Len | 0.3 | 0.0 | 0 | 0 | 2.2 |
| N-PerNeedBothSymp | 16 | 0.0 | 0 | 0 | 0.0 |
| S-PerNeedBothSymp | 0 | 0.0 | 0 | 0 | 3.0 |
| N-AvgPerDamage | 0.92 | 0.0 | 0 | 0 | 1.9 |
| S-AvgPerDamage | 0.31 | 0.0 | 0 | 0 | 2.1 |

# RHAM High School

## Biometric Data, Trees 1331-1335

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 10/21/2012 | | | | |
| Submitted by: | Frank Schmidt | | | | |
| **TreeNumber** | **1331** | **1332** | **1333** | **1334** | **1335** |
| DBH (cm) | 15.90 | 7.90 | 27.38 | 33.21 | 31.8 |
| CrownHeight (m) | 7.10 | 3.60 | 9.00 | 10.00 | 10.1 |
| TreeHeight (m) | 9.80 | 5.90 | 13.60 | 18.90 | 12.7 |
| N-Coll-Ht (m) | 4.50 | 4.00 | 8.00 | 8.00 | 5.3 |
| S-Coll-Ht (m) | 4.50 | 4.00 | 8.00 | 8.00 | 5.3 |
| N-Fas-Len (mm) | 64.00 | 79.00 | 113.00 | 97.00 | 91 |
| S-Fas-Len (mm) | 67.00 | 68.00 | 95.00 | 98.00 | 88 |
| N-Need-Ret (year) | 2.00 | 3.00 | 4.00 | 2.00 | 3 |
| S-Need-Ret (year) | 2.00 | 2.00 | 3.00 | 2.00 | 3 |
| N-Water (%) | 69.40 | 69.20 | 58.20 | 54.00 | 65 |
| S-Water (%) | 46.10 | 66.60 | 62.10 | 53.30 | 73 |
| N-NumNeedles | 30.00 | 30.00 | 30.00 | 30.00 | 30 |
| S-NumNeedles | 30.00 | 30.00 | 30.00 | 30.00 | 30 |
| N-AvgNeed-Len (mm) | 123.00 | 84.00 | 99.00 | 106.00 | 88 |
| S-AvgNeed-Len (mm) | 117.00 | 82.00 | 97.00 | 109.00 | 106 |
| N-PerTipNec | 1.00 | 0.00 | 0.00 | 0.00 | 0 |
| S-PerTipNec | 66.00 | 0.00 | 0.00 | 13.00 | 0 |
| N-PerChlMot | 7.00 | 15.00 | 0.00 | 3.00 | 0 |
| S-PerChlMot | 15.00 | 15.00 | 0.00 | 6.00 | 0 |
| N-AvgTotDamg-Len | 16.00 | 6.00 | 0.00 | 3.00 | 0 |
| S-AvgTotDamg-Len | 2.00 | 6.00 | 0.00 | 3.00 | 0 |
| N-PerNeedBothSymp | 0.00 | 10.00 | 0.00 | 0.00 | 0 |
| S-PerNeedle Both Symp | 0.00 | 11.00 | 0.00 | 0.00 | 0 |
| N-Avg Per Damage | 13.01 | 7.14 | 0.00 | 2.83 | 0 |
| S-Avg.PerDamage | 1.71 | 7.32 | 0.00 | 2.75 | 0 |


VIRIS Data - RHAM High School - Fall 2012
2012 Needles
Average Tree Reflectance (+/- Standard Deviations)
Forest Watch
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

RHAM High School Spectral Data

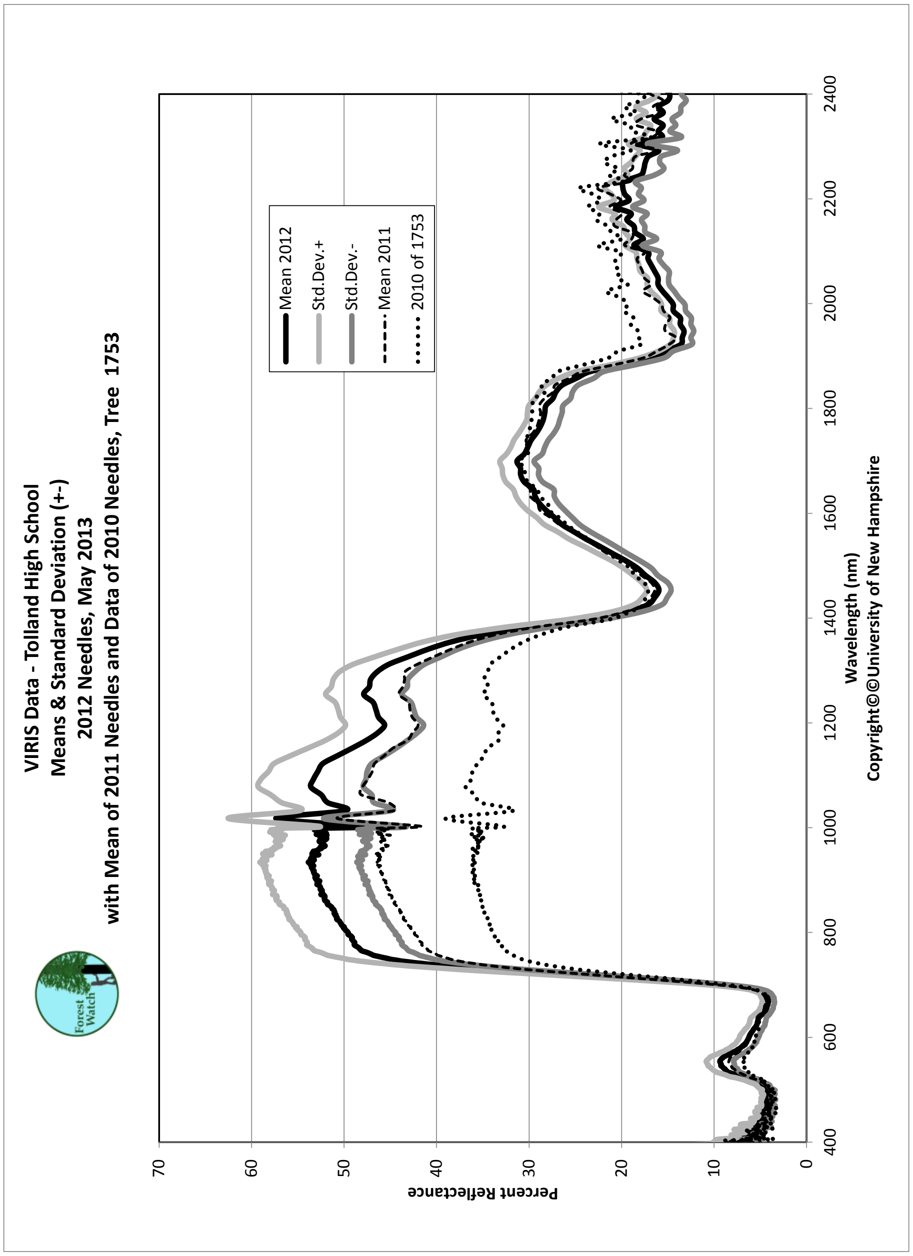
Trees 1321-1325 and 1331-1335

| | RHAM Needle Spectral Data | | | |
|---|---|---|---|---|
| **Tree** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1321N** | 723.9 | 0.852 | 0.543 | 0.88 |
| **1321S** | 725.4 | 0.874 | 0.497 | 0.847 |
| **1322N** | 720.8 | 0.832 | 0.599 | 0.883 |
| **1322S** | 728.5 | 0.824 | 0.744 | 0.959 |
| **1323N** | 725.4 | 0.86 | 0.508 | 0.883 |
| **1323S** | 723.9 | 0.848 | 0.536 | 0.905 |
| **1324NS** | 727 | 0.848 | 0.544 | 0.858 |
| **1325N** | 720.8 | 0.801 | 0.574 | 0.815 |
| **1325S** | 723.9 | 0.796 | 0.659 | 0.866 |
| **1331N** | 723.9 | 0.844 | 0.55 | 0.873 |
| **1331S** | 728.5 | 0.867 | 0.509 | 0.854 |
| **1332N** | 723.9 | 0.871 | 0.483 | 0.85 |
| **1332S** | 727 | 0.881 | 0.473 | 0.823 |
| **1333N** | 727 | 0.854 | 0.443 | 0.782 |
| **1333S** | 723.9 | 0.843 | 0.548 | 0.886 |
| **1334N** | 725.4 | 0.868 | 0.488 | 0.844 |
| **1334S** | 723.9 | 0.855 | 0.451 | 0.796 |
| **1335N** | 723.9 | 0.852 | 0.454 | 0.819 |
| **1335S** | 728.5 | 0.86 | 0.49 | 0.834 |
| **Avg.** | **725.0** | **0.849** | **0.531** | **0.856** |

Tolland High School

| | Tolland Spectral Data 2012 | | | |
|---|---|---|---|---|
| | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1751N** | 723.9 | 0.82 | 0.503 | 0.866 |
| **1751S** | 723.9 | 0.812 | 0.578 | 0.906 |
| **1752N** | 719.3 | 0.78 | 0.681 | 0.98 |
| **1752S** | 725.4 | 0.858 | 0.567 | 0.922 |
| **1753N** | 725.4 | 0.868 | 0.537 | 0.858 |
| **1753S** | 723.9 | 0.82 | 0.6 | 0.9 |
| **1754N** | 725.4 | 0.857 | 0.551 | 0.899 |
| **1754S** | 725.4 | 0.833 | 0.538 | 0.868 |
| **1755N** | 716.2 | 0.846 | 0.58 | 0.904 |
| **1755S** | 717.7 | 0.846 | 0.594 | 0.906 |
| **Mean** | 722.65 | 0.834 | 0.5729 | 0.9009 |

| | Tolland - 2nd and 3rd Year Indices | | | |
|---|---|---|---|---|
| | REIP | NDVI | TM54 | NIR31 |
| **1751-2** | 702.3 | 0.764 | 0.655 | 0.969 |
| **1752-2** | 726.2 | 0.792 | 0.666 | 0.994 |
| **1753-2** | 720.8 | 0.824 | 0.624 | 0.928 |
| **1754-2** | 713.1 | 0.825 | 0.64 | 0.953 |
| **1755-2** | 705.4 | 0.798 | 0.781 | 1.018 |
| **1753-3** | 714.6 | 0.763 | 0.83 | 0.983 |



VIRIS Data - Tolland High School
Means & Standard Deviation (+-)
2012 Needles, May 2013
with Mean of 2011 Needles and Data of 2010 Needles, Tree 1753
Forest Watch
Mean 2012
Std.Dev.+
Std.Dev.-
Mean 2011
2010 of 1753
Percent Reflectance
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Copyright©©University of New Hampshire

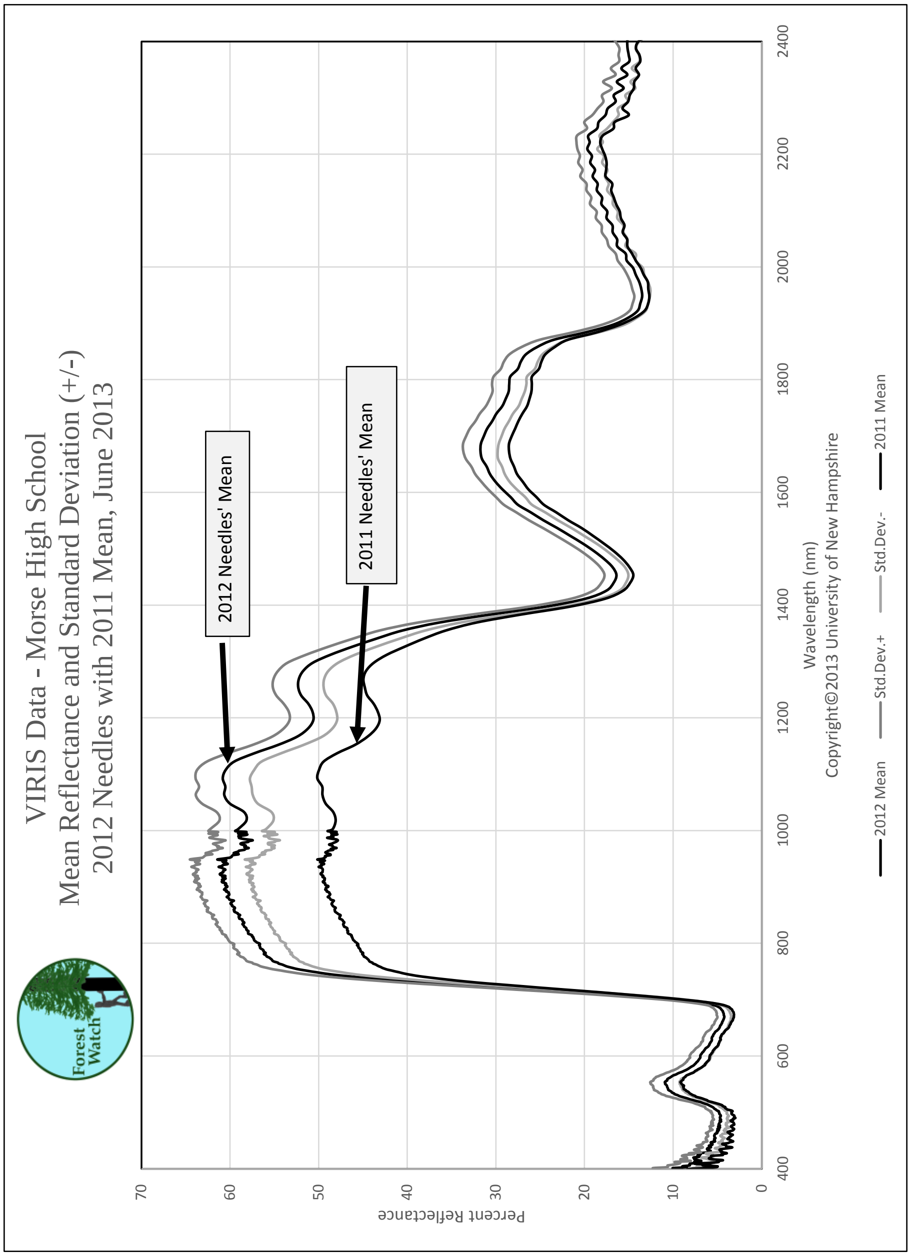
Morse High School, Bath. Maine

Biometric and Spectral Data

| | | | | | | |
|---|---|---|---|---|---|---|
| **Needle Year** | | **2012** | | | | |
| **Collection Date** | | **5/30/2013** | | | | |
| **Submitted by:** | | **Carolyn Nichols with George Schaab** | | | | |
| **TreeNumber** | | **1741** | **1742** | **1743** | **1744** | **1745** |
| **N-NumNeedles** | | 30 | 30 | 30 | 30 | 30 |
| **S-NumNeedles** | | 30 | 30 | 30 | 30 | 30 |
| **N-AvgNeed-Len (mm)** | | 87 | 76 | 86 | 81 | 73 |
| **S-AvgNeed-Len (mm)** | | 98 | 92 | 67 | 92 | 64 |
| **N-PerTipNec** | | 3.3 | 13.3 | 0 | 3 | 10 |
| **S-PerTipNec** | | 0 | | 0 | 0 | 13.3 |
| **N-PerChlMot** | | 23.3 | 86.7 | 3.0 | 17.0 | 40.0 |
| **S-PerChlMot** | | 10.0 | 2.7 | 20.0 | 0.0 | 40.0 |
| **N-AvgTotDamg-Len** | | 0.9 | 2.7 | 0.1 | 0.4 | 6.1 |
| **S-AvgTotDamg-Len** | | 0.0 | 2.9 | 1.2 | 0.0 | 3.4 |
| **N-PerNeedBothSymp** | | 0.0 | 13.3 | 0.0 | 0.0 | 3.3 |
| **S-PerNeedle Both Symp** | | 0.0 | 3.0 | 0.0 | 0.0 | 6.7 |
| **N-Avg Per Damage** | | 1.0 | 3.6 | 0.1 | 0.5 | 8.4 |
| **S-Avg.PerDamage** | | 0.0 | 3.2 | 1.8 | 0.0 | 5.2 |

| | Morse 2012 Spectral Data | | | |
|---|---|---|---|---|
| | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1741N** | 723.9 | 0.839 | 0.509 | 0.848 |
| **1741S** | 727 | 0.844 | 0.508 | 0.85 |
| **1742N** | 720.8 | 0.878 | 0.51 | 0.851 |
| **1742S** | 716.2 | 0.826 | 0.517 | 0.865 |
| **1743N** | 725.4 | 0.847 | 0.516 | 0.856 |
| **1743s** | 725.4 | 0.826 | 0.516 | 0.866 |
| **1744n** | 723.9 | 0.845 | 0.533 | 0.858 |
| **1744s** | 722.4 | 0.836 | 0.514 | 0.858 |
| **1745n** | 728.5 | 0.869 | 0.479 | 0.834 |
| **1745s** | 728.5 | 0.879 | 0.505 | 0.861 |
| **Mean** | 724.2 | 0.8489 | 0.5107 | 0.8547 |

| | Morse 2011 Spectral Data | | | |
|---|---|---|---|---|
| **Tree ID** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1741-2** | 719.3 | 0.836 | 0.631 | 0.944 |
| **1742-2** | 717.7 | 0.864 | 0.542 | 0.903 |
| **1743-2** | 703.8 | 0.838 | 0.542 | 0.903 |
| **1744-2** | 727 | 0.855 | 0.547 | 0.919 |
| **1745-2** | 719.3 | 0.87 | 0.59 | 0.905 |
| **Mean** | **717.42** | **0.8526** | **0.5704** | **0.9148** |


VIRIS Data - Morse High School
Mean Reflectance and Standard Deviation (+/-)
2012 Needles with 2011 Mean, June 2013
Forest Watch
2012 Needles' Mean
2011 Needles' Mean
Percent Reflectance
Wavelength (nm)
Copyright©2013 University of New Hampshire
2012 Mean
Std.Dev.+
Std.Dev.-
2011 Mean

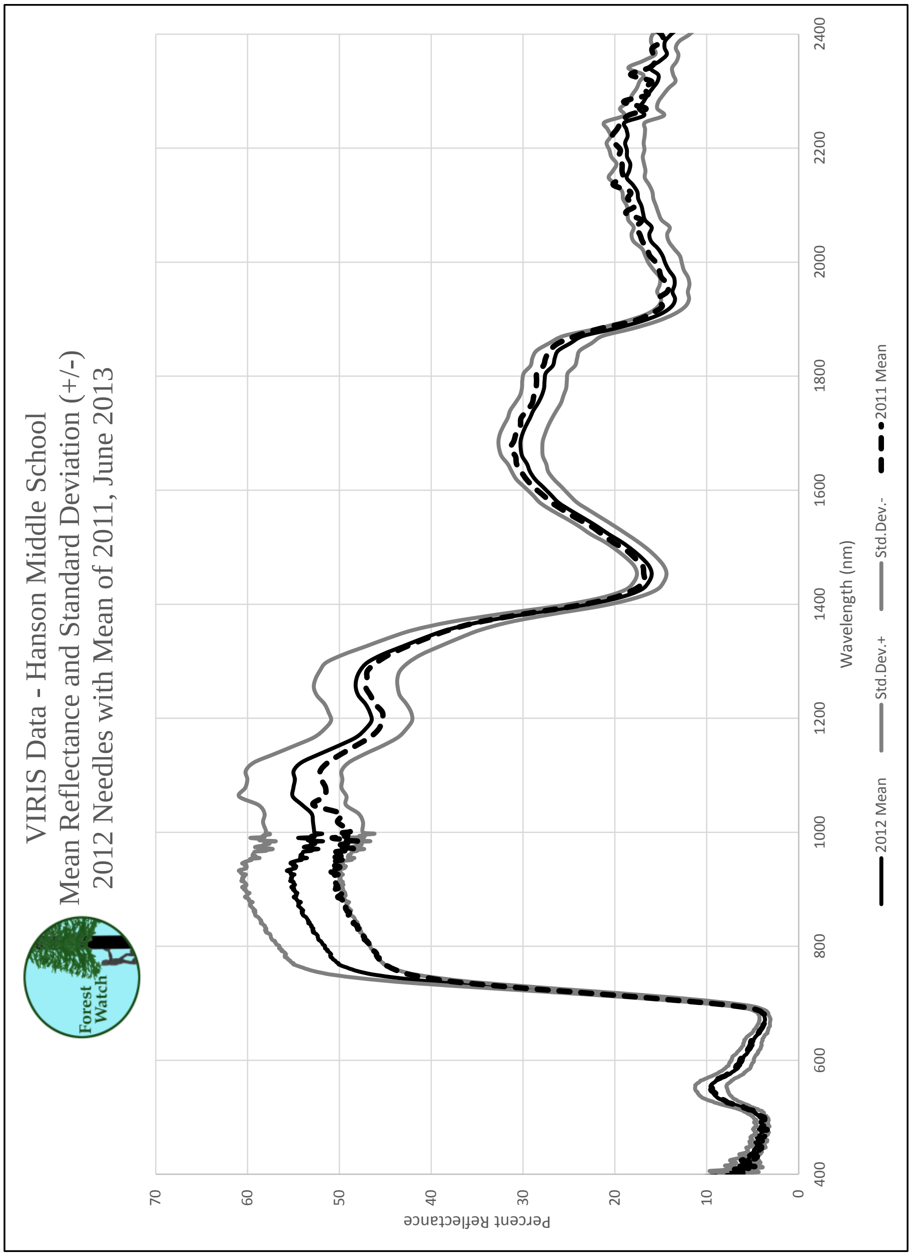
Hanson Middle School, Hanson, MA

Biometric Data, Trees 1661-1665

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 5/28/2013 | | | | |
| Submitted by: | Wes Blauss and Dave Hickey | | | | |
| TreeNumber | **1661** | **1662** | **1663** | **1664** | **1664** |
| DBH (cm) | 32.8 | 32.5 | 28.6 | 32.2 | 36.9 |
| CrownHeight (m) | 9 | 14 | 8.7 | 9.1 | 10.9 |
| TreeHeight (m) | 12.3 | 16.5 | 10 | 11.4 | 17.4 |
| N-Coll-Ht (m) | 3 | 7 | 5 | 5 | 7 |
| S-Coll-Ht (m) | 3 | 7 | 5 | 5 | 7 |
| N-Fas-Len (mm) | 83 | 71 | 63 | 70 | 83 |
| S-Fas-Len (mm) | 89 | 71 | 80 | 63 | 66 |
| N-Need-Ret (year) | 2 | 1 | 1 | 2 | 1 |
| S-Need-Ret (year) | 2 | 2 | 2 | 2 | 2 |
| N-NumNeedles | 720 | 360 | 390 | 330 | 390 |
| S-NumNeedles | 780 | 390 | 390 | 360 | 420 |
| N-AvgNeed-Len (mm) | 88 | 73 | 73 | 68 | 74 |
| S-AvgNeed-Len (mm) | 94 | 69 | 79 | 70 | 65 |
| N-PerTipNec | 28 | 21 | 17 | 27 | 10 |
| S-PerTipNec | 19 | 16 | 16 | 14 | 9 |
| N-PerChlMot | 36 | 58 | 33 | 59 | 22 |
| S-PerChlMot | 30 | 63 | 39 | 55 | 27 |
| N-AvgTotDamg-Len | 3 | 5 | 3 | 4 | 3 |
| S-AvgTotDamg-Len | 6 | 4 | 3 | 3 | 5 |
| N-PerNeedBothSymp | 9 | 5 | 9 | 9 | 3 |
| S-PerNeedle Both Symp | 10 | 7 | 5 | 10 | 3 |
| N-Avg Per Damage | 3 | 5 | 4 | 6 | 4 |
| S-Avg.PerDamage | 6 | 5 | 3 | 3 | 5 |

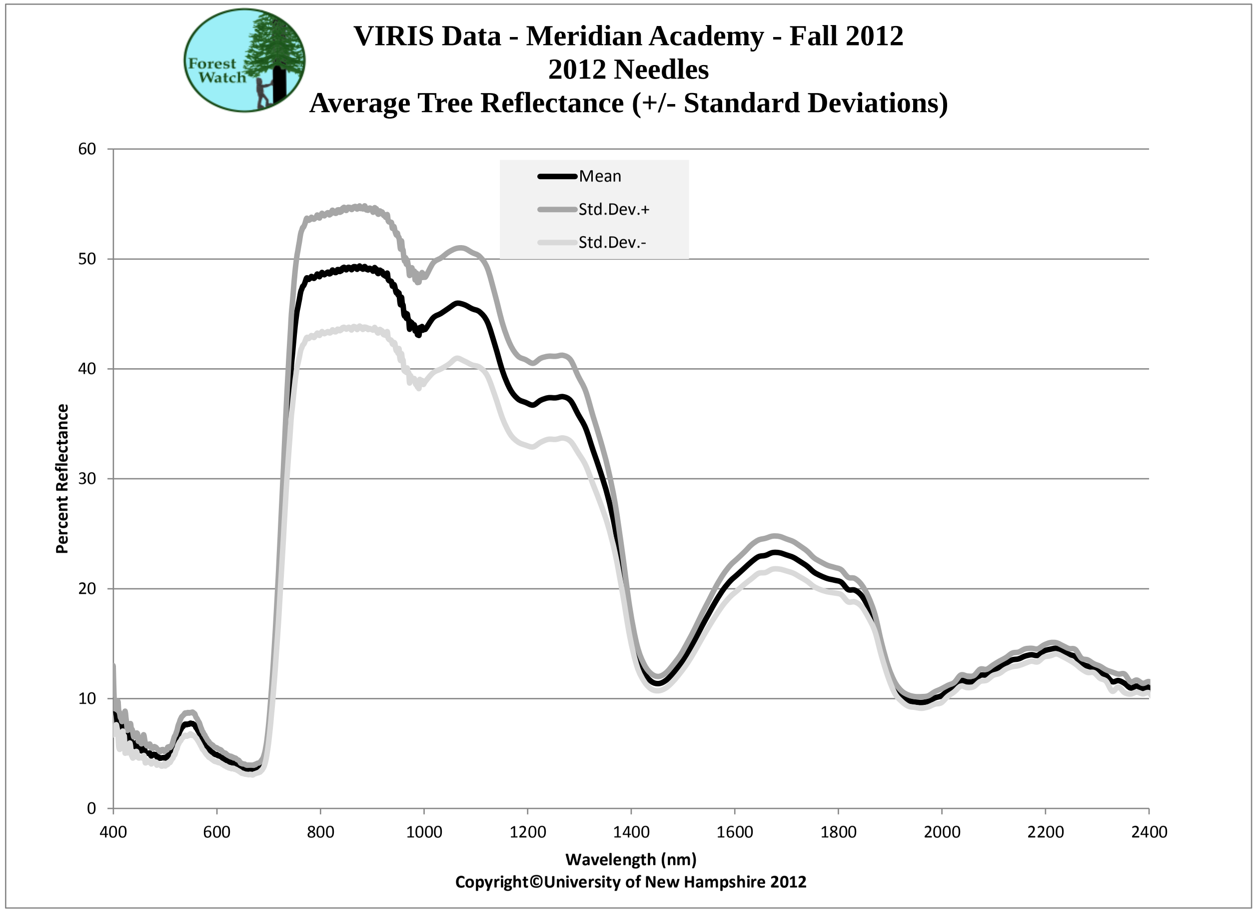
| | Hanson Middle Spectral Data 2012 | | | |
|---|---|---|---|---|
| **Index** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1661N** | 716.2 | 0.832 | 0.468 | 0.809 |
| **1661S** | 722.4 | 0.827 | 0.618 | 0.905 |
| **1662n** | 725.4 | 0.855 | 0.599 | 0.911 |
| **1662s** | 722.4 | 0.858 | 0.514 | 0.897 |
| **1663n** | 720.8 | 0.876 | 0.506 | 0.836 |
| **1663s** | 725.4 | 0.832 | 0.556 | 0.893 |
| **1664n** | 727 | 0.866 | 0.526 | 0.883 |
| **1664s** | 723.9 | 0.882 | 0.52 | 0.852 |
| **1665** | 722.4 | 0.858 | 0.556 | 0.871 |
| **Mean** | 722.9 | 0.854 | 0.540 | 0.873 |

| | Hanson 2011 Spectral Data | | | |
|---|---|---|---|---|
| | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1661-2** | 712.3 | 0.806 | 0.553 | 0.914 |
| **1662-2** | 722.4 | 0.857 | 0.55 | 0.913 |
| **1664-2** | 722.4 | 0.839 | 0.638 | 0.963 |
| **1665-2** | 725.4 | 0.853 | 0.745 | 0.998 |
| **Mean** | 720.625 | 0.83875 | 0.6215 | 0.947 |


Forest Watch
VIRIS Data - Hanson Middle School
Mean Reflectance and Standard Deviation (+/-)
2012 Needles with Mean of 2011, June 2013
Percent Reflectance
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
2012 Mean
Std.Dev.+
Std.Dev.-
2011 Mean

Meridian Academy, Brookline, MA

| | Meridian Needle Spectral Data | | | |
|---|---|---|---|---|
| **Index** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1971** | 728.5 | 0.852 | 0.478 | 0.756 |
| **1972** | 723.9 | 0.849 | 0.456 | 0.736 |
| **1973** | 733.2 | 0.861 | 0.434 | 0.753 |
| **1974** | 730.1 | 0.871 | 0.468 | 0.759 |
| **1975** | 730.1 | 0.849 | 0.481 | 0.768 |
| **Means** | 729.16 | 0.8564 | 0.464 | 0.754 |
| **1971-2011** | 730.1 | 0.863 | 0.516 | 0.787 |

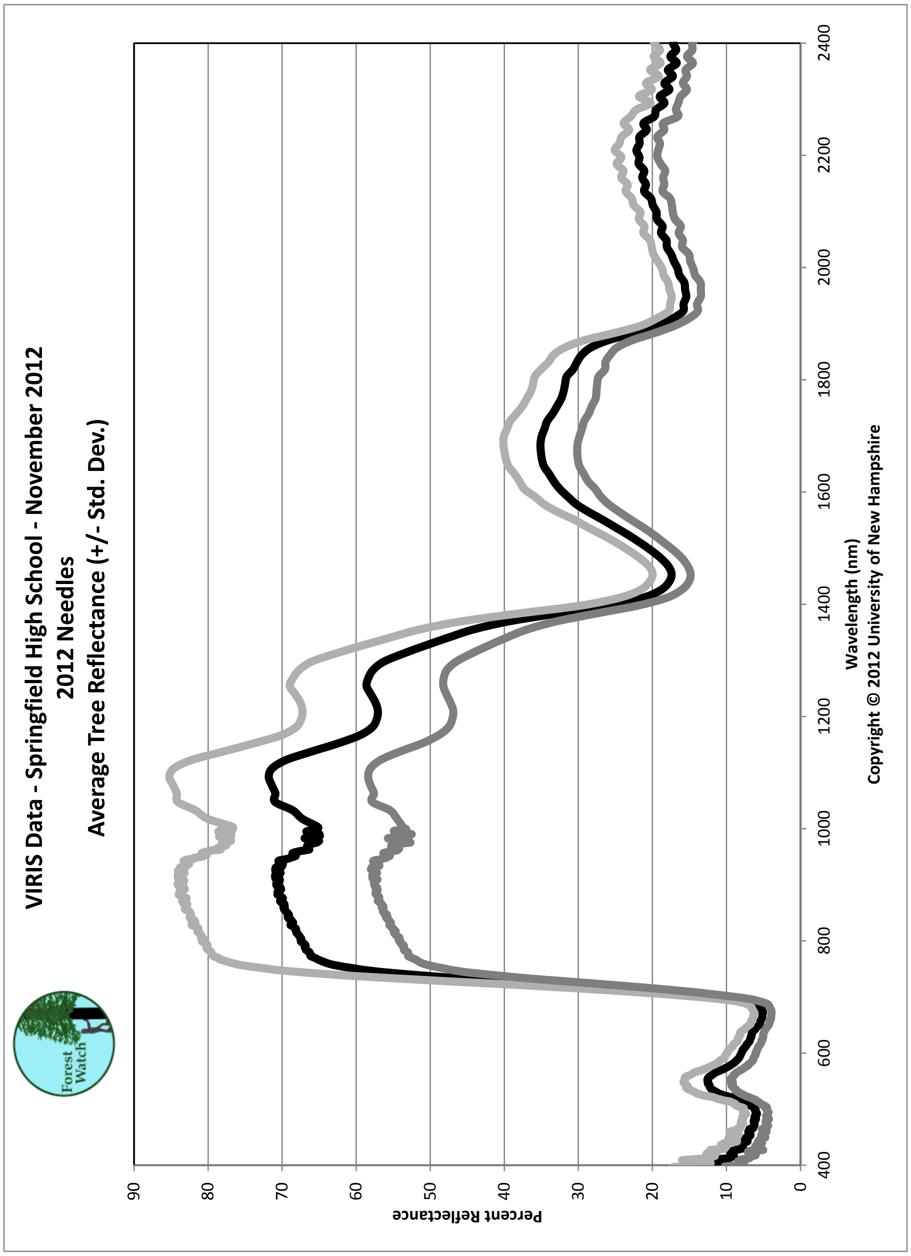

VIRIS Data - Meridian Academy - Fall 2012
2012 Needles
Average Tree Reflectance (+/- Standard Deviations)
Forest Watch
Mean
Std.Dev.+
Std.Dev.-
Percent Reflectance
0
10
20
30
40
50
60
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Copyright©University of New Hampshire 2012

Springfield Central High School

Biometric Data, Trees 1976-1980

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 9/25/2012 | | | | |
| Submitted by: | Naomi Volain | | | | |
| TreeNumber | **1976** | **1977** | **1978** | **1979** | **1980** |
| DBH (cm) | 33.6 | 40.8 | 36.7 | 32.6 | 40 |
| CrownHeight (m) | 17 | 14.3 | 18.5 | 28.3 | 23.6 |
| TreeHeight (m) | 22.5 | 29.8 | 25.9 | 37.5 | 27.2 |
| N-Coll-Ht (m) | 8.3 | 6.6 | 7.6 | | 8.3 |
| S-Coll-Ht (m) | 8.1 | 8.8 | 7.4 | 11.5 | 8.2 |
| N-Fas-Len (mm) | 90 | 82 | 83 | | 86 |
| S-Fas-Len (mm) | 94 | 87 | 77 | 87 | 77 |
| N-NumNeedles | 30 | 30 | 30 | | 30 |
| S-NumNeedles | 30 | 30 | 30 | | 30 |
| N-AvgNeed-Len (mm) | 81 | 93 | 78 | | 83 |
| S-AvgNeed-Len (mm) | 84 | 86 | 69 | | 79 |
| N-PerTipNec | 47 | 33 | 73 | | 7 |
| S-PerTipNec | 60 | 20 | 90 | | 43 |
| N-PerChlMot | 50 | 50 | 40 | | 10 |
| S-PerChlMot | 63 | 57 | 46 | | 37 |
| N-AvgTotDamg-Len | 2.6 | 3 | 1.9 | | 1.4 |
| S-AvgTotDamg-Len | 4.3 | 3 | 6.2 | | 5.8 |
| N-PerNeedBothSymp | 13.3 | 2.4 | 40 | | 0 |
| S-PerNeedle Both Symp | 43.3 | 13.3 | 46 | | 10 |
| N-Avg Per Damage | 3.2 | 3.2 | 2.5 | | 1.7 |
| S-Avg.PerDamage | 5.1 | 3.5 | 9.0 | | 7.3 |

| | Spring field Needle Spectral Data | | | | |
|---|---|---|---|---|---|
| Tree IDs | | REIP | NDVI | TM54 | NIR31 |
| 1976 | N | 730.1 | 0.869 | 0.472 | 0.82 |
| | S | 730.1 | 0.865 | 0.534 | 0.814 |
| 1977 | N | 725.4 | 0.857 | 0.444 | 0.76 |
| | S | 728.5 | 0.836 | 0.45 | 0.775 |
| 1978 | N | 730.1 | 0.855 | 0.507 | 0.837 |
| | S | 723.9 | 0.807 | 0.543 | 0.858 |
| 1979 | S | 730.1 | 0.847 | 0.45 | 0.768 |
| 1980 | N&S | 727 | 0.84 | 0.489 | 0.858 |
| Avg. | | 728.2 | 0.847 | 0.486 | 0.811 |

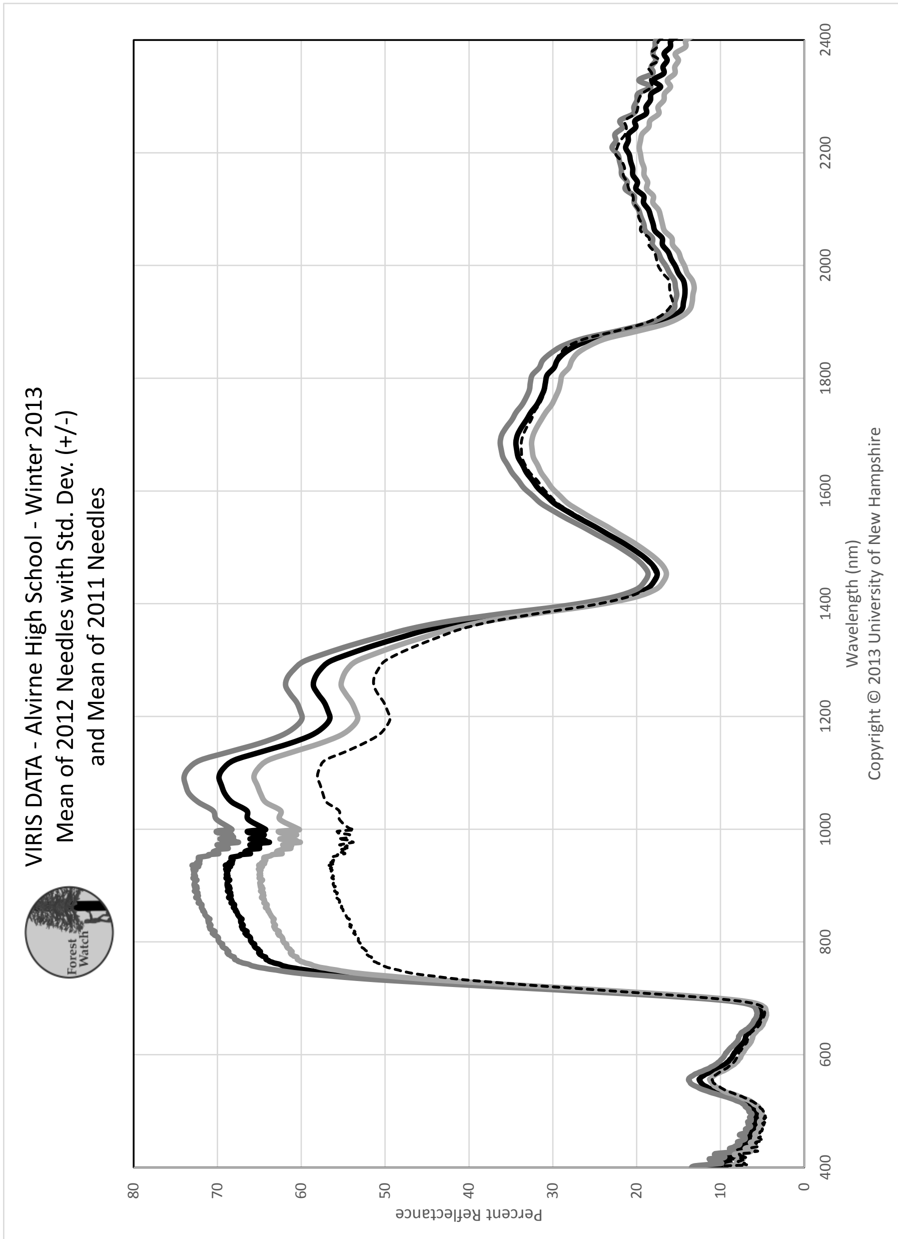

VIRIS Data - Springfield High School - November 2012
2012 Needles
Average Tree Reflectance (+/- Std. Dev.)
Forest Watch
Percent Reflectance
0
10
20
30
40
50
60
70
80
90
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Copyright © 2012 University of New Hampshire

Alvirne High School, Hudson, NH

Spectral Data, 2012 Needles and 2011 Needles

| | **Alvirne Spectral Indices 2012 Needles** | | | |
|---|---|---|---|---|
| **Tree ID** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1771N** | 720.8 | 0.855 | 0.467 | 0.826 |
| **1771S** | 723.9 | 0.848 | 0.465 | 0.822 |
| **1772N** | 720.8 | 0.828 | 0.486 | 0.842 |
| **1772S** | 720.8 | 0.827 | 0.532 | 0.879 |
| **1773N** | 720.8 | 0.866 | 0.5 | 0.837 |
| **1773S** | 717.7 | 0.851 | 0.497 | 0.871 |
| **1774N** | 720.8 | 0.84 | 0.481 | 0.846 |
| **1774S** | 717.7 | 0.826 | 0.473 | 0.821 |
| **1775N** | 722.4 | 0.843 | 0.466 | 0.822 |
| **1775S** | 717.7 | 0.841 | 0.5 | 0.846 |
| **1776N** | 719.3 | 0.83 | 0.45 | 0.807 |
| **1776S** | 726.2 | 0.835 | 0.48 | 0.826 |
| **1777N** | 720.8 | 0.852 | 0.486 | 0.839 |
| **1777S** | 717.7 | 0.842 | 0.471 | 0.818 |
| **1778N** | 720.8 | 0.824 | 0.481 | 0.817 |
| **1778S** | 720.8 | 0.852 | 0.466 | 0.809 |
| **1779N** | 717.7 | 0.833 | 0.488 | 0.851 |
| **1779S** | 722.4 | 0.828 | 0.49 | 0.813 |
| **1780N** | 720.8 | 0.868 | 0.452 | 0.814 |
| **1780S** | 720.8 | 0.851 | 0.523 | 0.836 |

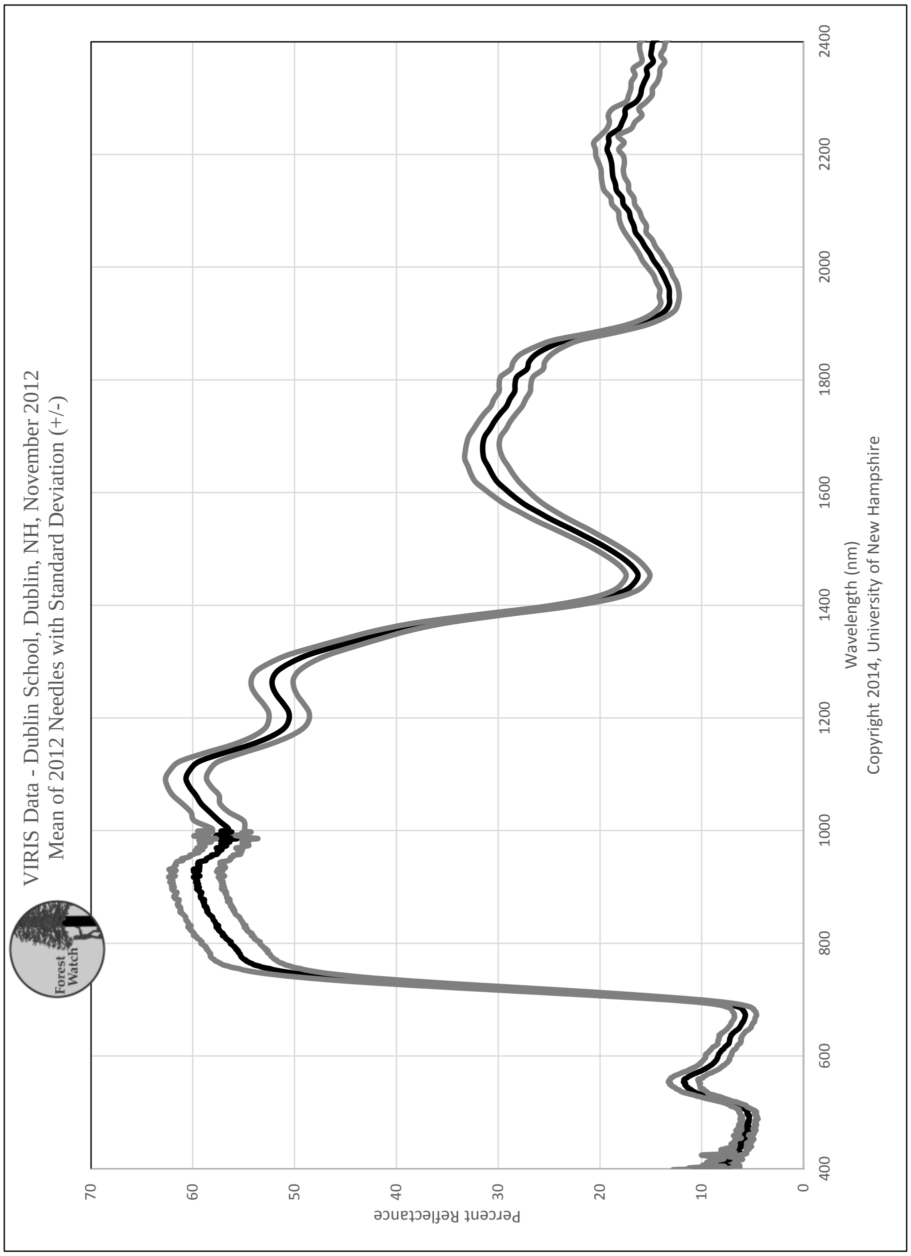
| **Alvirne 2011 Needles Spectral Indices in 2013** | | | | |
|---|---|---|---|---|
| **Tree ID** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1772N2** | 708.5 | 0.803 | 0.654 | 0.922 |
| **1775N2** | 717.7 | 0.824 | 0.538 | 0.869 |
| **1776S2** | 708.5 | 0.801 | 0.575 | 0.911 |
| **1778S2** | 717.7 | 0.834 | 0.525 | 0.873 |
| **1779N2** | 705.4 | 0.812 | 0.626 | 0.974 |
| **1780S2** | 720.8 | 0.826 | 0.631 | 0.922 |


VIRIS DATA - Alvirne High School - Winter 2013
Mean of 2012 Needles with Std. Dev. (+/-)
and Mean of 2011 Needles
Forest Watch
Percent Reflectance
0
10
20
30
40
50
60
70
80
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Copyright © 2013 University of New Hampshire

Dublin School, Dublin, NH

Biometric Data, Trees 1941-1945

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 11/6/2012 | | | | |
| Submitted by: | Katri Jackson | | | | |
| TreeNumber | **1941** | **1942** | **1943** | **1944** | **1945** |
| DBH (cm) | 31.5 | 40 | 29 | 85 | 26 |
| CrownHeight (m) | 1.6 | 2.1 | 4.8 | 3.7 | 4.6 |
| TreeHeight (m) | 11.6 | 18.9 | 27.9 | 16.7 | 13.1 |
| N-Fas-Len (mm) | 95 | | | | |
| S-Fas-Len (mm) | 83 | 87 | 74 | 77 | 82 |
| N-Need-Ret (year) | 2 | | | | |
| S-Need-Ret (year) | 1 | 3 | 2 | 2 | 1 |
| N-Water (%) | 65.5 | | | | |
| S-Water (%) | 66.7 | 68.1 | 52.5 | 63.4 | 67 |
| N-NumNeedles | 30 | | | | |
| S-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| N-AvgNeed-Len (mm) | 93 | | | | |
| S-AvgNeed-Len (mm) | 78 | 83 | 79 | 71 | 75 |
| N-PerTipNec | 30 | | | | |
| S-PerTipNec | 63 | 70 | 80 | 17 | 46 |
| N-PerChlMot | 43 | | | | |
| S-PerChlMot | 47 | 50 | 40 | 3 | 53 |
| N-AvgTotDamg-Len | 14 | | | | |
| S-AvgTotDamg-Len | 7.6 | 8.7 | 7 | 3.4 | 8 |
| N-PerNeedBothSymp | 30 | | | | |
| S-PerNeedle Both Sym | 37 | 50 | 23 | 0 | 40 |
| N-Avg Per Damage | 11.3 | | | | |
| S-Avg.PerDamage | 16.7 | 10.3 | 9.2 | 5 | 10 |



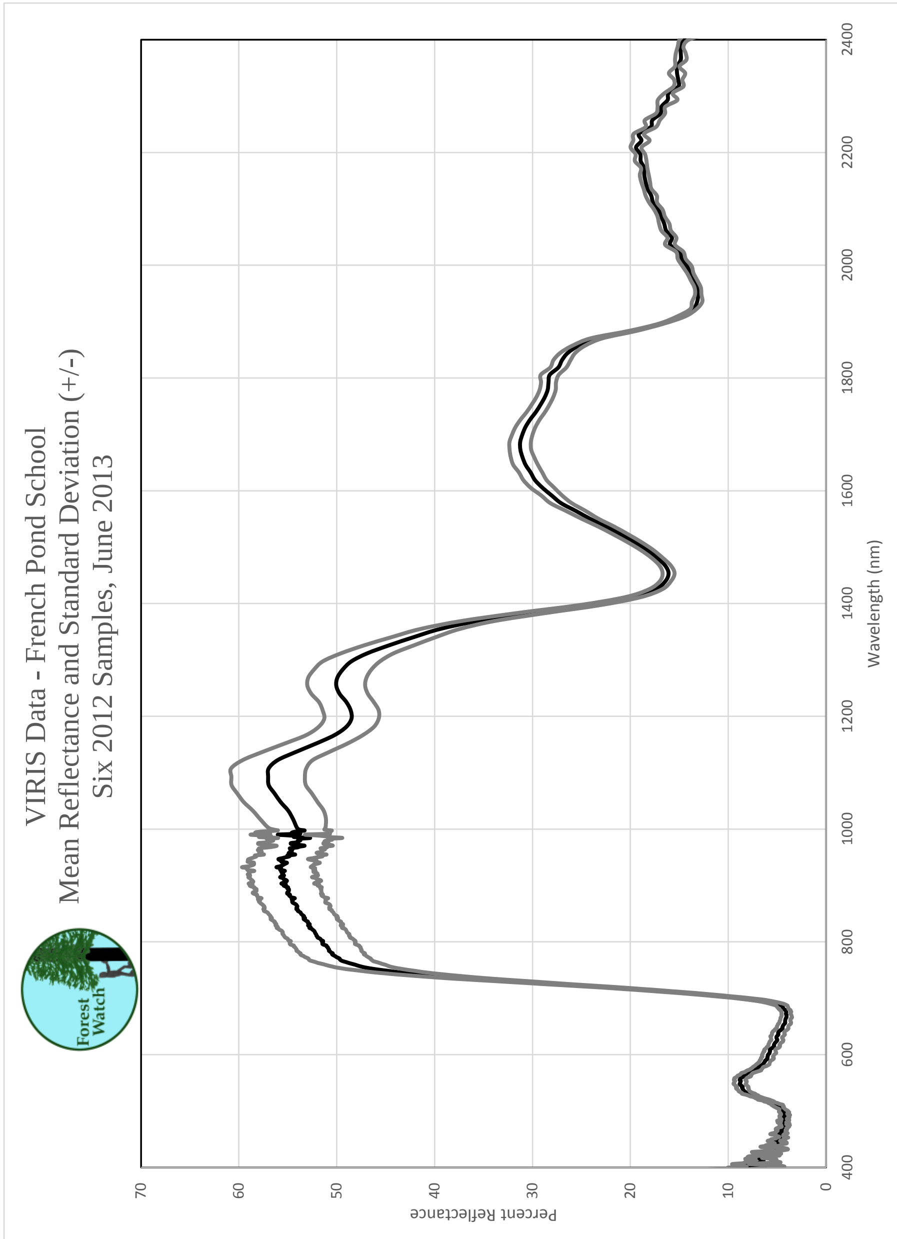

| | Dublin School - Spectral Data 2012-2013 | | | |
|---|---|---|---|---|
| | REIP | NDVI | TM54 | NIR31 |
| 1941n | 723.9 | 0.757 | 0.571 | 0.918 |
| 1941s | 725.4 | 0.803 | 0.554 | 0.91 |
| 1942s | 725.4 | 0.824 | 0.466 | 0.812 |
| 1943s | 723.9 | 0.85 | 0.488 | 0.844 |
| 1944s | 719.3 | 0.804 | 0.511 | 0.846 |
| 1945s | 714.6 | 0.776 | 0.511 | 0.866 |

French Pond School, Woodsville, NH

Biometric Data, Trees 1946-1950

| Needle Year | 2012 | | | | |
|---|---|---|---|---|---|
| Collection Date | 6/5/2013 | | | | |
| Submitted by: | Bill Emerson | | | | |
| TreeNumber | **1946** | **1947** | **1948** | **1949** | **1950** |
| N-Fas-Len (mm) | 75 | 92 | 76 | 80 | 85 |
| N-Need-Ret (year) | 2 | 1 | 2 | 1 | 1 |
| N-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| N-AvgNeed-Len (mm) | 74 | 91 | 70 | 79 | 83 |
| N-PerTipNec | 37 | 33 | 17 | 10 | 40 |
| N-PerChlMot | 37 | 0 | 17 | 13 | 33 |
| N-AvgTotDamg-Len | 6 | 47 | 9 | 9 | 30 |
| N-PerNeedBothSymp | 10 | 33 | 10 | 7 | 30 |
| N-Avg Per Damage | 8 | 52 | 13 | 11 | 36 |
| S-Avg.PerDamage | 7 | 52 | 13 | 11 | 36 |

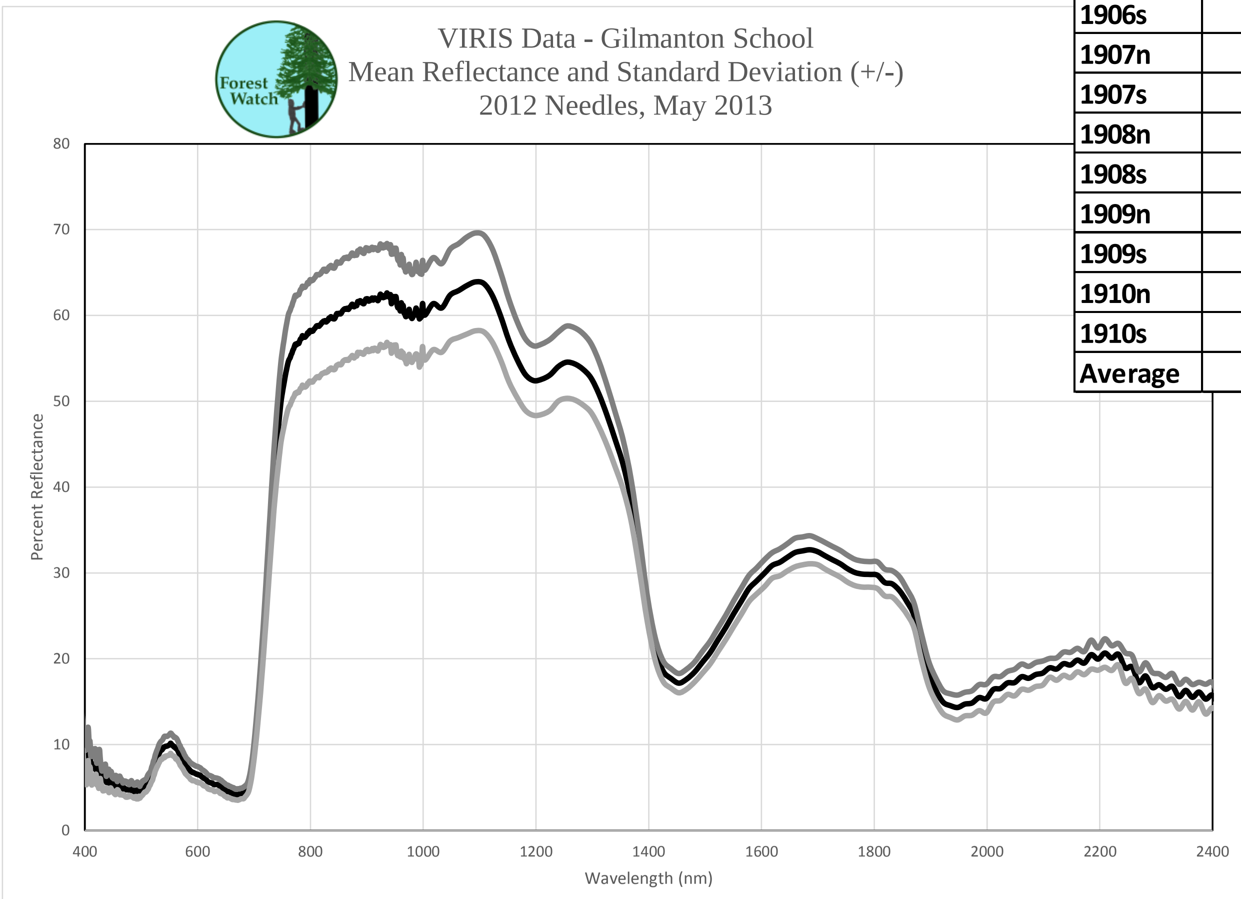
| | **French Pond Needle Spectral Data** | | | |
|---|---|---|---|---|
| **Tree IDs** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1946** | 723.9 | 0.839 | 0.591 | 0.924 |
| **1947** | 731.6 | 0.806 | 0.566 | 0.904 |
| **1948** | 731.6 | 0.871 | 0.546 | 0.886 |
| **1949** | 723.9 | 0.84 | 0.564 | 0.912 |
| **1950** | 720.8 | 0.854 | 0.523 | 0.9 |
| **Extra Tree** | 723.9 | 0.857 | 0.557 | 0.89 |


VIRIS Data - French Pond School
Mean Reflectance and Standard Deviation (+/-)
Six 2012 Samples, June 2013
Forest Watch
Percent Reflectance
Wavelength (nm)
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

Gilmanton School, Gilmanton, NH

Biometric Data, Trees 1906-1910

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 5/20/2013 | | | | |
| Submitted by: | Mary Fougere | | | | |
| TreeNumber | 371 | 372 | 373 | 374 | 375 |
| CrownHeight (m) | 2.8 | 2.9 | 4.6 | 2.2 | 2.1 |
| TreeHeight (m) | 3.3 | 3.6 | 6 | 2.9 | 2.8 |
| N-Coll-Ht (m) | 1.7 | 1.4 | 3.7 | 1.3 | 1.1 |
| S-Coll-Ht (m) | 1.2 | 1.5 | 3.3 | 1.4 | 1.2 |
| N-Fas-Len (mm) | 84.5 | 74.7 | 101.9 | 84.9 | 82.9 |
| S-Fas-Len (mm) | 75.9 | 80 | 82 | 67.4 | 82 |
| N-Need-Ret (year) | 1 | 2 | 2 | 2 | 2 |
| S-Need-Ret (year) | 2 | 2 | 3 | 2 | 2 |
| N-Water (%) | 51.7 | 50 | 46.4 | 45.9 | 50.2 |
| S-Water (%) | 50 | 47 | 47.9 | 54.5 | 48.4 |
| N-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| S-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| N-AvgNeed-Len (mm) | 78.2 | 80.2 | 99.7 | 85.1 | 77.2 |
| S-AvgNeed-Len (mm) | 69.8 | 76.2 | 88.7 | 68.8 | 77.6 |
| N-PerTipNec | 26.7 | 6.7 | 3.3 | 23.3 | 3.3 |
| S-PerTipNec | 26.7 | 20 | 20 | 13.3 | 1.6 |
| N-PerChlMot | 40 | 20 | 40 | 6.7 | 40 |
| S-PerChlMot | 50 | 23.3 | 1.2 | 6.7 | 1.2 |
| N-AvgTotDamg-Len | 3 | 2.1 | 0.8 | 0.9 | 4.4 |
| S-AvgTotDamg-Len | 1.6 | 0.7 | 1.5 | 0.7 | 2.5 |
| N-PerNeedBothSymp | 10 | 0 | 3.3 | 0 | 3.3 |
| S-PerNeedle Both Symp | 10 | 6.7 | 10 | 0 | 13.3 |
| N-Avg Per Damage | 3.8 | 2.6 | 0.8 | 1.1 | 5.7 |
| S-Avg.PerDamage | 2.3 | 0.9 | 1.7 | 1.0 | 3.2 |

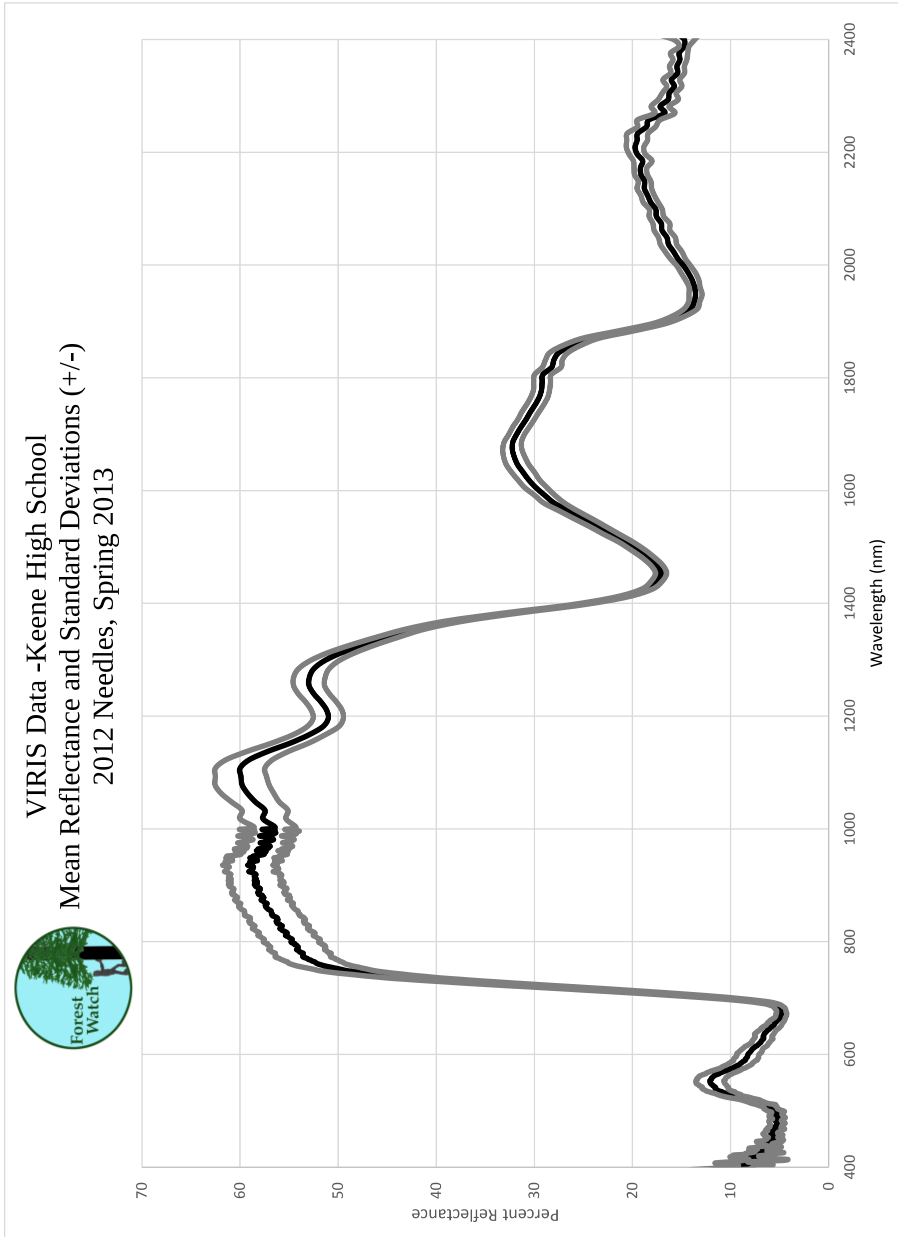



| | Gilmanton Needle Spectral Data | | | |
|---|---|---|---|---|
| **Tree ID** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1906n** | 719.3 | 0.859 | 0.557 | 0.926 |
| **1906s** | 730.1 | 0.852 | 0.499 | 0.869 |
| **1907n** | 734.7 | 0.877 | 0.465 | 0.843 |
| **1907s** | 730.1 | 0.858 | 0.453 | 0.832 |
| **1908n** | 722.4 | 0.822 | 0.531 | 0.894 |
| **1908s** | 723.9 | 0.817 | 0.615 | 0.913 |
| **1909n** | 734.7 | 0.855 | 0.487 | 0.857 |
| **1909s** | 723.9 | 0.867 | 0.564 | 0.899 |
| **1910n** | 734.7 | 0.866 | 0.551 | 0.881 |
| **1910s** | 723.9 | 0.87 | 0.477 | 0.841 |
| **Average** | 727.77 | 0.8543 | 0.5199 | 0.8755 |

Keene High School, Keene, NH

Spectral Data

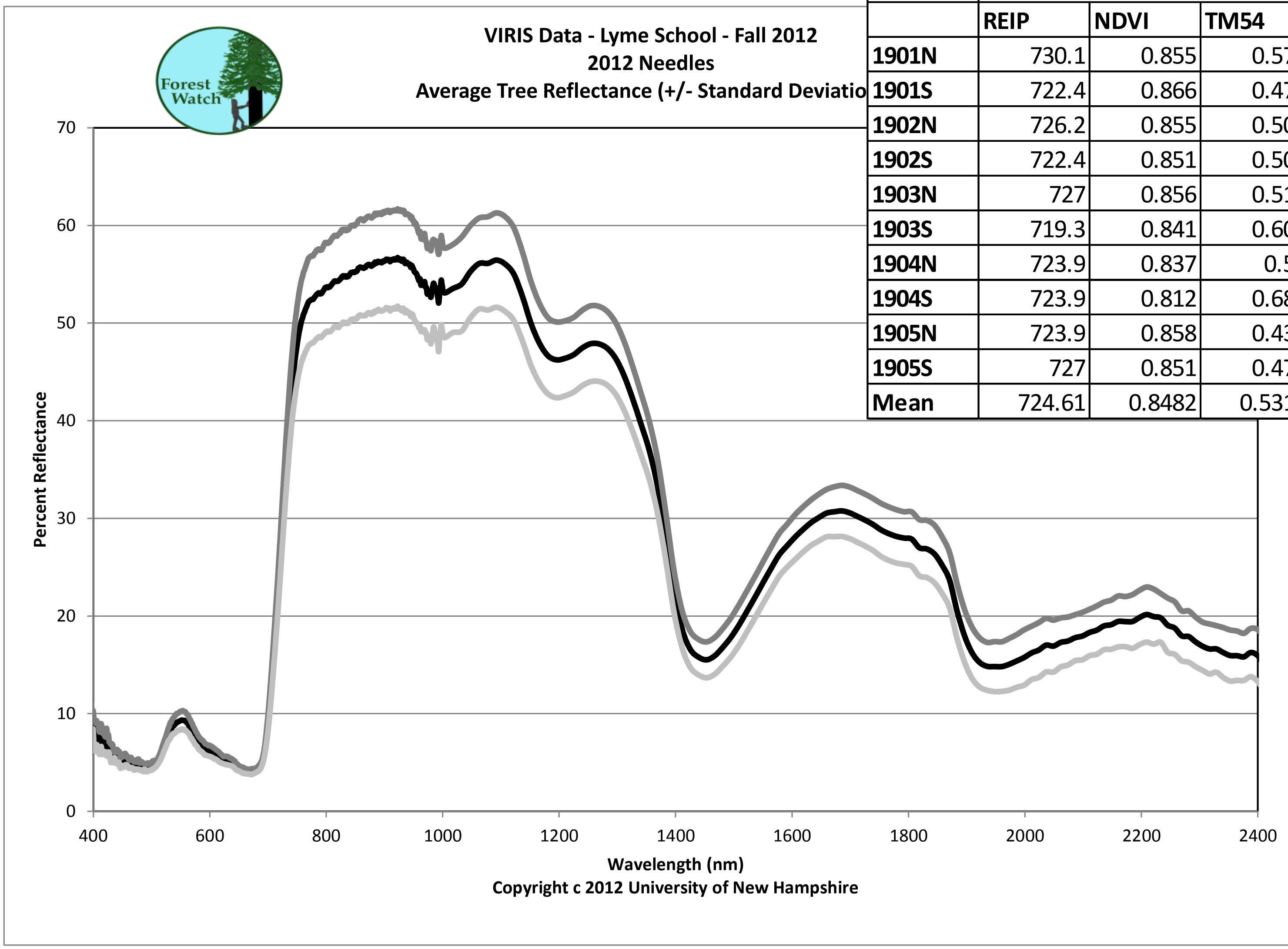
| | Keene High School Spectral Data | | | |
|---|---|---|---|---|
| | REIP | NDVI | TM54 | NIR31 |
| 1936N | 717.7 | 0.841 | 0.556 | 0.903 |
| 1936S | 719.3 | 0.835 | 0.518 | 0.9 |
| 1937N | 722.4 | 0.823 | 0.527 | 0.885 |
| 1937S | 722.4 | 0.804 | 0.562 | 0.915 |
| 1938N | 722.4 | 0.815 | 0.585 | 0.934 |
| 1938S | 719.3 | 0.827 | 0.548 | 0.909 |
| 1939N | 717.7 | 0.822 | 0.578 | 0.956 |
| 1939S | 714.6 | 0.788 | 0.509 | 0.882 |
| 1940N | 717.7 | 0.836 | 0.523 | 0.886 |
| 1940S | 720.8 | 0.811 | 0.51 | 0.888 |
| Average | 719.43 | 0.8202 | 0.5416 | 0.9058 |


VIRIS Data -Keene High School
Mean Reflectance and Standard Deviations (+/-)
2012 Needles, Spring 2013
Forest Watch
Percent Reflectance
Wavelength (nm)
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

Lyme School, Lyme, NH

Biometric Data, Trees 1901-1905

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 11/8/2012 | | | | |
| Submitted by: | Skip Pendleton | | | | |
| TreeNumber | **1901** | **1902** | **1903** | **1904** | **1905** |
| DBH (cm) | 6.1 | 7 | 3.4 | 9.7 | 16.8 |
| CrownHeight (m) | 1.3 | 1.25 | 1 | 1.45 | 1.3 |
| TreeHeight (m) | 5.06 | 7.03 | 4.53 | 7.2 | 6.66 |
| N-Coll-Ht (m) | 4.5 | 5 | 3.25 | 5 | 5 |
| S-Coll-Ht (m) | 4.5 | 5.5 | 3.25 | 5 | 5 |
| N-Fas-Len (mm) | 99 | 96 | 84 | 99 | 98 |
| S-Fas-Len (mm) | 95 | 90 | 78 | 98 | 83 |
| N-Need-Ret (year) | 2 | 2 | 2 | 2 | 2 |
| S-Need-Ret (year) | 2 | 2 | 2 | 2 | 2 |
| N-NumNeedles | 10 | 10 | 10 | 10 | 10 |
| S-NumNeedles | 10 | 10 | 10 | 10 | 10 |
| N-AvgNeed-Len (mm) | 99 | 96 | 84 | 99 | 98 |
| S-AvgNeed-Len (mm) | 95 | 90 | 78 | 98 | 83 |
| N-PerTipNec | 2 | 10 | 50 | 20 | 40 |
| S-PerTipNec | 10 | 20 | 20 | 60 | 20 |
| N-PerChlMot | 9 | 70 | 30 | 50 | 40 |
| S-PerChlMot | 0 | 60 | 10 | 80 | 20 |
| N-AvgTotDamg-Len | 0.7 | 2 | 1.5 | 1 | 0.3 |
| S-AvgTotDamg-Len | 0.5 | 6 | 0.3 | 2 | 2 |
| N-PerNeedBothSymp | 0 | 0 | 20 | 20 | 30 |
| S-PerNeedle Both Symp | 0 | 10 | 0 | 50 | 0 |
| N-Avg Per Damage | 0.9 | 2 | 1.7 | 1 | 0.3 |
| S-Avg.PerDamage | 0.5 | 7 | 0.4 | 2 | 2 |



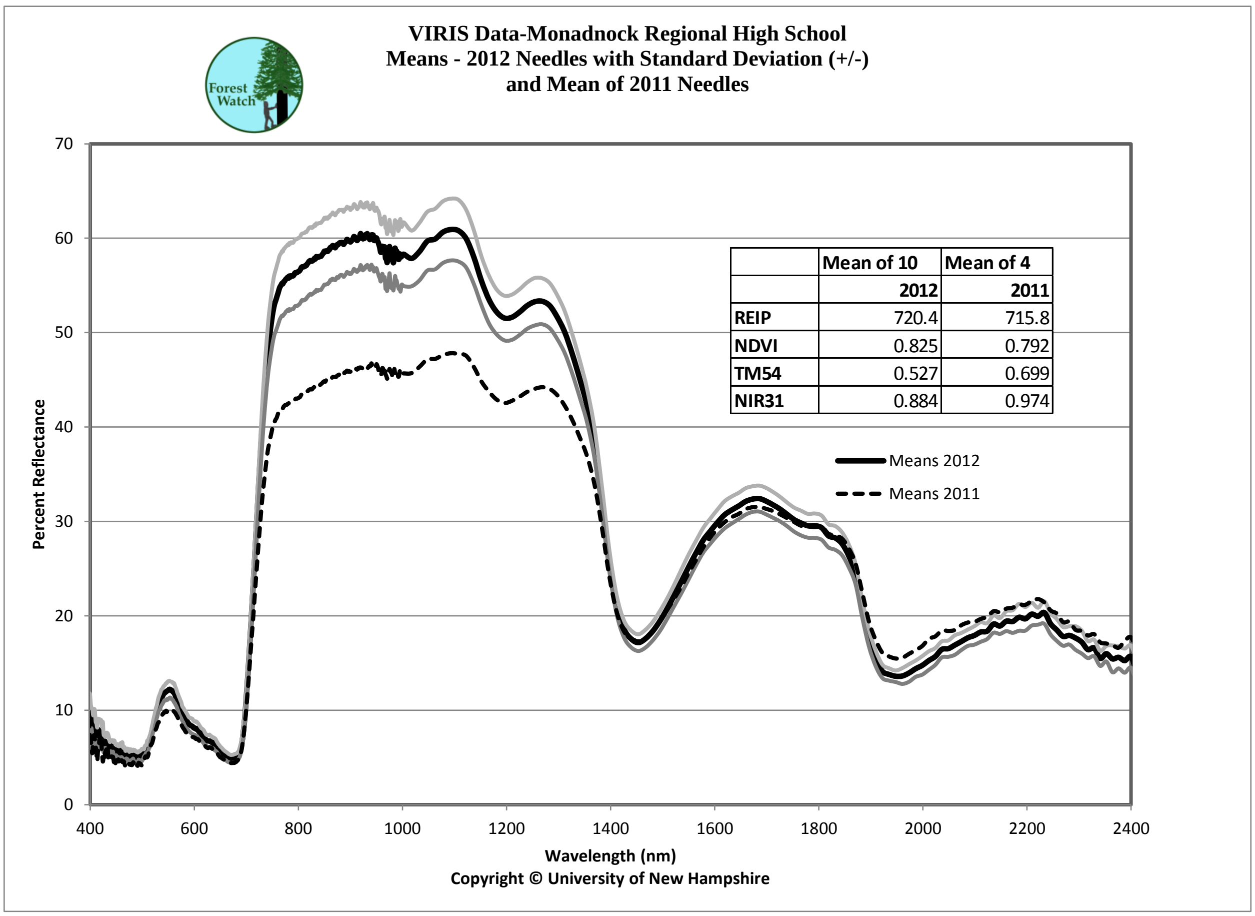

| | Lyme School Spectral Data | | | |
|---|---|---|---|---|
| | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1901N** | 730.1 | 0.855 | 0.573 | 0.852 |
| **1901S** | 722.4 | 0.866 | 0.474 | 0.826 |
| **1902N** | 726.2 | 0.855 | 0.503 | 0.827 |
| **1902S** | 722.4 | 0.851 | 0.504 | 0.803 |
| **1903N** | 727 | 0.856 | 0.513 | 0.855 |
| **1903S** | 719.3 | 0.841 | 0.606 | 0.857 |
| **1904N** | 723.9 | 0.837 | 0.54 | 0.876 |
| **1904S** | 723.9 | 0.812 | 0.689 | 0.901 |
| **1905N** | 723.9 | 0.858 | 0.439 | 0.772 |
| **1905S** | 727 | 0.851 | 0.473 | 0.8 |
| **Mean** | 724.61 | 0.8482 | 0.5314 | 0.8369 |

Monadnock Regional High School, Swanzey, NH

Biometric and Spectral Data, Trees 1266-1270

| Needle Year | 2012 | Column1 | Column2 | Column3 | Column4 |
|---|---|---|---|---|---|
| Collection Date | 4/30/2013 | | | | |
| Submitted by: | Gerry Babonis | | | | |
| TreeNumber | **1266** | **1267** | **1268** | **1269** | **1270** |
| DBH (cm) | 76.4 | | 92.4 | 70.1 | 90.1 |
| CrownHeight (m) | 24.35 | | 19.52 | 24.53 | 33.45 |
| TreeHeight (m) | 27.85 | 29.29 | 26.92 | 29.23 | 35.9 |
| N-Coll-Ht (m) | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| S-Coll-Ht (m) | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| N-Fas-Len (mm) | 71 | 71 | 78 | 71 | 66 |
| S-Fas-Len (mm) | 88 | 73 | 83 | 70 | 72 |
| N-Need-Ret (year) | 3 | 2 | 2 | 2 | 2 |
| S-Need-Ret (year) | 1 | 2 | 2 | 2 | 2 |
| N-Water (%) | 49.8 | 48.76 | 50.32 | 50.23 | 47.7 |
| S-Water (%) | 49.12 | 44.84 | 52.48 | 47.7 | 49.37 |
| N-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| S-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| N-AvgNeed-Len (mm) | 68 | 67 | 80 | 75 | 76 |
| S-AvgNeed-Len (mm) | 72 | 71 | 79 | 84 | 77 |
| N-PerTipNec | 97 | 23 | 80 | 60 | 76 |
| S-PerTipNec | 56 | 50 | 20 | 8 | 96 |
| N-PerChlMot | 43 | 33 | 40 | 47 | 13 |
| S-PerChlMot | 33 | 67 | 37 | 6 | 70 |
| N-AvgTotDamg-Len | 36.5 | 3.9 | 1.6 | 4.4 | 2.8 |
| S-AvgTotDamg-Len | 9.1 | 11.9 | 2.2 | 4.1 | 7 |
| N-PerNeedBothSymp | 43 | 10 | 37 | 33 | 13 |
| S-PerNeedle Both Symp | 20 | 40 | 10 | 3 | 70 |
| N-Avg Per Damage | 37 | 23 | 4 | 5.8 | 3.5 |
| S-Avg.PerDamage | 8 | 16 | 3 | 5.9 | 9.7 |

| | Monadnock Spectral Data 2012 | | | |
|---|---|---|---|---|
| | **REIP** | **NDVI** | **TM54** | NIR31 |
| **1266N** | 719.3 | 0.801 | 0.527 | 0.878 |
| **1266S** | 723.9 | 0.838 | 0.538 | 0.89 |
| **1267N** | 713.1 | 0.826 | 0.547 | 0.918 |
| **1267S** | 723.9 | 0.827 | 0.521 | 0.876 |
| **1268N** | 723.9 | 0.81 | 0.54 | 0.897 |
| **1268S** | 720.8 | 0.829 | 0.501 | 0.867 |
| **1269N** | 719.3 | 0.839 | 0.508 | 0.86 |
| **1269S** | 722.4 | 0.817 | 0.549 | 0.902 |
| **1270N** | 713.1 | 0.816 | 0.536 | 0.894 |
| **1270S** | 723.9 | 0.846 | 0.505 | 0.859 |
| **Mean** | 720.4 | 0.825 | 0.527 | 0.884 |



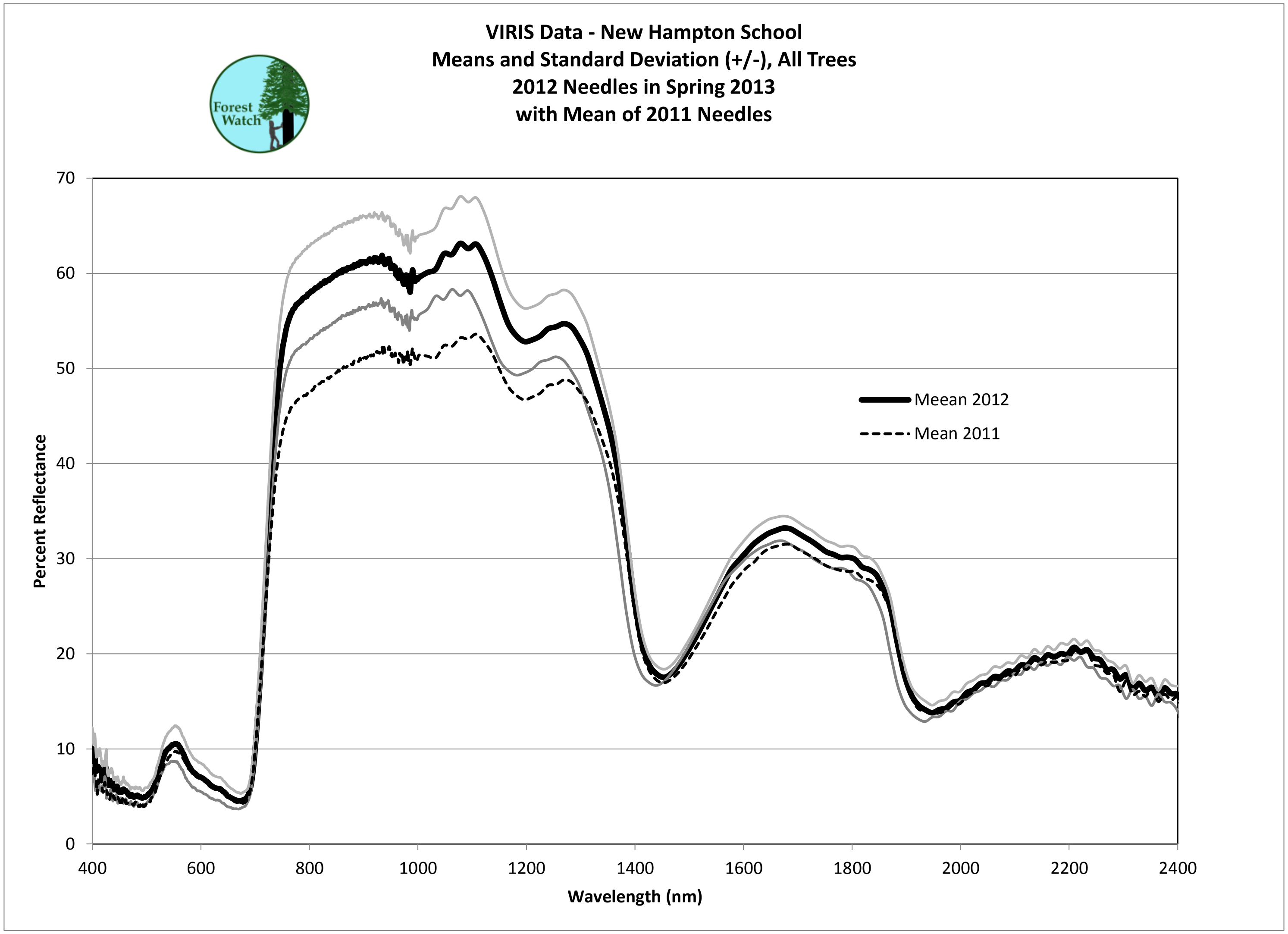
New Hampton School, New Hampton, NH

Biometric Data, Trees 1722-1725 and 1915

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | 5/1/2013 | | | | |
| Submitted by: | Jon Shackett | | | | |
| TreeNumber | **1915** | **1722** | **1723** | **1724** | **1725** |
| DBH (cm) | 11.4 | 42.7 | 16.3 | 35 | 55.9 |
| CrownHeight (m) | 4.5 | 11.3 | 6 | 11.6 | 13.9 |
| TreeHeight (m) | 4.9 | 13.9 | 6.5 | 15.7 | 17.8 |
| N-Fas-Len (mm) | 86 | 68 | 80 | 86 | 79 |
| S-Fas-Len (mm) | 84 | 62 | 80 | 80 | 82 |
| N-Need-Ret (year) | 2 | 2 | 2 | 2 | 2 |
| S-Need-Ret (year) | 2 | 2 | 2 | 2 | 2 |
| N-Water (%) | 52.2 | 58.3 | 53.2 | 56.8 | 52 |
| S-Water (%) | 56.7 | 71 | 56.5 | 54.3 | 56.3 |
| N-NumNeedles | 60 | 60 | 60 | 60 | 60 |
| S-NumNeedles | 60 | 60 | 60 | 60 | 60 |
| N-AvgNeed-Len (mm) | 74 | 75 | 73 | 70 | 54 |
| S-AvgNeed-Len (mm) | 66 | 72 | 72 | 79 | 68 |
| N-PerTipNec | 5 | 13 | 7 | 0 | 0 |
| S-PerTipNec | 13 | 2 | 8 | 43 | 7 |
| N-PerChlMot | 42 | 27 | 18 | 43 | 0 |
| S-PerChlMot | 50 | 12 | 17 | 33 | 0 |
| N-AvgTotDamg-Len | 2.3 | 2.9 | 13.7 | 2.1 | 0.5 |
| S-AvgTotDamg-Len | 3.7 | 2.9 | 1 | 9.2 | 0.9 |
| N-PerNeedBothSymp | 2 | 4 | 0 | 0 | 0 |
| S-PerNeedle Both Symp | 8 | 2 | 0 | 13 | 0 |
| N-Avg Per Damage | 3 | 3.1 | 2 | 2.9 | 1.2 |
| S-Avg.PerDamage | 5.9 | 2.7 | 9.7 | 12.2 | 1.4 |

| | New Hampton Spectral Data 2012 | | | |
|---|---|---|---|---|
| **Tree IDs** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1722N** | 727 | 0.857 | 0.497 | 0.874 |
| **1722S** | 723.9 | 0.88 | 0.551 | 0.931 |
| **1723N** | 727 | 0.838 | 0.617 | 0.937 |
| **1723S** | 723.9 | 0.841 | 0.539 | 0.914 |
| **1724N** | 723.9 | 0.868 | 0.528 | 0.869 |
| **1724S** | 716.2 | 0.821 | 0.51 | 0.879 |
| **1725N** | 725.4 | 0.85 | 0.546 | 0.905 |
| **1725S** | 719.3 | 0.828 | 0.516 | 0.856 |
| **1915N** | 722.4 | 0.809 | 0.489 | 0.843 |
| **1915S** | 713.1 | 0.843 | 0.509 | 0.867 |
| **Mean** | 722.2 | 0.844 | 0.530 | 0.888 |

| | New Hampton Spectral Data 2011 | | | |
|---|---|---|---|---|
| **Tree IDs** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1722-2** | 719.3 | 0.855 | 0.648 | 0.983 |
| **1723-2** | 722.4 | 0.82 | 0.636 | 0.96 |
| **1724-2** | 714.6 | 0.818 | 0.542 | 0.931 |
| **1725-2** | 717.7 | 0.801 | 0.59 | 0.947 |
| **1915-2** | 713.1 | 0.807 | 0.624 | 0.985 |
| **Mean** | 717.42 | 0.8202 | 0.608 | 0.9612 |

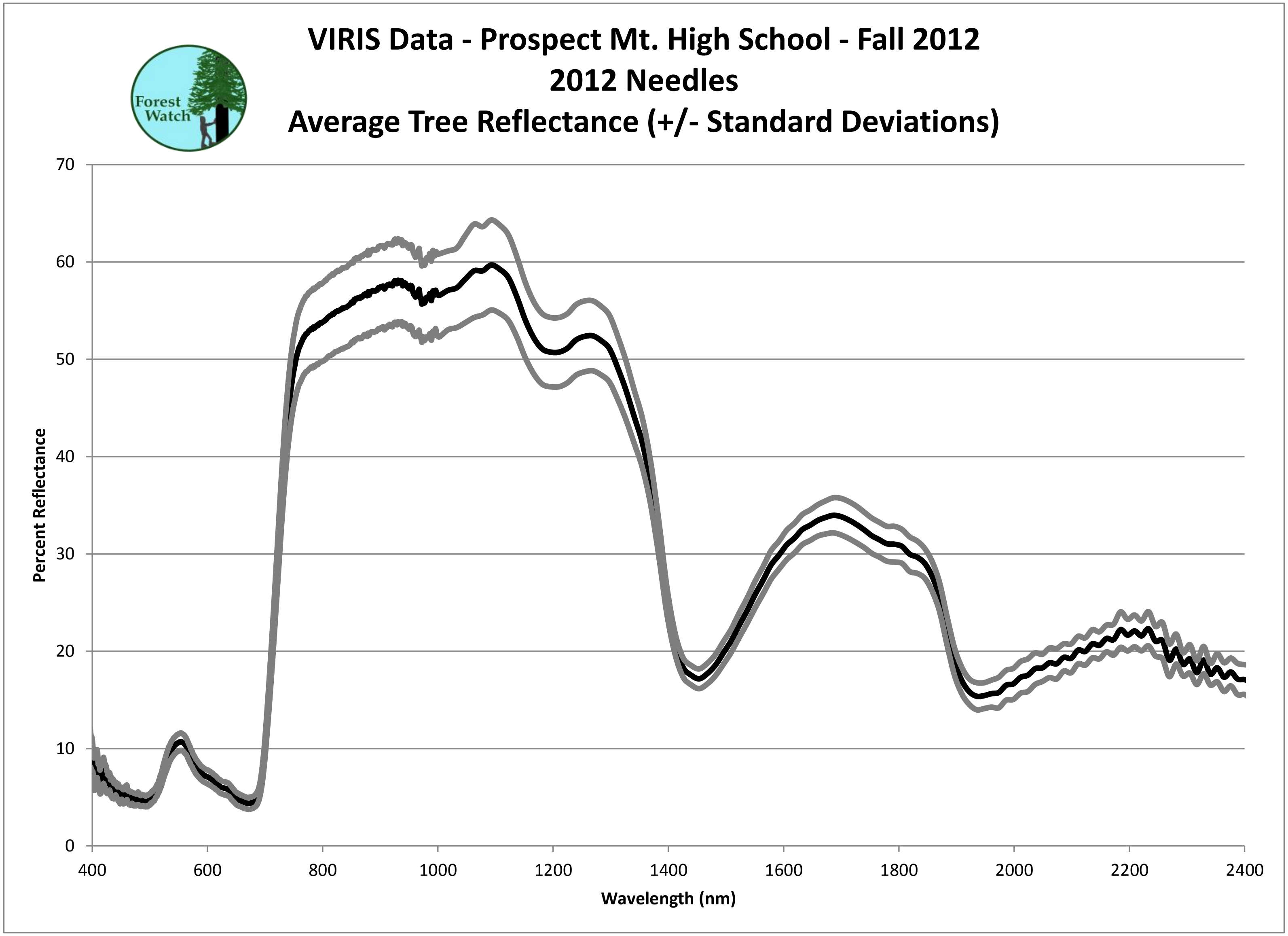

VIRIS Data - New Hampton School
Means and Standard Deviation (+/-), All Trees
2012 Needles in Spring 2013
with Mean of 2011 Needles
Forest Watch
Percent Reflectance
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Meean 2012
Mean 2011

Prospect Mountain High School, Alton, NH

Spectral Data 2012 Needles

| | Prospect Mt. 2012 Spectral Data | | | |
|---|---|---|---|---|
| **Tree IDs** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1926N** | 717.7 | 0.856 | 0.595 | 0.925 |
| **1926S** | 719.3 | 0.844 | 0.552 | 0.926 |
| **1927N** | 723.9 | 0.848 | 0.503 | 0.858 |
| **1927S** | 725.4 | 0.826 | 0.536 | 0.9 |
| **1928N** | 716.2 | 0.781 | 0.632 | 0.972 |
| **1928s** | 722.4 | 0.834 | 0.555 | 0.881 |
| **1929N** | 722.4 | 0.843 | 0.597 | 0.897 |
| **1929S** | 727 | 0.862 | 0.595 | 0.915 |
| **1930N** | 722.4 | 0.857 | 0.542 | 0.899 |
| **1930S** | 722.4 | 0.847 | 0.594 | 0.93 |
| **1931N** | 720.8 | 0.827 | 0.558 | 0.893 |
| **1931S** | 727 | 0.836 | 0.579 | 0.924 |
| **1932N** | 722.4 | 0.826 | 0.575 | 0.892 |
| **1932S** | 722.4 | 0.834 | 0.572 | 0.929 |
| **1933N** | 722.4 | 0.818 | 0.528 | 0.913 |
| **1933S** | 719.3 | 0.84 | 0.634 | 0.954 |
| **1934N** | 722.4 | 0.841 | 0.568 | 0.9 |
| **1934S** | 717.7 | 0.832 | 0.675 | 0.936 |
| **1935N** | 723.9 | 0.839 | 0.625 | 0.92 |
| **1935S** | 725.4 | 0.83 | 0.539 | 0.878 |
| **Average** | 722.1 | 0.836 | 0.578 | 0.912 |

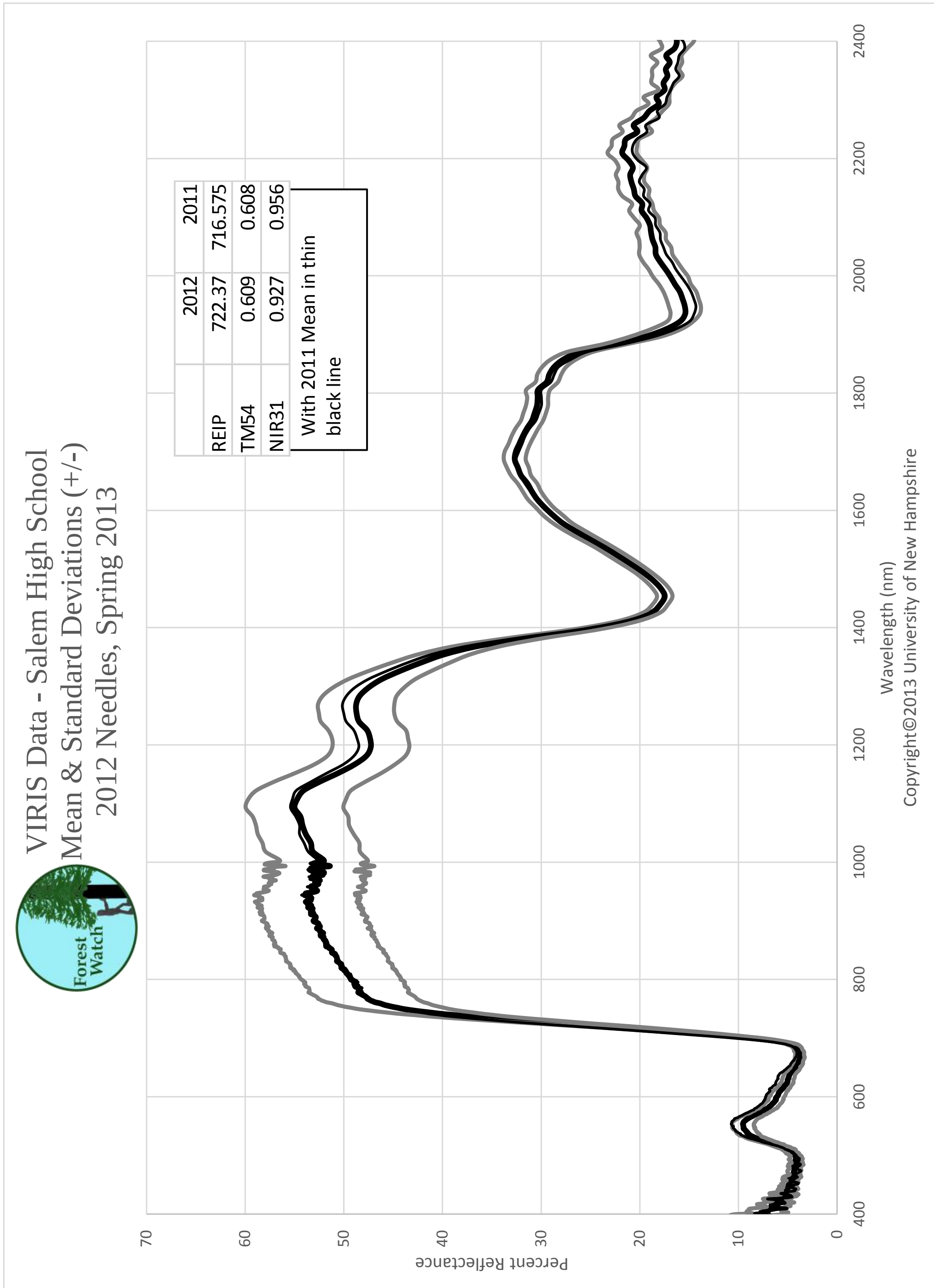
| | Prospect Mt. 2011 Spectral Data | | | |
|---|---|---|---|---|
| | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **2-1927N** | 716.2 | 0.809 | 0.782 | 1.063 |
| **2-1927S** | 722.4 | 0.829 | 0.509 | 0.877 |
| **2-1928N** | 716.2 | 0.8 | 0.695 | 0.975 |
| **2-1929N** | 727 | 0.812 | 0.724 | 0.993 |
| **2-1929S** | 722.4 | 0.813 | 0.761 | 0.989 |
| **2-1930S** | 722.4 | 0.815 | 0.713 | 0.981 |
| **2-1931S** | 716.2 | 0.785 | 0.832 | 0.996 |
| **2-1933N** | 727 | 0.834 | 0.61 | 0.886 |
| **2-1933S** | 716.2 | 0.802 | 0.756 | 1.013 |
| **2-1934N** | 719.3 | 0.771 | 0.718 | 0.989 |
| **2-1935N** | 716.2 | 0.775 | 0.862 | 1.046 |
| **2-1935S** | 728.5 | 0.827 | 0.599 | 0.944 |
| **Averages** | 720.8 | 0.806 | 0.713 | 0.979 |


VIRIS Data - Prospect Mt. High School - Fall 2012
2012 Needles
Average Tree Reflectance (+/- Standard Deviations)
Forest Watch
Percent Reflectance
Wavelength (nm)
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

Salem High School

Biometric Data, Trees 1351-1355 and 150

| | | | | | |
|---|---|---|---|---|---|
| Needle Year | 2012 | | | | |
| Collection Date | Norma Bursaw | | | | |
| Submitted by: | 5/16/2013 | | | | |
| TreeNumber | **1351** | **1353** | **1354** | **1355** | **1504** |
| DBH (cm) | 14.7 | 9.6 | 16.1 | 16.45 | 13.1 |
| CrownHeight (m) | 11.7 | 12.4 | 10.9 | 9.2 | 9.4 |
| TreeHeight (m) | 13.3 | 13 | 12.1 | 11.3 | 10.2 |
| N-Coll-Ht (m) | 5.2 | 4.7 | 5.2 | 5.3 | 4.9 |
| S-Coll-Ht (m) | 4.8 | 4.8 | 5 | 5.3 | 4.7 |
| N-Fas-Len (mm) | 79 | 76 | 78 | 60 | 82 |
| S-Fas-Len (mm) | 77 | 77 | 90 | 78 | 90 |
| N-Need-Ret (year) | 2 | 3 | 3 | 2 | 3 |
| S-Need-Ret (year) | 2 | 3 | 3 | 2 | 2 |
| N-Water (%) | 47.4 | 48.1 | 44.6 | 70.3 | 49.6 |
| S-Water (%) | 50.5 | 57.9 | 49.7 | 48 | 50.5 |
| N-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| S-NumNeedles | 30 | 30 | 30 | 30 | 30 |
| N-AvgNeed-Len (mm) | 79 | 72 | 57 | 77 | 84 |
| S-AvgNeed-Len (mm) | 85 | 74 | 89 | 77 | 89 |
| N-PerTipNec | 3 | 27 | 17 | 20 | 17 |
| S-PerTipNec | 20 | 33 | 20 | 20 | 10 |
| N-PerChlMot | 23 | 17 | 20 | 17 | 40 |
| S-PerChlMot | 63 | 23 | 50 | 17 | 37 |
| N-AvgTotDamg-Len | 2.2 | 3.1 | 1.9 | 0.8 | 3.4 |
| S-AvgTotDamg-Len | 2.4 | 2.5 | 2.1 | 1 | 1.5 |
| N-PerNeedBothSymp | 23 | 3 | 3 | 0 | 7 |
| S-PerNeedle Both Symp | 13 | 13 | 10 | 0 | 3 |
| N-Avg Per Damage | 2.8 | 4.3 | 3.3 | 1.0 | 4.0 |
| S-Avg.PerDamage | 2.8 | 3.4 | 2.4 | 1.3 | 1.7 |


VIRIS Data - Salem High School
Mean & Standard Deviations (+/-)
2012 Needles, Spring 2013
Forest Watch
2012
2011
REIP
722.37
716.575
TM54
0.609
0.608
NIR31
0.927
0.956
With 2011 Mean in thin black line
Percent Reflectance
Wavelength (nm)
Copyright©2013 University of New Hampshire
0
10
20
30
40
50
60
70
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

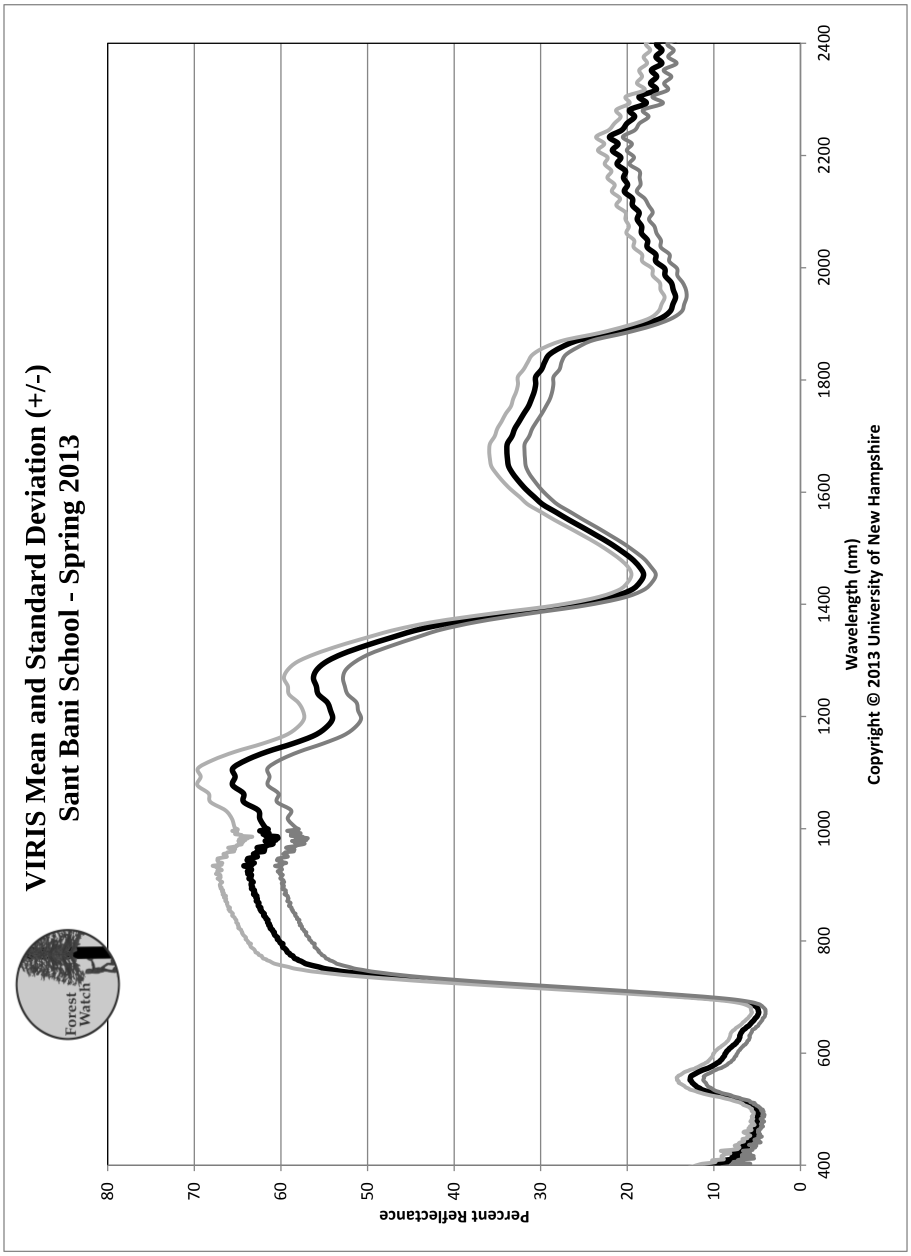
| | Salem 2012 Spectral Data | | | |
|---|---|---|---|---|
| | REIP | NDVI | TM54 | NIR31 |
| 1351N | 719.3 | 0.837 | 0.582 | 0.926 |
| 1351S | 725.4 | 0.846 | 0.59 | 0.926 |
| 1353N | 719.3 | 0.825 | 0.701 | 0.939 |
| 1353S | 722.4 | 0.846 | 0.566 | 0.904 |
| 1354N | 725.4 | 0.854 | 0.7 | 0.97 |
| 1354S | 720.8 | 0.847 | 0.53 | 0.872 |
| 1355N | 722.4 | 0.857 | 0.64 | 0.97 |
| 1355S | 722.4 | 0.832 | 0.627 | 0.934 |
| 1504N | 723.9 | | 0.611 | 0.919 |
| 1504S | 722.4 | | 0.545 | 0.907 |
| Average | 722.4 | 0.843 | 0.609 | 0.927 |

| | Salem 2011 Spectral Data in 2013 | | | |
|---|---|---|---|---|
| | 1351-2 | 1353-2 | 1354-2 | 1355-2 |
| REIP | 714.6 | 705.4 | 727 | 719.3 |
| NDVI | 0.829 | 0.813 | 0.848 | 0.804 |
| TM54 | 0.588 | 0.652 | 0.58 | 0.61 |
| NIR31 | 0.952 | 0.992 | 0.931 | 0.949 |

Sant Bani School, Sanbornton, NH

Spectral Data, 2012 Needles

| | Sant Bani Spectral Indices 2012 | | | |
|---|---|---|---|---|
| **Tree IDs** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **96N** | 720.8 | 0.856 | 0.554 | 0.889 |
| **96S** | 720.8 | 0.872 | 0.514 | 0.861 |
| **97N** | 722.4 | 0.835 | 0.509 | 0.869 |
| **97S** | 703.8 | 0.772 | 0.592 | 0.933 |
| **98N** | 719.3 | 0.831 | 0.506 | 0.877 |
| **98S** | 717.7 | 0.829 | 0.503 | 0.851 |
| **99N** | 714.6 | 0.826 | 0.513 | 0.857 |
| **99S** | 716.2 | 0.839 | 0.506 | 0.877 |
| **100N** | 719.3 | 0.82 | 0.522 | 0.886 |
| **100S** | 713.1 | 0.818 | 0.504 | 0.879 |
| **Mean** | 716.8 | 0.8298 | 0.5223 | 0.8779 |


VIRIS Mean and Standard Deviation (+/-)
Sant Bani School - Spring 2013
Forest Watch
Percent Reflectance
0
10
20
30
40
50
60
70
80
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)
Copyright © 2013 University of New Hampshire

Windham High School, Windham, NH

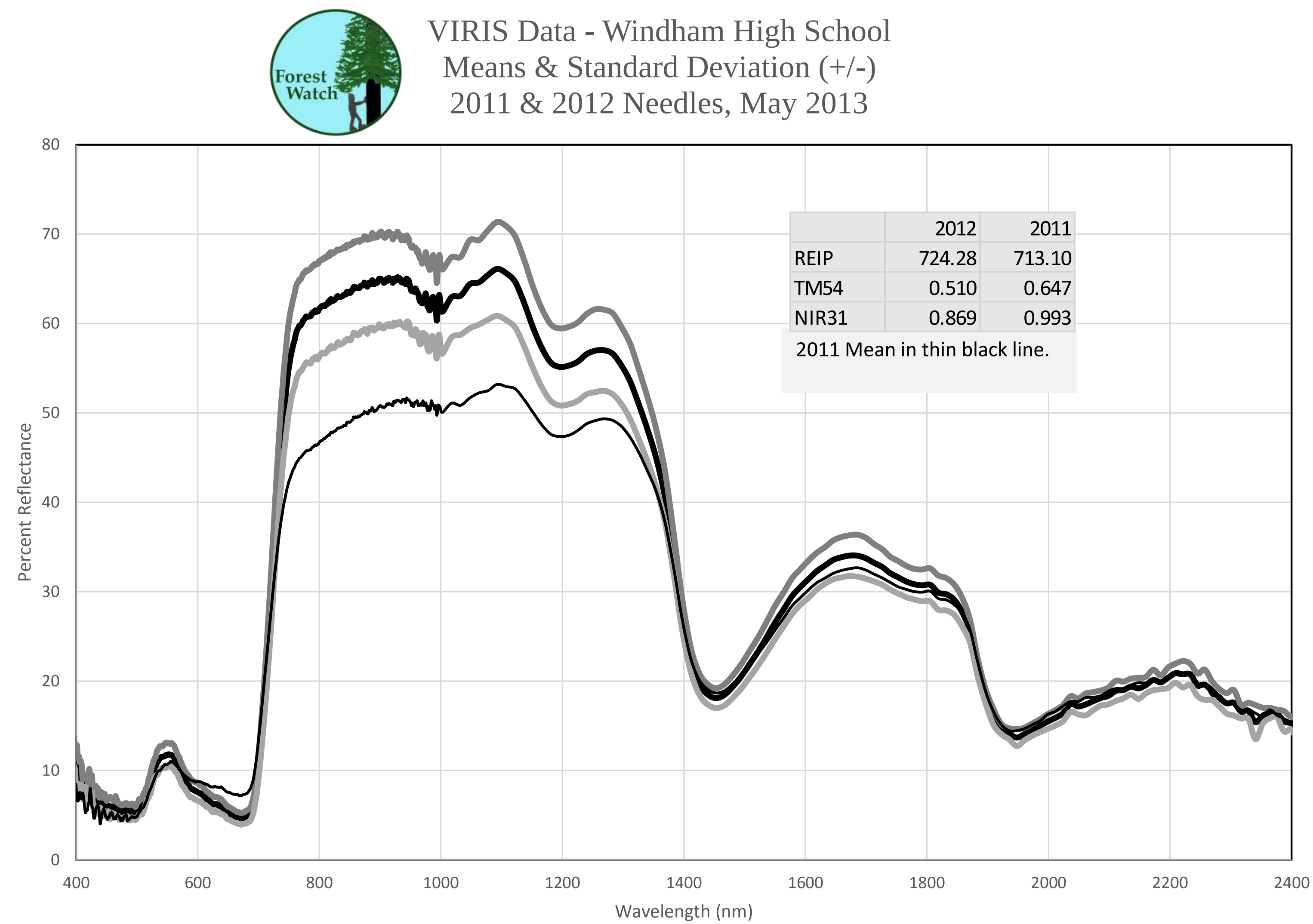
Biometric and Spectral Data, Trees 1916-1919

| | **Windham Spectral Data 2012 in 2013** | | | |
|---|---|---|---|---|
| **2012** | **1916** | **1917** | **1918** | **1919** |
| **REIP** | 725.4 | 723.9 | 722.4 | 725.4 |
| **NDVI** | 0.854 | 0.838 | 0.84 | 0.856 |
| **TM54** | 0.51 | 0.488 | 0.514 | 0.529 |
| **NIR31** | 0.872 | 0.862 | 0.868 | 0.872 |

| | **Windham Spectral Data 2011 in 2013** | | | |
|---|---|---|---|---|
| **2011** | **1916-2** | **1917-2** | **1918-2** | **1919-2** |
| **REIP** | 716.2 | 699.2 | 717.7 | 719.3 |
| **NDVI** | 0.783 | 0.533 | 0.765 | 0.815 |
| **TM54** | 0.604 | 0.813 | 0.607 | 0.563 |
| **NIR31** | 0.963 | 1.117 | 0.975 | 0.915 |

| | | | | |
|---|---|---|---|---|
| Needle Year | 2012 | | | |
| Collection Date | 5/17/2013 | | | |
| Submitted by: | Christy Johnson | | | |
| TreeNumber | **1916** | **1917** | **1918** | **1919** |
| CrownHeight (m) | 2.13 | 3.2 | 7.23 | 5.96 |
| TreeHeight (m) | 8.54 | 4.22 | 9.43 | 6.79 |

VIRIS Data - Windham High School
Means & Standard Deviation (+/-)
2011 & 2012 Needles, May 2013

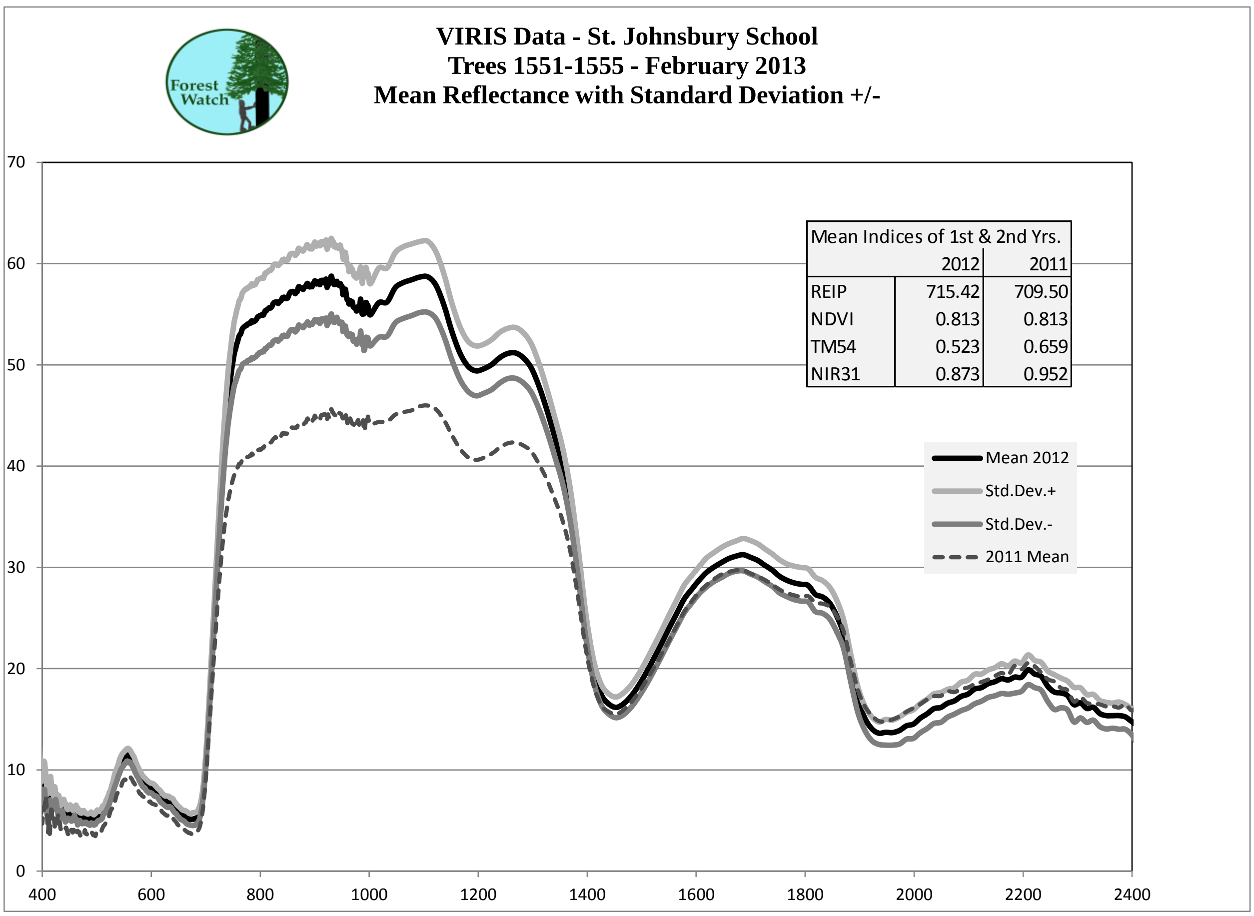



| | 2012 | 2011 |
|---|---|---|
| REIP | 724.28 | 713.10 |
| TM54 | 0.510 | 0.647 |
| NIR31 | 0.869 | 0.993 |

St. Johnsbury School, St. Johnsbury, VT

Spectral Data, Trees 1551-1555

| | St. Johnsbury 1551-1555 Spectral Data | | | |
|---|---|---|---|---|
| **Tree IDs** | **REIP** | **NDVI** | **TM54** | **NIR31** |
| **1551N** | 716.2 | 0.791 | 0.56 | 0.91 |
| **1551S** | 710 | 0.808 | 0.541 | 0.93 |
| **1552N** | 719.3 | 0.797 | 0.58 | 0.905 |
| **1552S** | 713.1 | 0.827 | 0.487 | 0.841 |
| **1553N** | 716.2 | 0.796 | 0.535 | 0.869 |
| **1553S** | 717.7 | 0.841 | 0.464 | 0.835 |
| **1554N** | 717 | 0.839 | 0.535 | 0.853 |
| **1554S** | 706.9 | 0.817 | 0.515 | 0.851 |
| **1555N** | 722.4 | 0.802 | 0.494 | 0.865 |
| **Average** | 715.4 | 0.813 | 0.523 | 0.873 |



St. Johnsbury School, St. Johnsbury, VT

Spectral Data, Trees 1806-1810

| | **St. Johnsbury School Spectral Data** | | | |
|---|---|---|---|---|
| Tree IDs | **REIP** | **NDVI** | **TM54** | **NIR31** |
| 1806N | 719.3 | 0.812 | 0.554 | 0.895 |
| 1807N | 723.9 | 0.84 | 0.623 | 0.965 |
| 1807S | 719.3 | 0.82 | 0.572 | 0.932 |
| 1808N | 723.9 | 0.802 | 0.579 | 0.931 |
| 1808S | 716.2 | 0.823 | 0.546 | 0.914 |
| 1809N | 722.4 | 0.83 | 0.536 | 0.906 |
| 1809S | 725.4 | 0.821 | 0.583 | 0.952 |
| 1810N | 716.2 | 0.826 | 0.525 | 0.892 |
| 1810S | 717.7 | 0.825 | 0.499 | 0.874 |
| Mean | 720.5 | 0.822 | 0.557 | 0.918 |