Chapter Six
Forest Watch Biometric Data Analysis

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

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

Histograms of 2011 Tree Size

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

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

Figure 6.1A: DBH in 2011

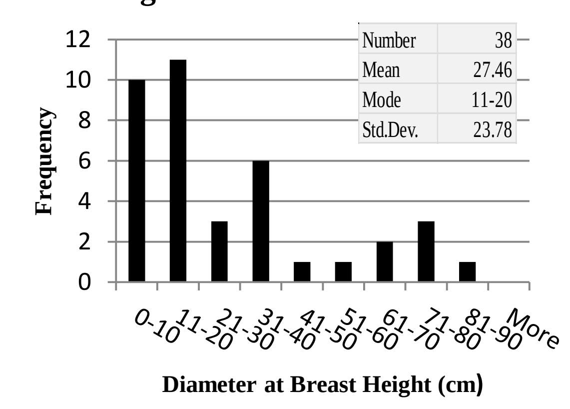
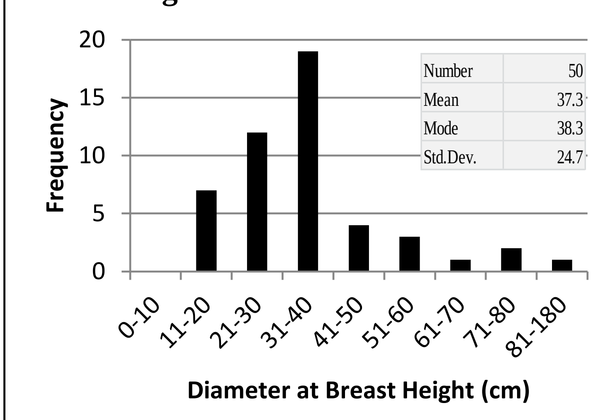


Figure 6.1B: DBH in 2010



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

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

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

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

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

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

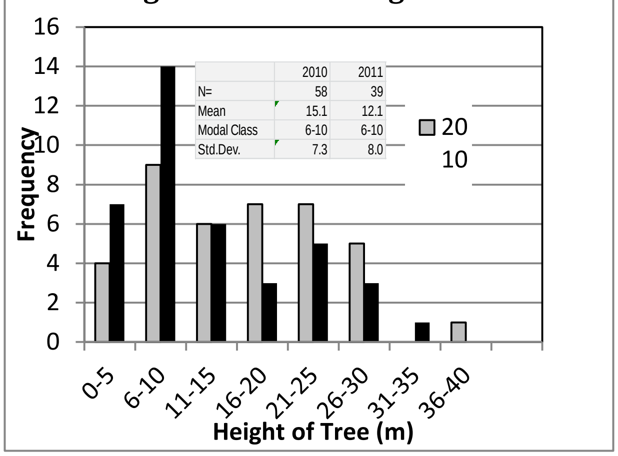
This year, the mean DBH is 27.4 cm but look at the mode; the main cluster of trees is in the 11-20 cm group.   There are lots more small trees this year. But the average of all trees' DBH is increased by a few old trees, like those giants at Monadnock Regional or Sant Bani. Some trees are wide and some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

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

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

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

Figure 6.2: Tree Height 2011



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

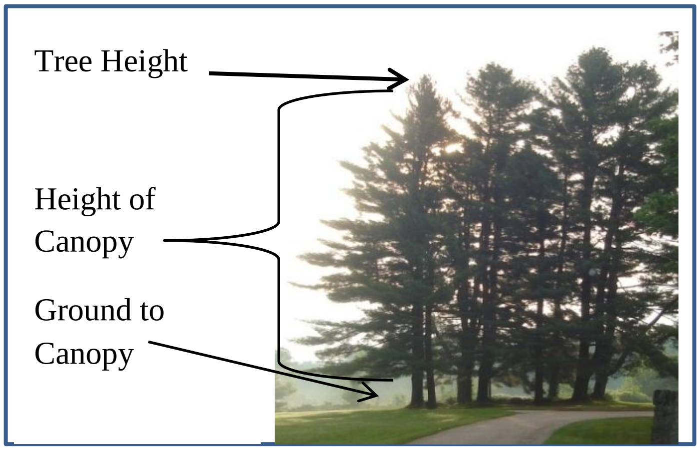


Figure 6.3: Classic white pines allow students to see, draw, photograph and understand the shape of a pine, its swooping arms and round-top triangular shape. Ideal trees have deep canopies with branches close to the ground, giving students ample opportunity to sample needles in the mid-canopy. (Photo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

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

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

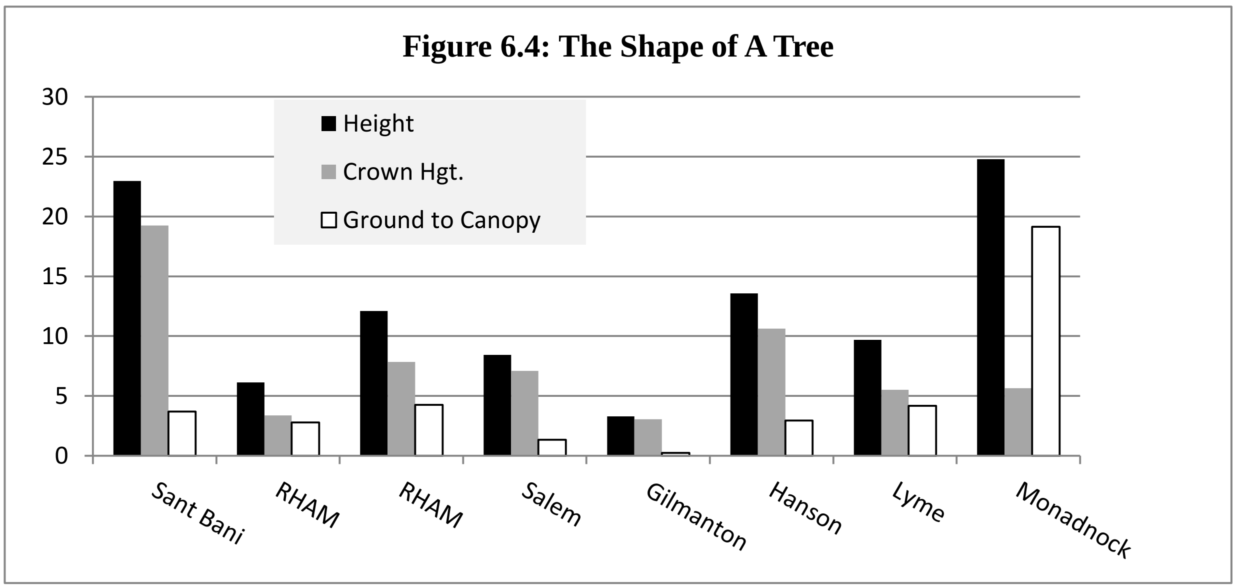


Figure 6.4: Tree height, canopy height and ground-to-canopy height are graphed side by side to show the average shape of eight Forest Watch schools' trees.

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

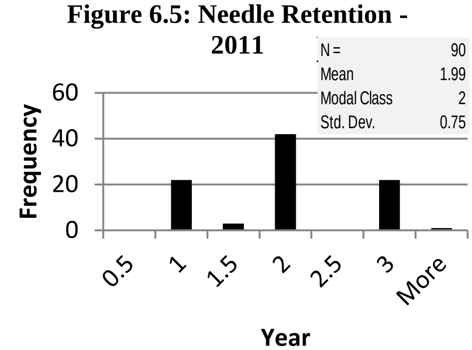
Many other Forest Watch teachers had the same difficult decision. As the chart shows, Gilmanton and Lyme, for instance, took the plunge and chose new trees. Their old trees still remain fond friends on the school grounds. But they have selected new trees with deep canopies and accessible needles.

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

Histograms Graphed from Student Measurements of Needles

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

Figure 6.5: Needle Retention - 2011



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

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

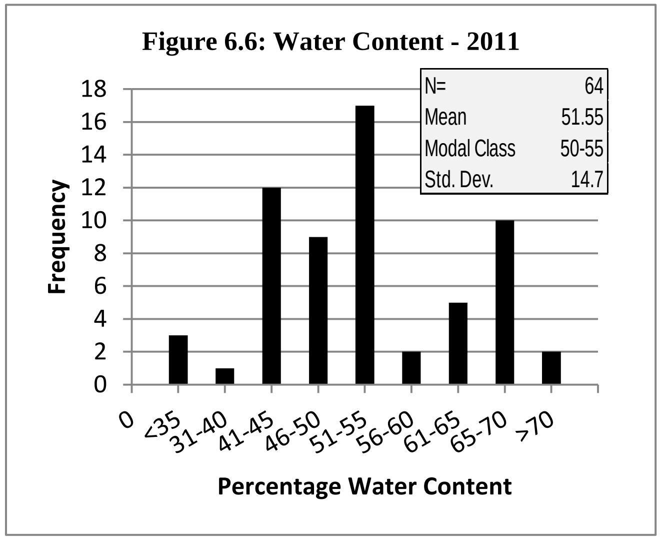


Figure 6.6: Water Content - 2011

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

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

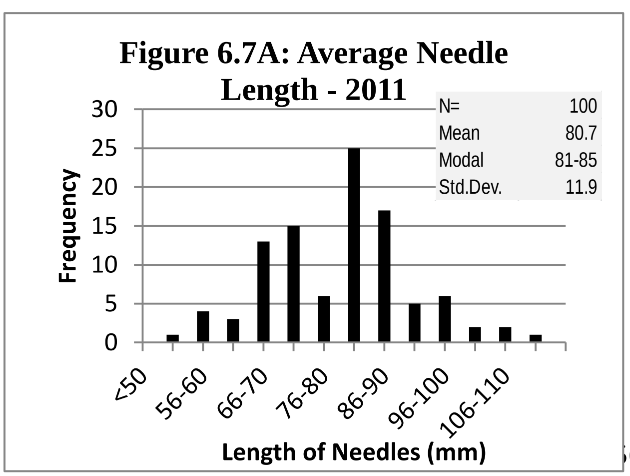


Figure 6.7A: Average Needle Length - 2011

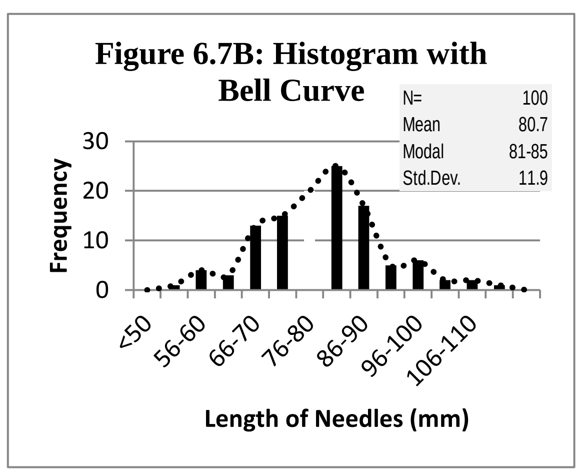


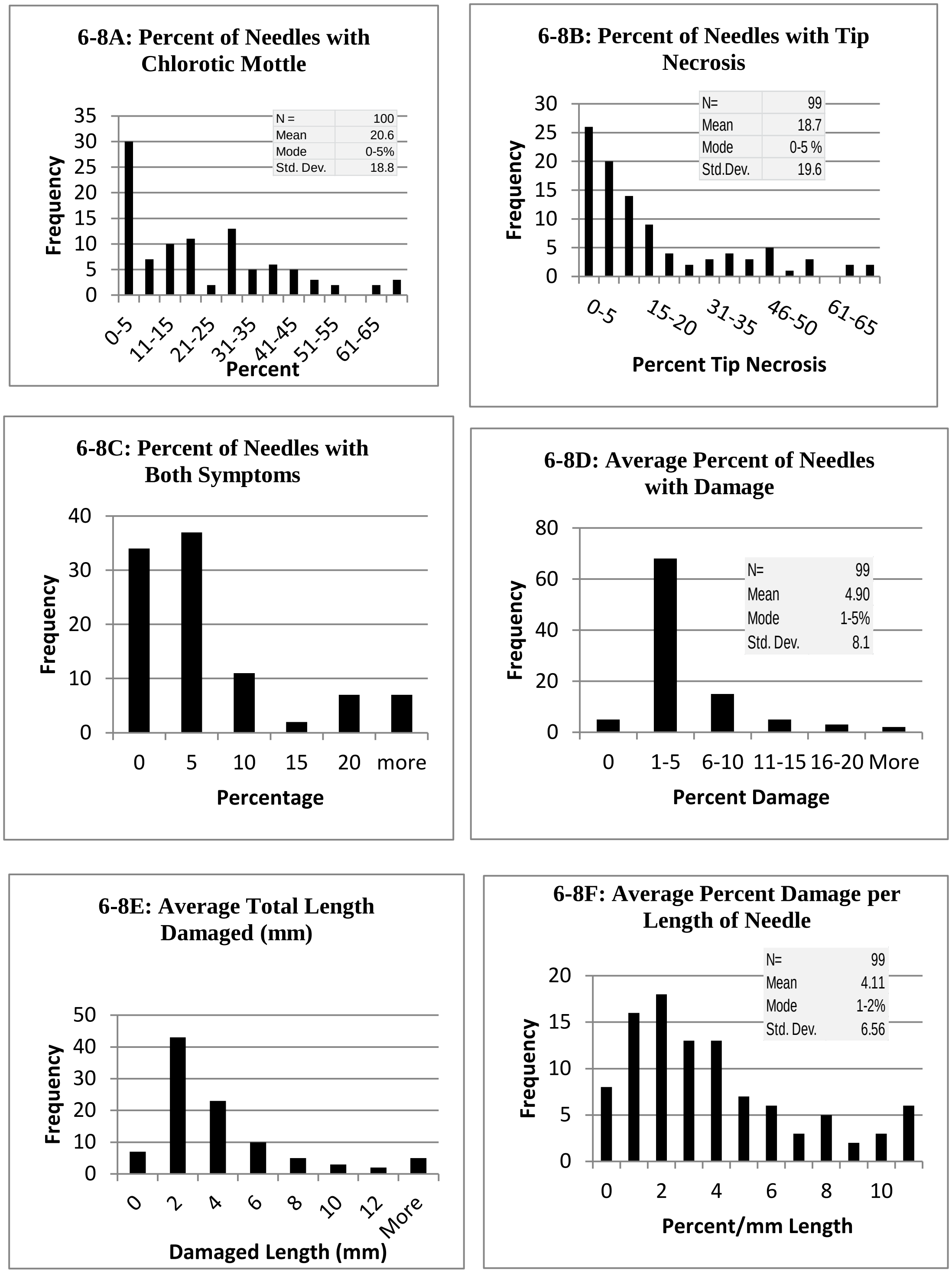
Figure 6.7B: Histogram with Bell Curve

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

Other Histograms

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

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



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

Long-Term Biometric Analysis

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

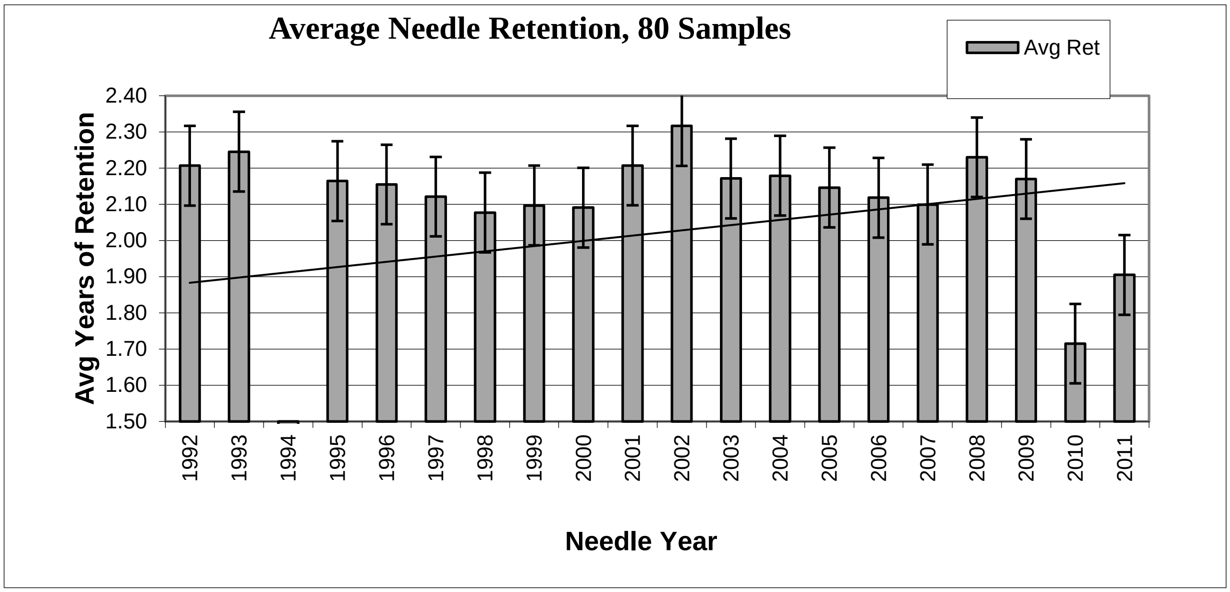


Figure 6-9: Average needle retention of trees in 2011 was 1.905.

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

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

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

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

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

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

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

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

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

Needle Anatomy

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

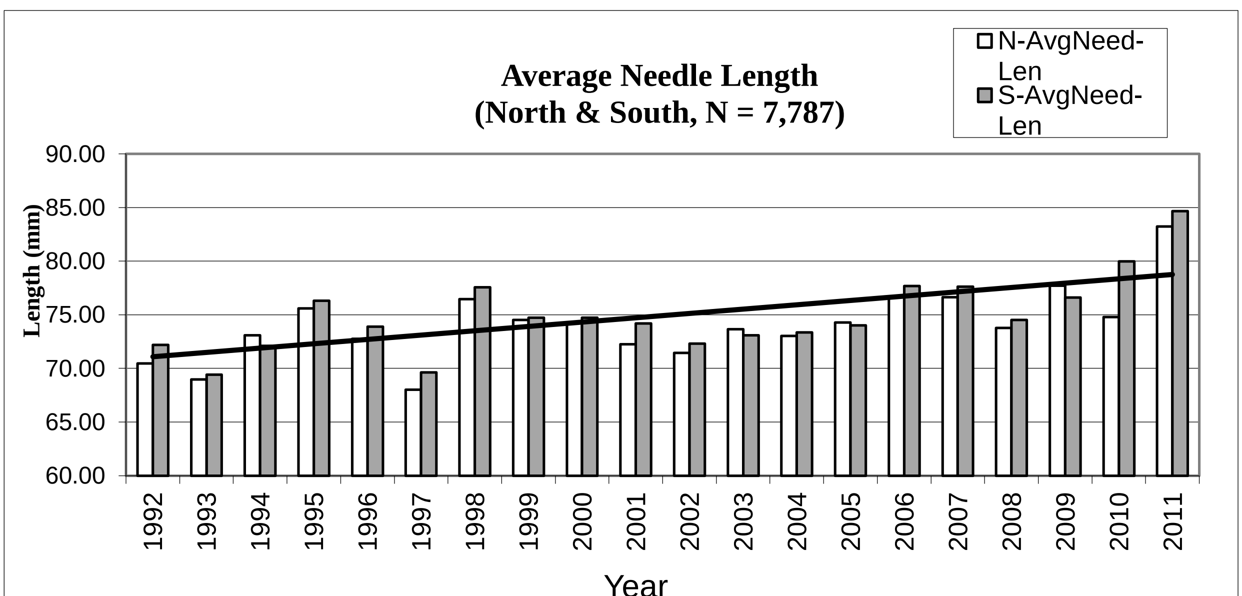


Figure 6-12: Average needle length of 6,887needles was 84 mm, the longest lengths in 22 years.

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

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

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

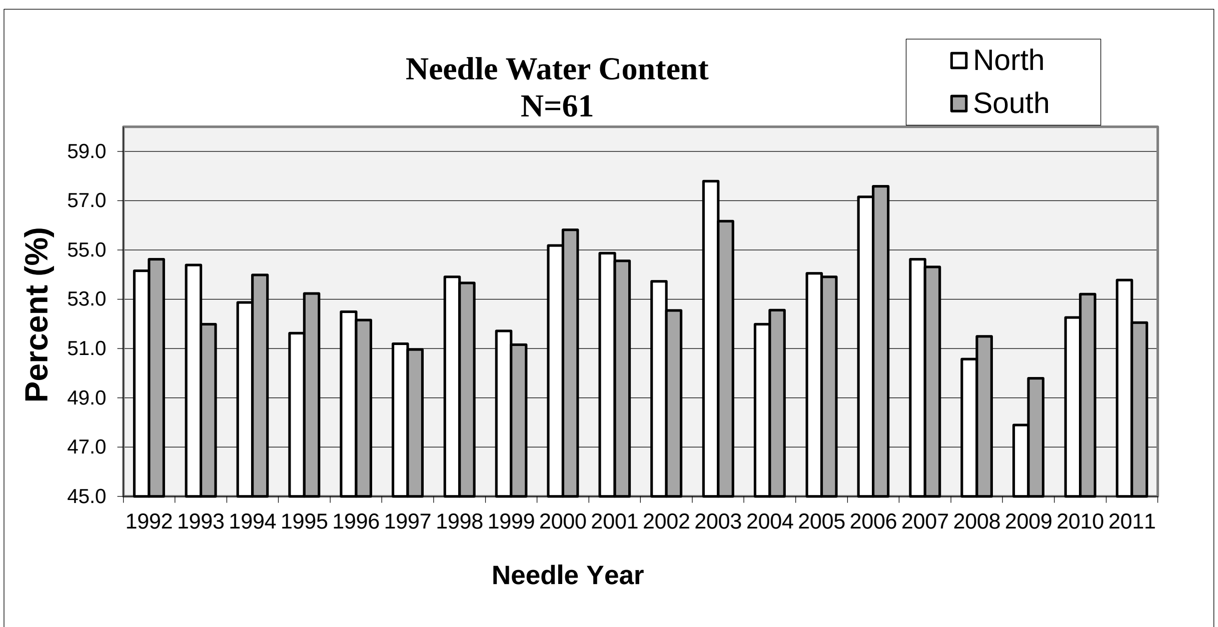


Figure 6-13: Water content was 53 and 52% for N and S side trees. This measurement, very easy to do on classroom countertops or in an oven, is a test Forest Watch hopes more schools will try.

Needle Condition

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

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

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

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

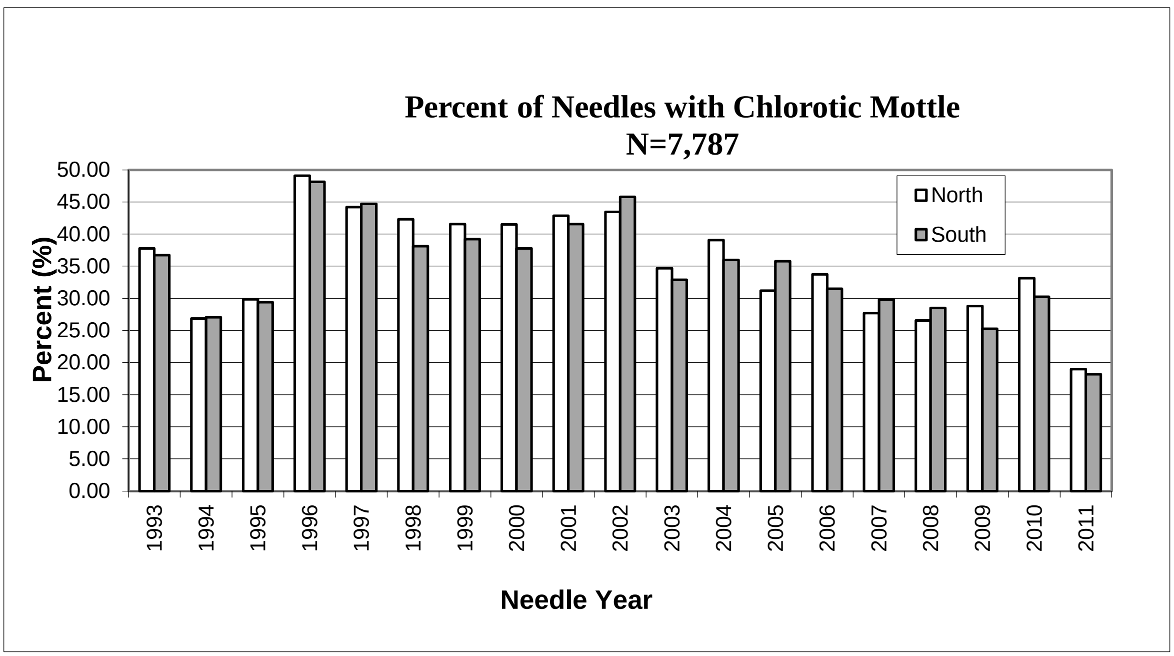


Figure 6-14: 2011 needles average 18.9 and 18.2% chlorotic mottle.

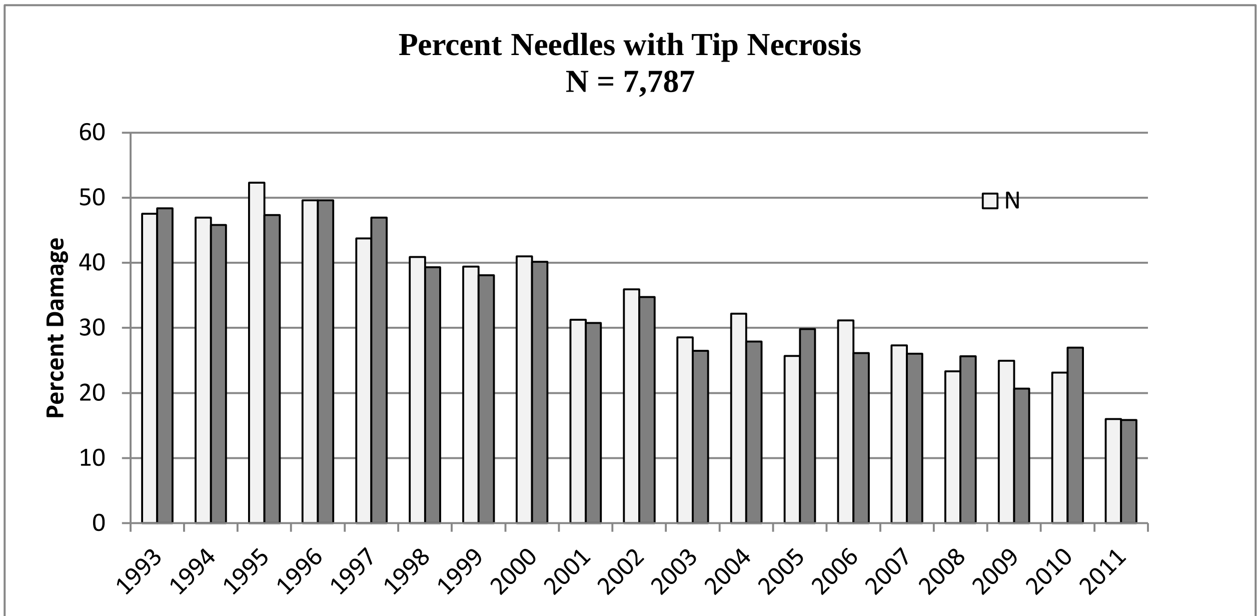


Figure 6-15: Needles averaged 10.4 percent tip necrosis in 2011.-2012.

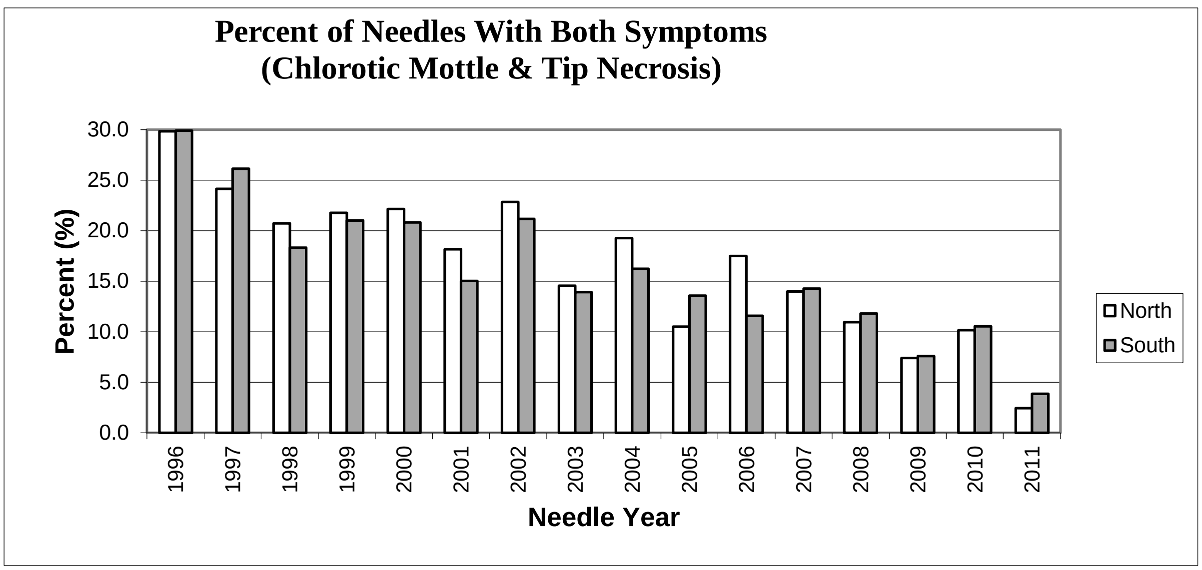


Figure 6-14:: The percent of needles exhibiting both types of damage falls below 5% for the first time in 22 years.

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

Table 6.1: Comparison of needle condition.

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

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

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

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