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Climate Change at the top: Investigating New England's treeline.

I am standing alone on a car-sized granite boulder, trying to see through the fog that walls off my view a dozen yards away. I feel isolated in a circumscribed world of white cloud and muted grey rock. Condensed water hangs in beads on a low bilberry bush. The wind is buffeting me so hard that I worry about twisting an ankle as I maneuver through this boulder-field, high above the valley. How long would it take someone to find me if I couldn't walk? Plenty of people will climb Katahdin today, but I am off-trail and not near a popular route. Despite its being August, I lose heat quickly and my hands are already creaky with cold. I hold a computer printout of a photograph, which flaps furiously and tries to get a free ride on a gust. I smooth the vital paper against my green pants and look again at the features of Witherle Ravine. There it all was in 1959: the ravine, the fir waves, and the cliffs. When I look up again the clouds have begun to dissipate and I can see farther down-slope. Suddenly I'm blessing the wind as it blows clear my line of sight. Shafts of sun hit the trees and rocks as the whole world reveals itself in sky blue and forest green. For a moment I take in the miraculous sight, and then it's back to work. With a little rock scrambling I am standing in the same spot where the original photographer took this picture nearly fifty years ago. While cloud-shadows flow across the topography like leaves in a stream, I hold my breath, raise my own camera, and take the same picture.

This is just one of the innumerable memories I have from my first summer of field research on the effect of climate change at New England's treelines. I was trying to find out; would a warmer climate mean a shrinking alpine zone?

Given the harsh environment high on New England's mountains, it is rather a wonder that any trees grow at all. Indeed, above a certain height, trees become very sparse as the plant community switches to alpine tundra species only a few inches high. Tree species like Balsam Fir and Black Spruce do persist in scattered clumps, but they are trimmed back by the winter storms and take on a stunted bush-like form. They are called krummholz, a German word meaning "twisted wood". Debate exists as to what causes treeline-the elevation where trees give way to the alpine zone-but we know that different limiting factors are important at different treelines around the world. Climate is the main cause of treelines, specifically short growing seasons. In addition to temperature, other climactic factors fine-tune the location of treelines. In the Northeast, the effects of high winds, rime ice build-up and snow abrasion are thought to be especially important (Marchand 1987; Kimball 2000). It is easy to observe that some locations in the tundra are "safer" than others for trees. A big boulder, for instance, may provide enough shelter in its lee for a fir to establish itself, but the tree will be unable to grow taller than the protection of the rock. There are also non-climate factors that can exert a degree of influence on treelines. These include cliffs (not even the mildest climate will allow a forest to grow on sheer rock), human impact (the effects of recreational impact around huts or hotels) and natural disturbance such as an insect outbreak.

It is an amazing experience to spend time in this environment, especially alone-when the other-worldliness is most

sensible. Krummholz "forests" are like no other woods. Lilliputian in scale, they smell strongly of soil, moss and balsam. Moving through 4-7 ft high krummholz is not easy. Branches that have fought hurricane force winds to get where they are do not easily move aside. The boughs form a tight, almost impenetrable, canopy on the top and sides of a patch of trees, but the inside is dark and relatively clear. When navigating to a research site my strategy is to swim, not fight my way forward. The trees will damage me as much as I damage them if I push too hard. Instead I lean forward and feel for the path of least resistance. I am often reminded of a moment from the children's book "The Lion the Witch and the Wardrobe" (Lewis 1950). The children in the story push past some fir trees and find themselves in a new world. I never know what the inside of a given krummholz forest will be like but I always feel like I am separate from the rest of humanity when I am there. Popping my head above the canopy after an hour or two, I am actually surprised to see that the world is so extensive as to stretch over range after range of mountains! My research has exposed me to new aspects of the mountains and I feel I can appreciate them more deeply than I did before.

I often crawl on my belly, winding past the 3-inch trunks of 70-year-old trees. Having read historical accounts of brave pre-trail hikers (Waterman 1989), I know not to bring extra gear. The trees would grab any loose backpack strap or jacket, and I would not make it through tight spots. Adventure was greater in Victorian times, but I thank my lucky stars to be wearing Labonville pants instead of layers of wet wool skirts as I navigate the "thickets". Krummholz is usually wet. The needles efficiently collect water from the clouds and the sphagnum moss holds moisture exquisitely, making up the bulk of the "soil" these trees live on. In fact, the ground is often a pile of boulders or felsenmeer (sea of rocks) with the thinnest skin of humus above it. I have to move slowly and test each step to avoid putting my foot in a hidden 5 foot hole. Even when I find this frustrating, I know my presence has a purpose.

Between 1906 and 2005, the global temperature rose 1.33˚F (IPCC 2007). sts in many parts of the world are able to grow at higher altitudes than they did a century ago. Scientists believe that the milder climate of today allows trees to grow where only low-growing alpine species could survive previously (Kullman 2002; Roush 2007). Should we expect a rise in treeline in New England also? We do know that there has been a rise in temperature and change in many climatic variables in the last century. Surface temperatures in the northeast have climbed 1.75˚F, even more than the global average. Warming has accelerated in recent decades and winters

have been warming faster than summers (Union of

Concerned Scientists 2006).as already risen in elevation. Today the place where maples and beech give way to spruce and fir is higher up on mountains than it was in the 1960's (Beckage 2008).

For trees that are limited by cold, warmer temperatures, especially longer growing seasons, should make growing easier. It is my goal to find out if trees in New England are growing higher on the mountains than they did 100 years ago.

I first became interested in this topic when I worked as a Naturalist in Appalachian Mountain Club huts in the Presidential Range. I had the precious opportunity then to live above treeline and observe at leisure that most striking of ecological boundaries. When I climbed the Valley Way or Ammonoosuc Ravine Trail I witnessed the changing life forms as I neared the summit. Tall Balsam Firs gave way to stunted krummholz and then to lawn-like sedges and miniature cushion plants. What is it, I wondered, that allows a tree seedling to sprout and proceed to live eighty or a hundred years in one spot, while a few feet away it cannot? The huts were also the first place I heard worries that global warming might cause this treeline to move up. My fascination with the alpine landscape led me to pursue answers in graduate school. At the University of Vermont Botany Department I have the freedom to find a gap in our knowledge of the natural world and try to fill it. I relish this opportunity to contribute to understanding of the environment because it is comprehension that allows us to be good stewards.

I came full circle when I began my research. After some years in the mountains of the western U.S., I came back to New England to follow up on my questions about this landscape. It was wonderful to stay in Madison and Lakes of the Clouds huts again and think back to when I worked there myself. On the practical side, these solid stone buildings provided a safe base camp from which to set out picture-hunting on sunny days or cower in thunderstorms.

I knew that treelines in other regions had risen with temperature and that New England's temperature had climbed. I decided to find out whether our treelines also had risen and I needed a good way to measure change. Other researchers had used repeat historical photography (re-photography) with success (Sturm 2001; Munroe 2003). If you want to see change in a landscape and you have old photographs of it, all you need to do is re-occupy the spot where the first photographer stood and take another picture. Simple photo-pairs of "then and now" allow analysis of things like erosion or human development as well as of vegetation change (for examples see the Landscape Change Program at www.uvm.edu/landscape). Though my focus is treeline elevation, the pictures I have taken tell the story of how the high huts changed shape and size through the years and also how fir waves move up mountain slopes. I can trace the paths of landslides and see how they have filled in with alders over time.

I played historian to find photographs, spending hours in the archives at the University of Vermont and the Appalachian Mountain Club. In their wonderful collections I found photographs, some over 140 years old, taken by amateurs and professionals. People were climbing these mountains and recording the views then as now. It was a joy to see happy outings of snowshoers in wool skirts or proud groups at the summit and know that folks still enjoy the hills that way. Enjoyment of the landscape may be much the same, but I was looking for a change in the forested background of those pictures. The long gone hikers inadvertently recorded information about the state of the mountain at that point in time.

I found pictures of treeline from Mt. Mansfield in Vermont, the White Mountains in New Hampshire, and Katahdin in Maine. Once the snow melted in spring of 2007, I headed for the hills to track down the spots where those hikers had stood decades earlier. For my work I needed to be as exact as possible when relocating images in the field. Field copies of my chosen historical images were my guide, and past summers of hiking helped me to find the right general area to begin looking for the original location. I used the principle of parallax by changing my position until foreground objects, like boulders, lined up correctly with background objects, like summit ridges. The puzzle of finding the exact spot is addictive, something like a scavenger hunt for which I have to scamper from mountain top to mountain top, trying to take advantage of rare clear days.

As a researcher I constantly find my experience in the woods useful. Months of backpacking have taught me how to stay comfortable and safe in severe weather, but I have also gained scientific insight. The more time I spend in forests or on top of mountains, the better a sense I have of how the ecosystems are put together, which plants are most common, and what a "normal" state looks like. My undergraduate mentor, Dr. Joan Edwards, always stressed to me the importance of old-fashioned observation. In this era of remote sensing and computer models (which are excellent tools), it is important still to know an ecosystem on the ground. I think this familiarity provides a base from which to make realistic new hypothesis and interpret data. Each season in the field adds to that foundation.

Field seasons do come to an end, and autumn saw me back in Burlington with piles of photo-pairs to analyze. For every day in the field it seems to take weeks in the lab to process data and try to find the important results. I spent winter days in my university lab studying the photo-pairs while snow drifted down onto brick buildings outside. I may have been sitting in front of a computer all winter, but the images of the mountains in summertime reminded me why I was doing it. I used mapping software to resize digital copies of my new pictures to match the originals. Painstakingly, I searched for fixed objects (like cracks in rock) that I could locate in both images. I linked them

together so that the two pictures overlapped exactly. I then matched the contrast and brightness to accurately compare the extent of tree coverage then and now.
I ended up with about 70 photo pairs that were of high enough resolution to distinguish trees from rocks and tundra. Most of the historical images were taken in the early years of the 20th century. Within each image I studied a slope that had uniform conditions (slope and aspect) and was distant from areas of known human impact. I also excluded landslides and avalanche shoots, which are a constantly changing aspect of steep areas. Zooming in on the area of interest, I flipped back and forth between the old and new image, noting the size of krummholz patches and areas where trees formed continuous canopy. I scored each picture for increase or decrease in tree cover.
Spring is coming again to New England and I am finally able to put some preliminary numbers on the trends I've been seeing in my three northern New England study sites. The more pictures I examine, the clearer the trend becomes. A majority of the 2007 photographs show more trees covering a larger area at treeline than their historical counterparts. Some images show no net change, but many of these are areas where treeline would not be expected to move as readily, such as areas with extremely steep slopes, which are forbidding to tree growth in any climate. Some slopes may also be more or less prone to vegetation change due to aspect. I hope to know soon with further analysis. Increased tree cover after a century of warming is consistent with the hypothesis that warmer temperatures would cause higher treelines in the northeast. However, the complexity of both the causes of treeline and the changes in multiple climatic variables must be considered. As is often the case in science, these results will raise further questions.

With growing season expected to lengthen by 29 to 43 days in the next century (NECIA 2006), we might expect high altitude trees to be able to mature and cold-harden their needles, allowing them to survive more ice abrasion in the winter. Given that annual temperature is expected to increase 5.0 to 9.5°F in the next century, should we expect treeline trees to be able to out-compete tundra plants for space? Alpine areas are effectively small sky islands in New England. If trees are more and more successful and invade into tundra, than the area of alpine zone will shrink ever smaller. Will slowly rising forest be yet another threat for plant species like dwarf cinquefoil, which lives no where else on earth? What will summits look like in another 100 years? It all depends on how trees respond to the changing climate of the northeast and how long it takes them to react. After all, trees are long-lived and slow growing so we expect some lag time in their reaction to change. Predicting the future gets trickier the farther out one tries to calculate, especially when the amount of warming that will occur depends on the gasses humanity decides to emit. Unforeseen circumstances, like the introduction of a devastating exotic insect, may turn the tables and reduce tree cover. Luckily the past is full of clues if we are willing to take the time to look for them. The more we can understand about how treeline has responded to climate in the past, the more we can say about how it will react in the future. The more we know about the ecosystems we love, the better we can care for them.
I've reached the summit of Katahdin on an August day that has become clear and bright, with distant lakes twinkling in the sun. There are through-hikers finishing the Appalachian Trail, day hikers visiting from Europe-a few dozen people enjoying the view of Maine spread out below them like one big picnic blanket. In my mind I see even more people here. For me, the summit is crowded with the presence of climbers from many eras who came before and left records through their photographs. Their clothing looks strange but the expressions on their faces are familiar. At this point in the summer I have begun to realize that the view on which these hikers of the past looked down was different from the one I see today. The forest has been creeping slowly upwards since their time and I am here to investigate that change.

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