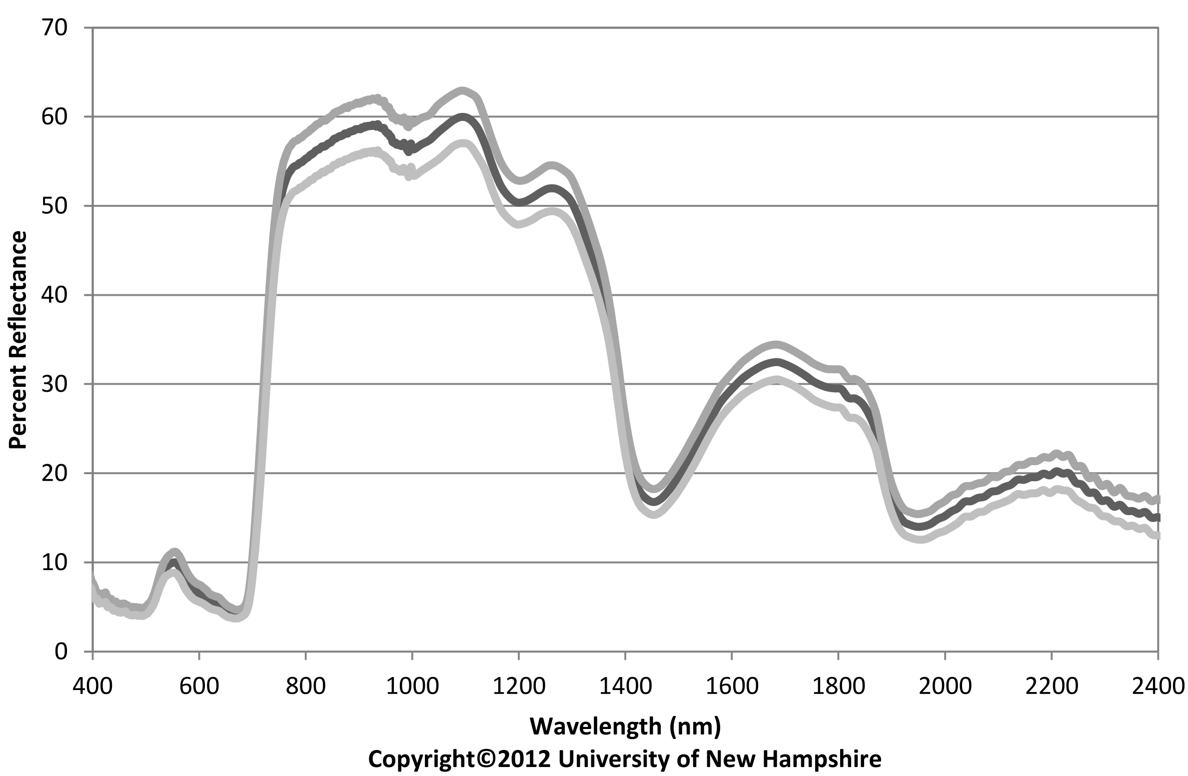
Chapter Five
Spectral Measures of 2011 Needles

Reading Light

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

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

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



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

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

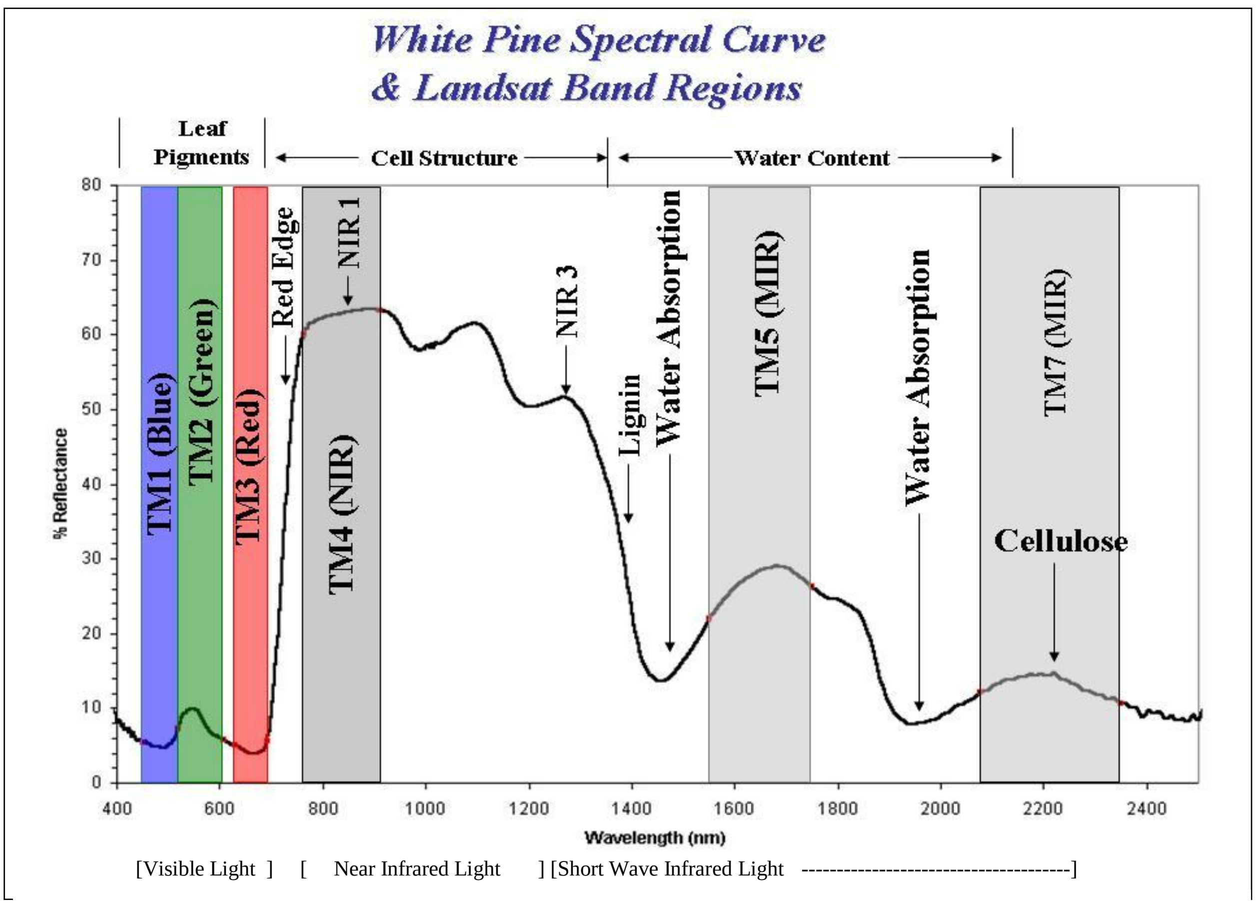


Figure 5.2:shows visible light, near infrared and short wave infrared light. TM bands are identified by number as they are in Landsat imagery sets as well as by the information they provide as to plant conditions.

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

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

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

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

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

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

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

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

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

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

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

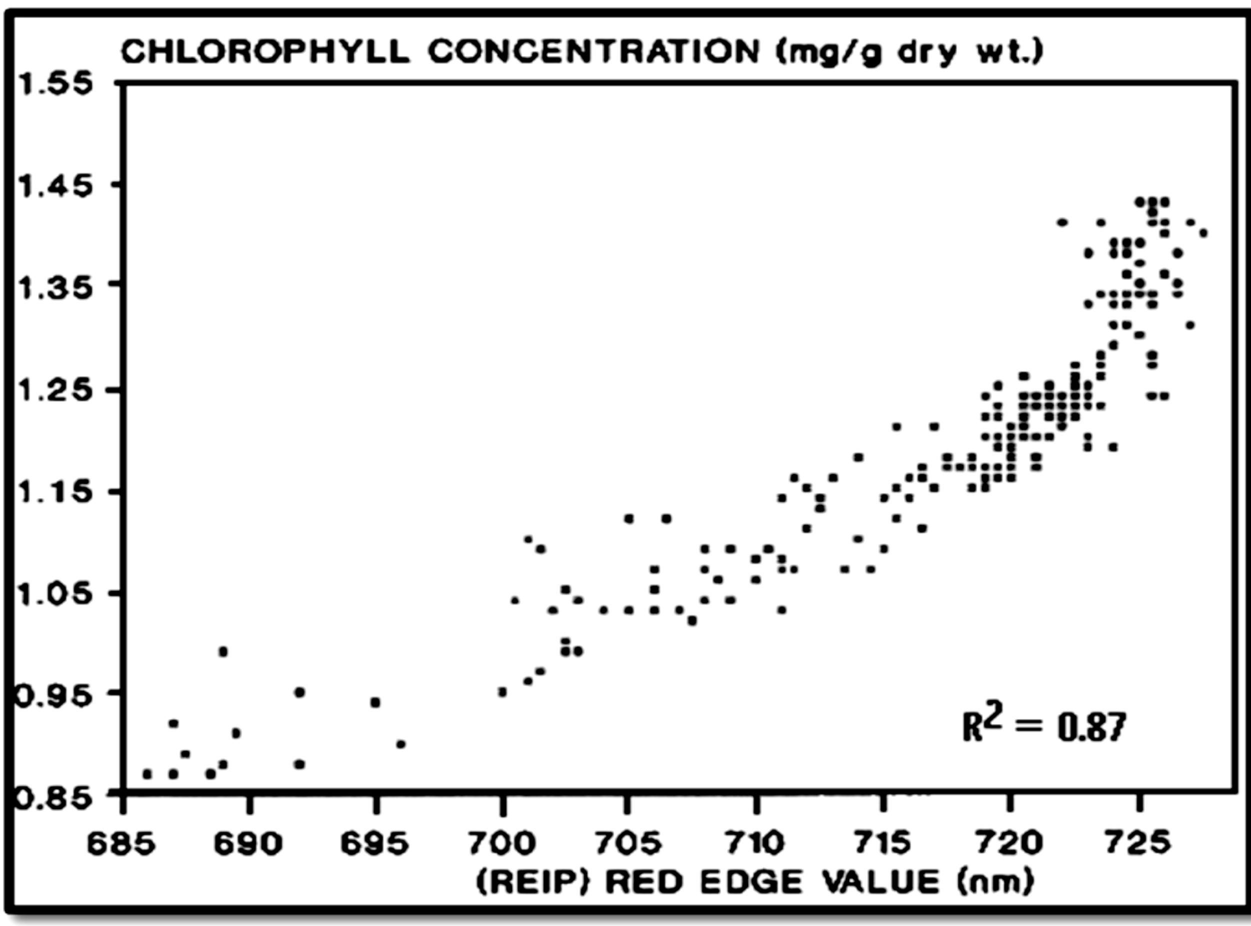


Figure 5.3: A positive correlation between chlorophyll and REIP (Moss & Rock, 1991.)

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

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

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

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

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

Long-Term Spectral Analysis

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

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

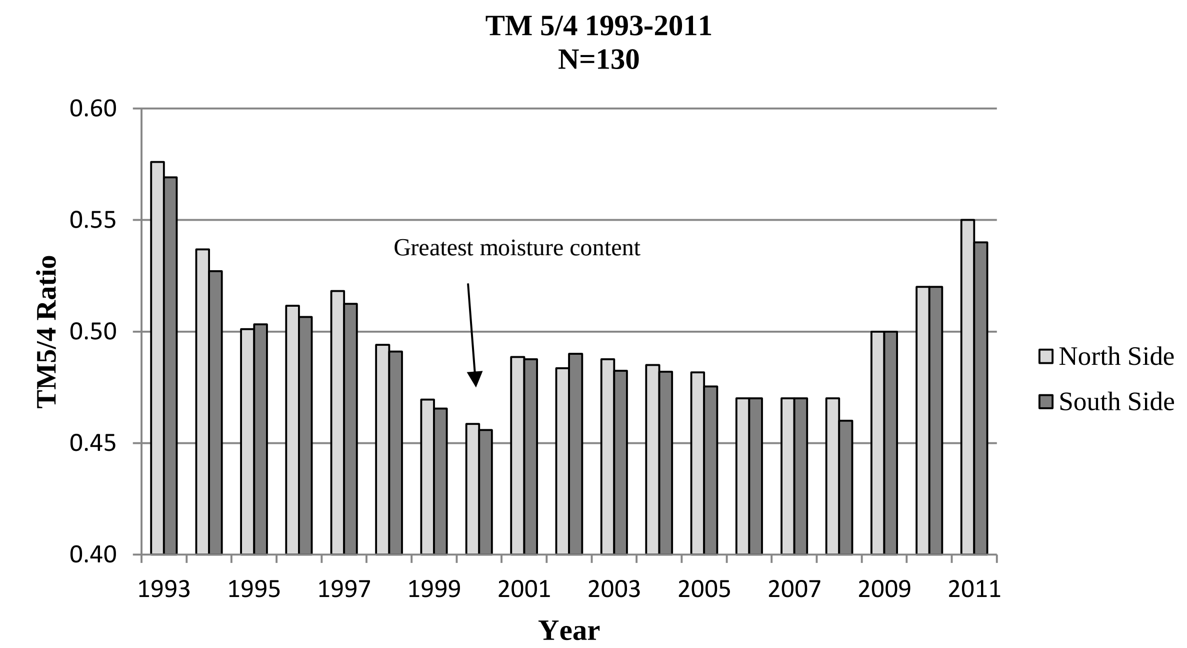


Figure 5.4: Water stress is apparent in the 2011 average TM5/4 ratio. At 0.55, the index is higher than at any time since 1993.

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

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

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

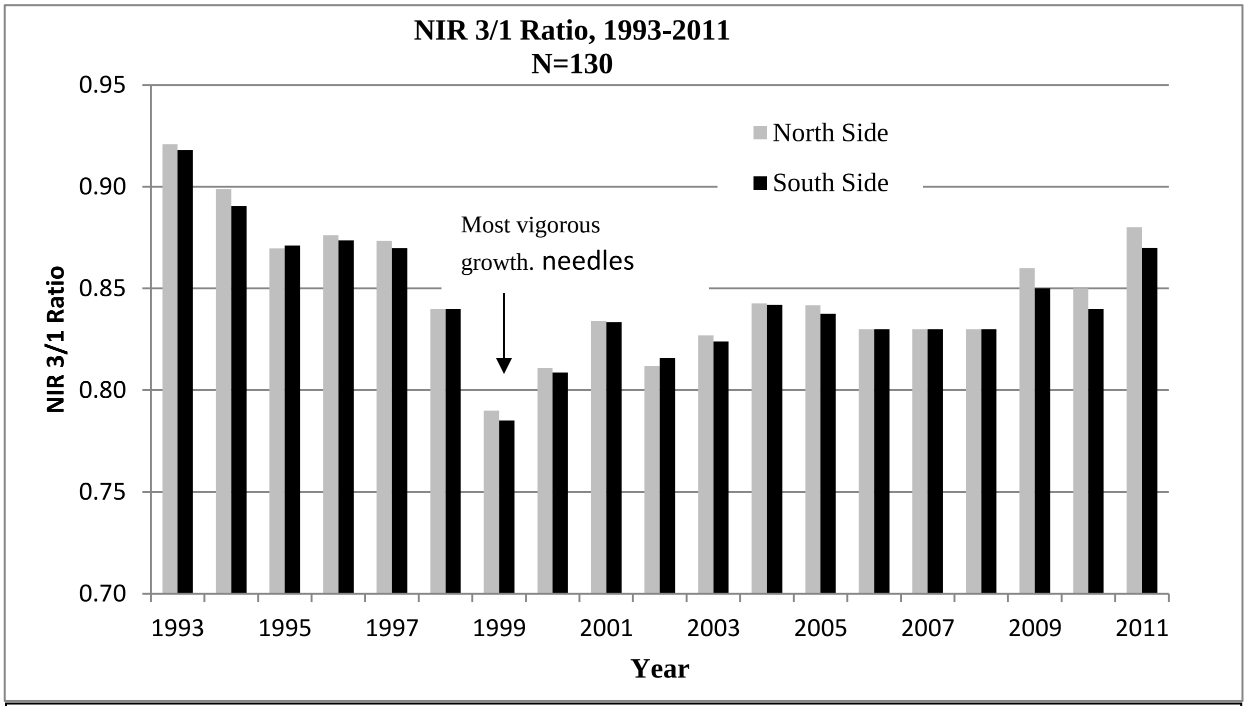


Figure 5.5: NIR 3/1 ratios are an indicator of cell maturity or senescence. 2011 first year needles show unusually high NIR3/1 ratios.

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

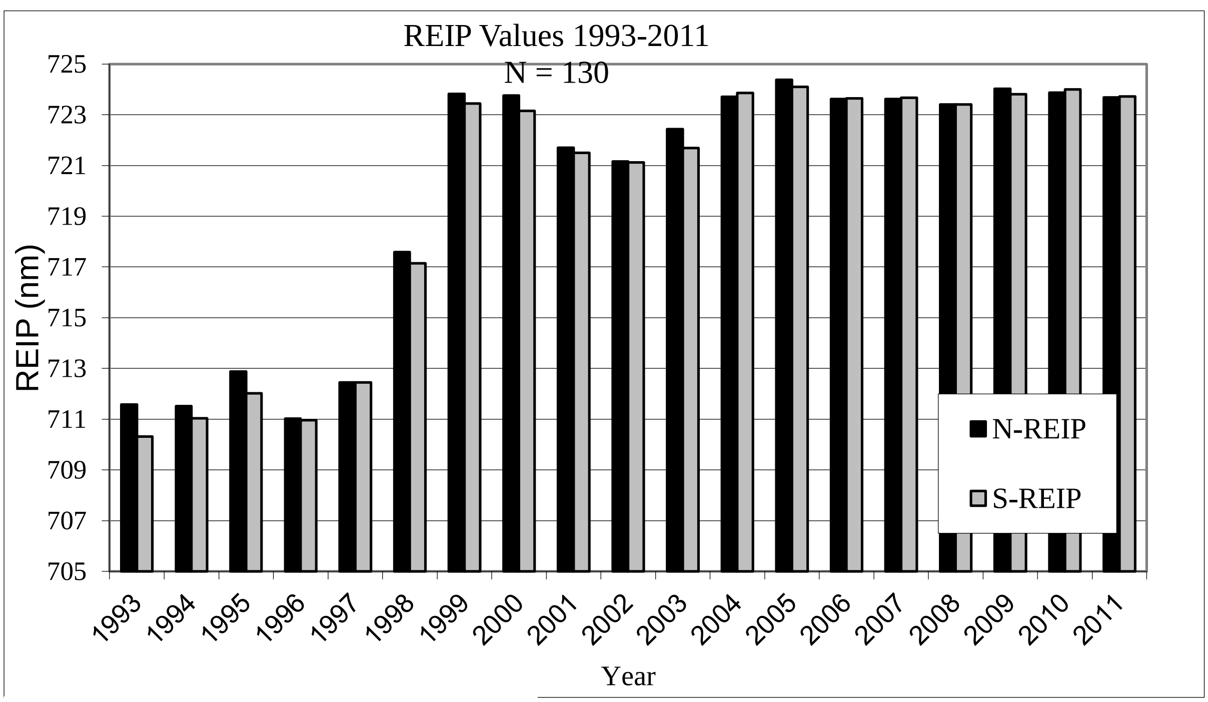


Figure 5.6: REIPs 1993-2001.

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

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

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

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

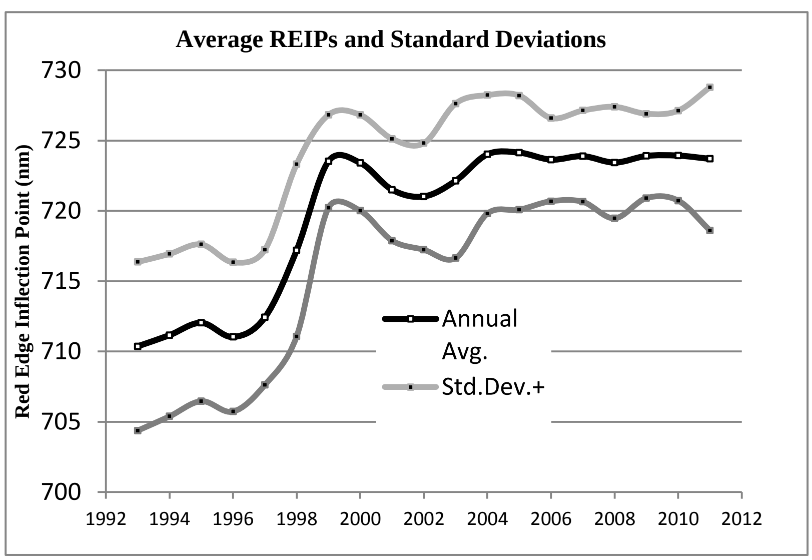


Figure 5.7: Average REIPs and standard deviations + and – show wider variation or greater deviation in stressful years.

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

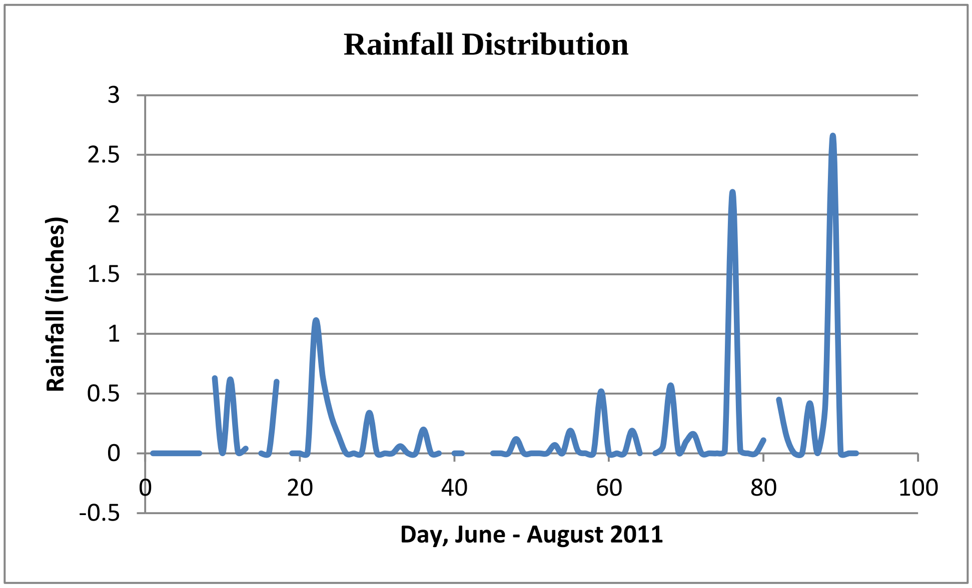


Figure 5.8: Rainfall was unevenly distributed in summer 2011.

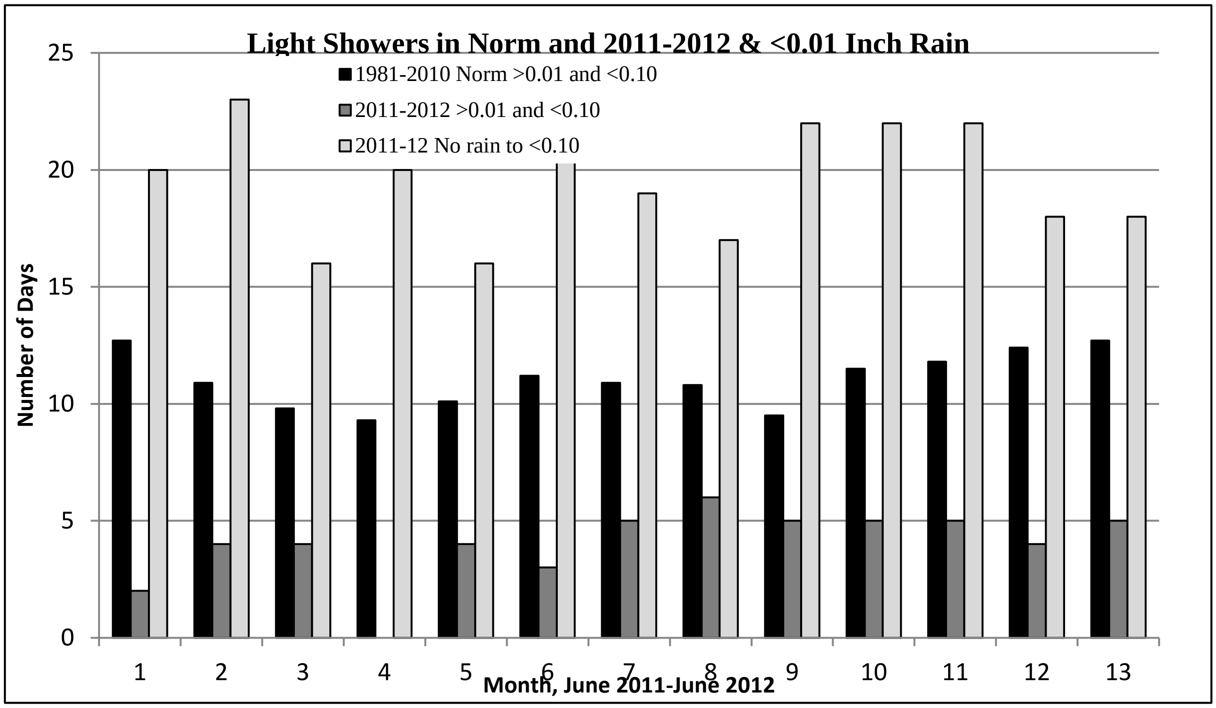


Figure 5.9: Rain in 2011-2012 rarely fell as gentle showers. Black columns show the 30-year norm of the number of days when rainfall is measureable but less than 0.1 inch. About 10 days each month see these light showers, as the norm. The grey bars show the number of days when light showers occurred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

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

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

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

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

References

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

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