Treeline Monitoring in the San Juan Basin Tundra:

A pilot project

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Knowledge to Go Places

Summary of results: The GIS analysis, conducted on a south-facing slope above Deer Creek Park, exhibited a 3-8 m upward movement of base treeline since 1951, and a 12% increase in tree density, at and below treeline, during this same time period. Although treeline had not significantly changed, the rate of growth had increased. The accelerated growth rate was evident in the Krumholtz as well as young trees that were cored. Nearly all of the Krumholtz had bolted, mostly within the last 15 to 50 years. Of the seven cores that we examined, all of them exhibited an increased growth rate after 1996, correlating quite closely with an increase in summer temperatures recorded at the Red Mountain Pass SNOTEL(SNOwpack TELemetry) site. Growing degree days increased 25%, from an average of 404 in 1986-1990 to 512 in 2006-2010. On a 4 acre area, above base treeline, we documented nearly 40 trees that were under 50 years old. Moisture may play an important role in seedling establishment and survivorship as we observed that nearly all the young trees at treeline were generally uphill and very close to the parent tree. The uphill side at the study site is on the north side of the parent tree and probably provides higher moisture due to longer snow cover or reduced desiccation from insolation.

All indicators point towards a changing climate that will support upwards tree movement into the alpine zone. This is an excellent time to set up numerous monitoring sites in the treeline zone as there is a good chance that we will see significant changes in the near future. Understanding when and how change occurs will help managers. We recommend applying the GIS analysis at a larger scale to assess if the observed pattern at Deer Creek Park is repeated in other areas across the San Juans, with special effort to identify different aspects, slope, and latitude. Areas that are relatively easy to access should also include a field component that includes mapping, coring, and photo documentation. Permanent plots in these areas would help assess rate of growth and tree recruitment dates. In summary, although there is little evidence for rapid migration of treeline on the south-facing slope above Deer Creek Park, there is ample evidence that a warming environment is accelerating tree growth and increasing tree density, and conditions may be good for elevated tree recruitment in the near future.

Introduction. The IPCC has said with "high confidence" that mountain ecosystems are among the most vulnerable ecosystems to climate alteration (IPCC 2007). One example of this vulnerability is a projected reduction of areas of mountaintop tundra around the world. For instance, scientists studying the effects of climate change on Rocky Mountain National Park in Colorado, home to the largest expanse of alpine tundra in the United States outside of Alaska, projected that warming of 5.6 degrees Fahrenheit (3.1 C) could cut the park's area of tundra in half and a 9 to 11 degrees Fahrenheit (5-6 C) increase could virtually eliminate it (as cited in Saunders et al. 2008).

Trees and shrubs are likely to start migrating into the alpine zone due to an increase in growing degree days. In general, the concept of growing degree days (GDD) is used as an indication of the average length of the growing season (period during which temperatures are adequate for plant growth) for a particular location. The length of the growing season is particularly important for the alpine and subalpine zones. Alpine areas have the fewest growing degree days, and lowest potential evapotranspiration of any habitat in the San Juans. Prentice et al. (1992) found that alpine treeline is not determined by winter temperatures but rather by summer temperatures that support growth (e.g., treeline corresponds closely to areas with fewer than 350 GDD, 5 ^{0}C base). **Consequently, the distribution of alpine habitats is determined by the paucity of summer days that are warm enough for tree growth rather than the excessively cold winter temperatures.** Other alpine conditions, including lack of soil development, steep slopes, wetlands, wind, and dense turf that restricts seedling establishment may also inhibit tree growth.

Southwestern Colorado has warmed about 1.1 degree Celsius (°C) (2.0 degrees Fahrenheit [°F]) in the last three decades and temperatures are likely to increase by an additional 0.8°C to 1.9°C (1.5°F to 3.5°F) by 2025 and 1.4°C to 3.1°C (2.5°F to 5.5°F) by 2050 (Nydick et al. 2012).

In order to monitor the effects of climate change in the San Juan alpine, the Colorado Natural Heritage Program (CNHP) set up permanent monitoring plots near treeline, the most likely area to notice tree and shrub recruitment. We field checked three sites (Lizard Head Pass, Kendall Mountain, and Deer Creek Park) prior to choosing the Deer Creek Park area near Kendall Mountain and Silverton (Figure 1). In addition to the field work, we conducted a GIS analysis to detect changes in treeline and tree density between the years 1951 and 2011. This report discusses the methods and results of the field monitoring and GIS analysis and describes a scenario to expand this project to more sites within the San Juan Mountains.

In 2012, the CNHP met with Gretchen Fitzgerald at the San Juan National Forest to discuss potential areas to set up a pilot treeline monitoring program. The ideal monitoring site requires minimum travel time to obtain access to gentle and moderate xeric and mesic tundra adjacent to treeline. The Kendall Mountain and Lizard Head Pass areas were field checked to verify if one or both of these sites might be an adequate sampling site. The field checks verified that both of these areas have ideal conditions for setting up permanent treeline monitoring sites, however due to time and resource constraints we chose the Kendall Mountain area to conduct a pilot study. The field monitoring was conducted in September of 2012.

Description of Study Site. The site is a BLM parcel above Silverton in Deer Creek Park, just south of Kendall Mountain. It is a south-facing slope with base treeline between 11,800 and 11,880 feet and the subalpine forest dominated by Engelman Spruce trees (Figure 1). The far western portion of the study site, along a windswept ridge, has many Krumholtz trees that have bolted. Historic mining and sheep grazing occurred in the area and currently there is a four-wheel drive road, maintained by the county, that provides access to the base of the study area. Although historic mining activities included cutting down trees in the Deer Park area, the actual study area was primarily void of this activity.

Methods. Two methods were tested during this pilot study: 1) A **GIS analysis** of the area to detect treeline and tree density changes between 1951 and 2011 and 2) **Detailed mapping** of a 4 acre area that had 36 young trees (under 50 years old) that were found above the 1951 treeline. We estimated age and height of all of them, and measured basal diameter of 15 of them, and cored seven. To estimate tree age, we counted bud scars. In addition to the GIS analysis and tree mapping, we photographed the treeline area with nearly 50 georeferenced photos within the study area. Weather data was accessed from the nearby Red Mountain Pass SNOTEL site (11,200 feet). Growing degree days were calculated from daily temperature data from 1986-2012. Precipitation data for the same years was also downloaded.

For the **GIS analysis** we used a scanned aerial photograph from 1951 (USGS 1951; Figure 2) and a digital composite aerial photograph from 2011 (USDA 2011; Figure 1). Other historic photographs evaluated were from 1945, 1975, and 1978. The photo from 1951 was deemed to have the clearest representation of the treeline of interest, as well as shadows that were reasonably similar to the modern photo.

Methods to identify treeline were based on Kummel et al. (in prep). The two images were smoothed using a focal mean with a 6 m diameter moving window. The smoothed results were then reclassified as either "tree/shadow" or "not tree/shadow" (shadows were indistinguishable from the trees themselves, but the shadows along the treeline itself are from trees and of a reasonably similar size and orientation between the two images). The reclassification cut-off value was initially chosen via Jenks Natural Breaks classification, but then adjusted by visually reviewing how well trees were represented. The cut-off for the 1951 image was 165 (out of theoretical possible of 255), and was 70 for the 2011 image.

USGS 10 m National Elevation Data was used to identify a local mountain peak (un-named) from which we originated virtual transects across the treeline. Straightline 1,500 m transects were drawn radiating from the local peak in 5 degree increments. In this way, all transects travel downhill through the treeline (Figure 3). A point was hand placed along each transect where it first intersects areas identified as "tree/shadow" for the two time periods. These points were then connected into lines representing the treeline at 1951 and 2011. The distance, in meters, from the 1951 point to the 2011 point along each transect was measured (positive if uphill, negative if downhill) and the average calculated. One of the point pairs was considered an outlier, because the large distance between them was an artifact of the exact placement of the transect (if the transect had been shifted even slightly in either direction, the distance would have been less). The average was calculated with and without the outlier.

We then evaluated the density of trees of the forested area downhill of the measured treeline, to the edge of the clipped study area. A focal sum was calculated on the "tree/shadow" reclassified rasters using a 1 acre moving window. The 1951 density raster was then subtracted from the 2011 density raster to evaluate the change in density over time. Additionally, the percentage of "tree/shadow" cells for each time period was calculated.

Once we were in the field, we used a Trimble Yuma tablet to locate each transect and the 1951 and 2011 tree that was observed in the GIS analysis. When it was obvious that the GIS measurements were wrong for either the 1951 or 2011 tree we took a new GPS point and measured the distance between the 1951 and 2011 trees. There were two sources of error from the GIS analysis that we considered on the basis of ground level examination. One was that distortion present in both the 1951 and 2011 photographs created spurious apparent movement of treeline where in reality there was none. Two, some trees were not detected in the GIS analysis, especially in the 1951 aerial photograph due to the lower resolution of the photo; they did not cast enough of a shadow in 1951 to be picked up in the analysis yet when we were on the ground it was clear that the tree that was on the transect was older than 60 years old. For each transect we measured the tree diameter for the 1951 and 2011 tree, above the base, as well as the height of the tree and recorded elevation. If the coordinates were different than the GIS analysis we recorded the new UTM's. For each transect a photo was taken, with direction and time noted.

We mapped and cored two krumholz trees on transect 27 as this area had numerous krumholz trees that had bolted, probably within the last 50 years. The core was taken at the base of the tree; both were at 11,924 feet in elevation.

Mapped Young Trees. In the eastern portion of the study area we located a large south-southwest drainage area that had numerous "young" trees (< 50 years old) above the 1951 treeline, between 11,840 and 12,000 feet (Figures 1 and 4). For this area we mapped 43 trees of which seven were cored near the base to determine the age. For each mapped tree we estimated tree age, using bud scar counts, and collected height. For 15 trees we also noted aspect, diameter at base of tree and recorded elevation. Five representative photo points were taken and UTMs, lens direction, and time were noted.

Results. Figure 5 shows the resulting changes in treeline from 1951 to 2011, including the GIS distance and the field verified distance. The average GIS distance from the 1951 treeline to the 2011 treeline was 8 meters (without outlier, with outlier, average = 13 m, Table 1). Remaining image distortion and shadow variation that we were unable to eliminate may account for up to two thirds of this difference. The average field verified distance was 3 m (Table 1). Therefore, we do not believe that base treeline has changed significantly in the last 60 years. Tree density, however, has increased approximately 12% over this time period (Figure 6, Table 2).

In a 4 acre area between 11,840 feet (base treeline) and 12,000 feet, we mapped 43 trees. Nearly 84% (36) of them were less than 50 years old, sprouting no earlier than 1963 (Table 3, Figure 4). Of the seven cored trees, all of them were less than 51 years old, ranging from 23 to 50 years old (Table 4). If this area fills in and becomes the "new" treeline it will be 160 feet above current base treeline.

Red Mountain Pass SNOTEL data exhibited a significant warming trend since data collection began in the mid 1980's, especially with regard to summer temperatures that were warm enough for tree growth, calculated as growing degree days (Figure 7). In the five year period 1986-1990 growing degree days averaged 412 whereas in 2006-2010the average had increased to 512 (Figure 7). The single year record was set in 2012 which recorded 628 growing degree days. All of the tree cores exhibited an increase in growth rate since 1996 (see Figure 8 for an example). Temperature was a better indicator of growth rate than was precipitation. There was no obvious trend in precipitation during the same time period (Figure 7).

Discussion. Kummel et al. (in prep) conducted a similar but more in-depth and long-term treeline study at Pikes Peak. They found a century-long trend of regional summer warming, a sharp increase of yearly average and spring temperature in the past 30-40 years, and an absence of any linear trend in precipitation. The treeline had advanced 13 m in elevation between 1938 and 2009. The rate accelerated through time and was significantly related to tree growth and average annual temperature. They concluded that average annual temperature strongly influenced tree growth.

The treeline above Deer Creek Park currently resides between 11,800 and 11,880 feet and treeline movement was between 3 to 8 m since 1951 as observed by the GIS analysis and field verification. While treeline had hardly changed since 1951, subalpine tree density increased 12% since 1951. The current treeline is diffuse with numerous scattered trees above base treeline, which may be important since infill is likely to occur if the observed density increase continues. We also observed that the young trees at treeline were routinely 0-5 m uphill (north-side) of a large parent tree, thus supporting the notion that tree recruitment is much more likely to occur near a parent tree rather than a large distance uphill of a parent tree. Nearly all of the observed Krumholtz appear to have bolted within the last 50 years. We mapped 43 trees in a 4 acre area, near but above treeline, where most trees (84%) were less than 50 years old, thereby supporting the idea that growing degree days are adequate for growing trees above the current 11,800 foot treeline in at least one area.

An independent analysis by Dr. Imtiaz Rangwala and Dr. James Miller of observed surface air temperatures from National Weather Service (NWS) and SNOTEL stations in the San Juan Mountain region from 1906 to 2005 found a warming of over 1°C (1.8°F) between 1910 and 2005, mostly occurring after 1993; (Rangwala and Miller 2010). The tree cores from our study had a significant increase in growth rate starting in 1996. While summer temperatures steadily increased, precipitation did not show any consistent trend; 2002 and 2012 were drought years and the growth rate in 2002 was noticeably less than adjacent years, yet 2012 growth was similar to prior non-drought years.

Literature cited

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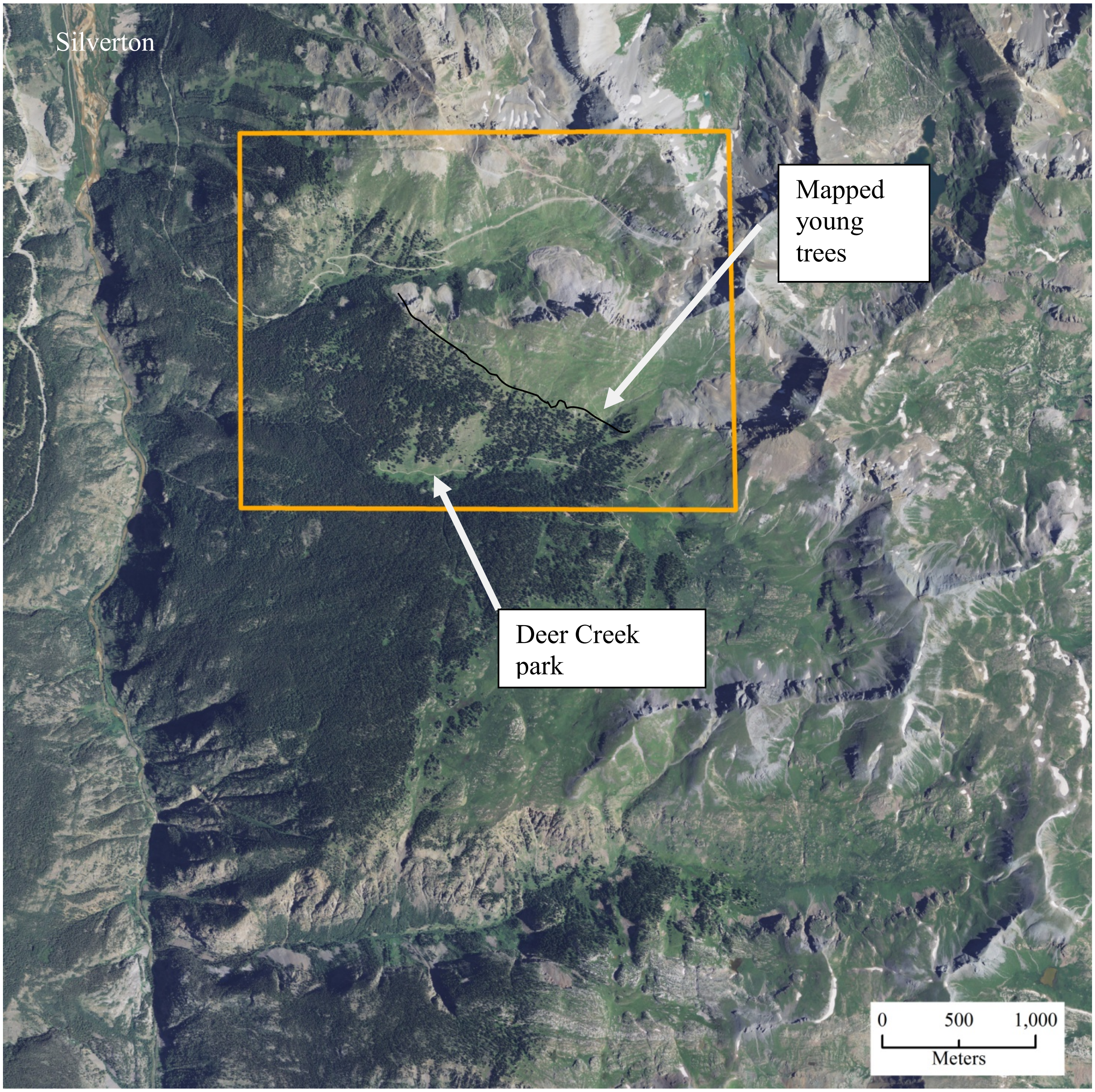

Figure 1. Aerial imagery (year 2011) with the GIS study area shown in orange and treeline area shown by the black line.

Figure 2. Original 1951 aerial image used, before processing (rotated so that north is at the top). The arrow points to the treeline above Deer Creek.

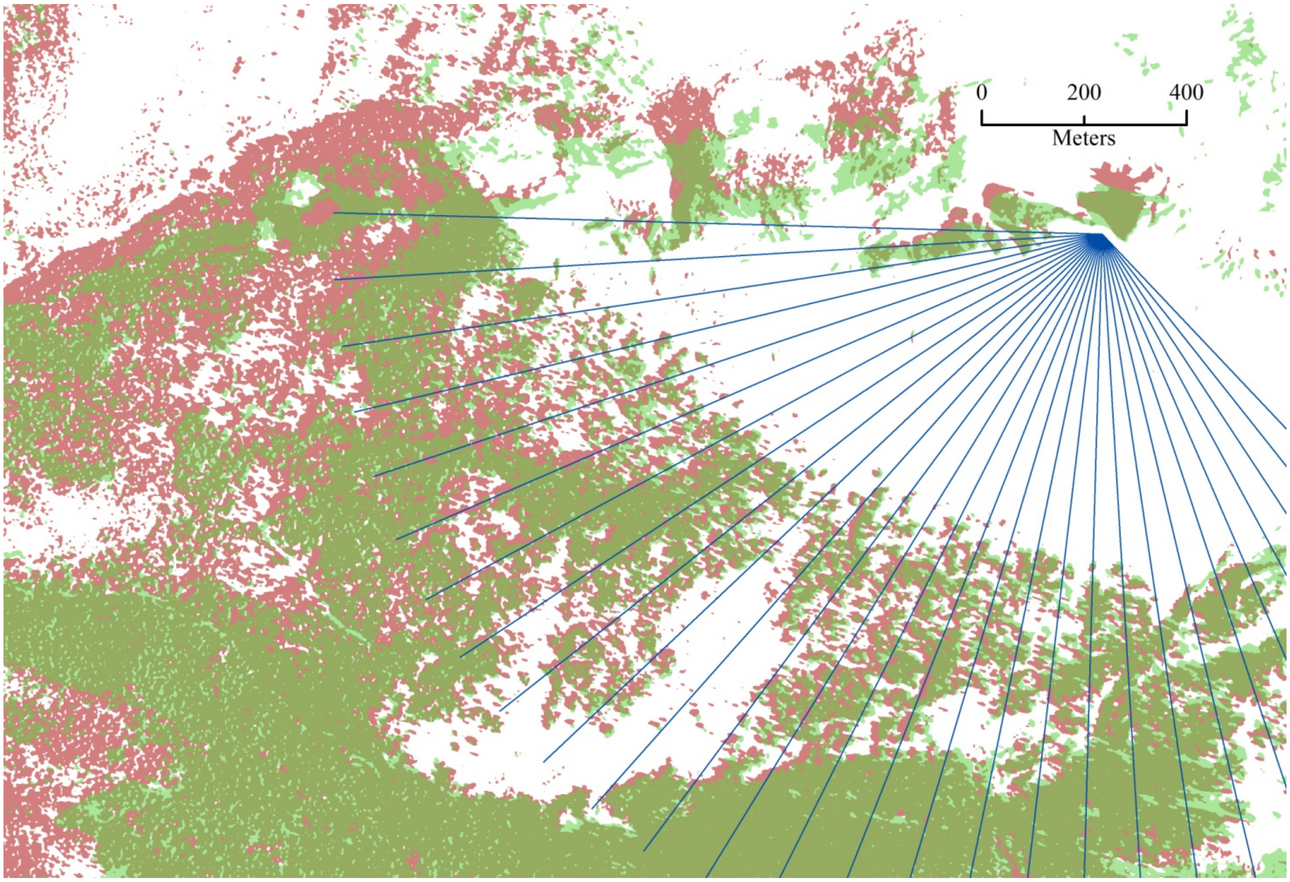

Figure 3. The smoothed and processed datasets shown with overlaid transects. Brown = 2011, green (semi-transparent) = 1951.

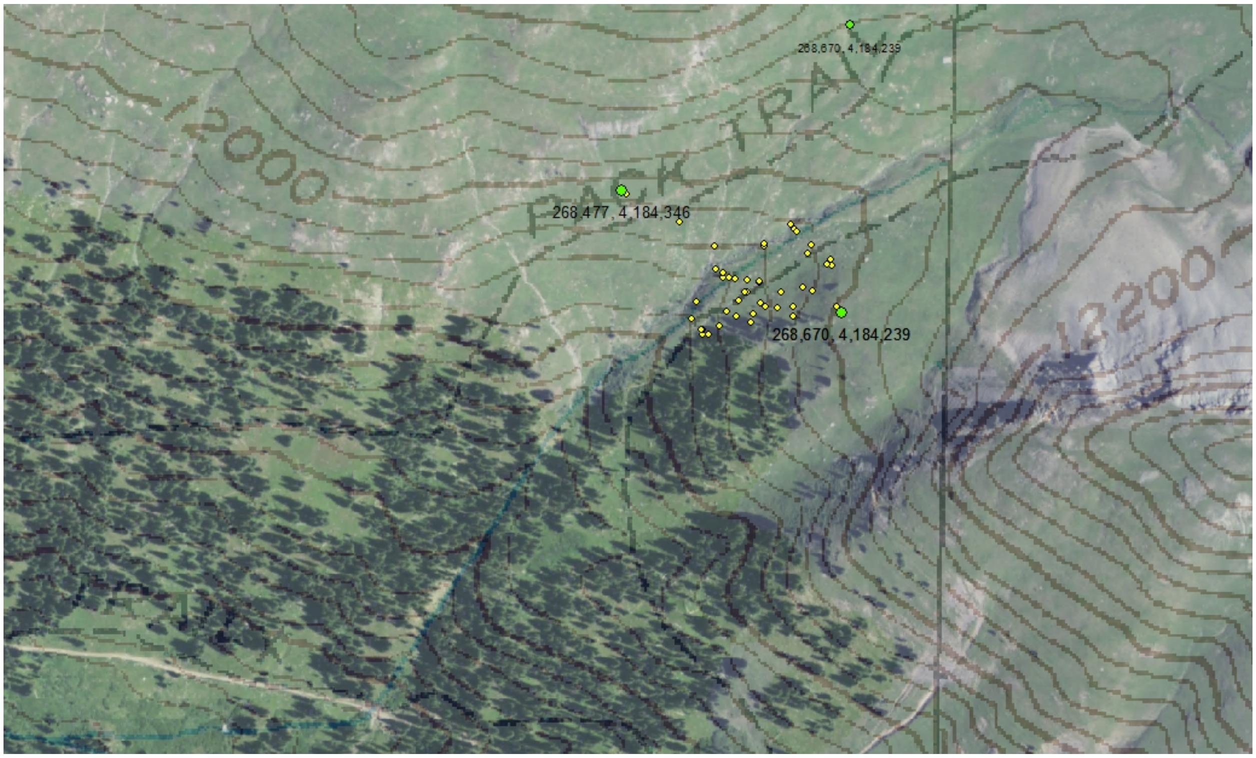

Figure 4. Mapped and aged trees (yellow dots). Nearly all of the mapped trees were under 50 years old. Green dots are permanent photo points.

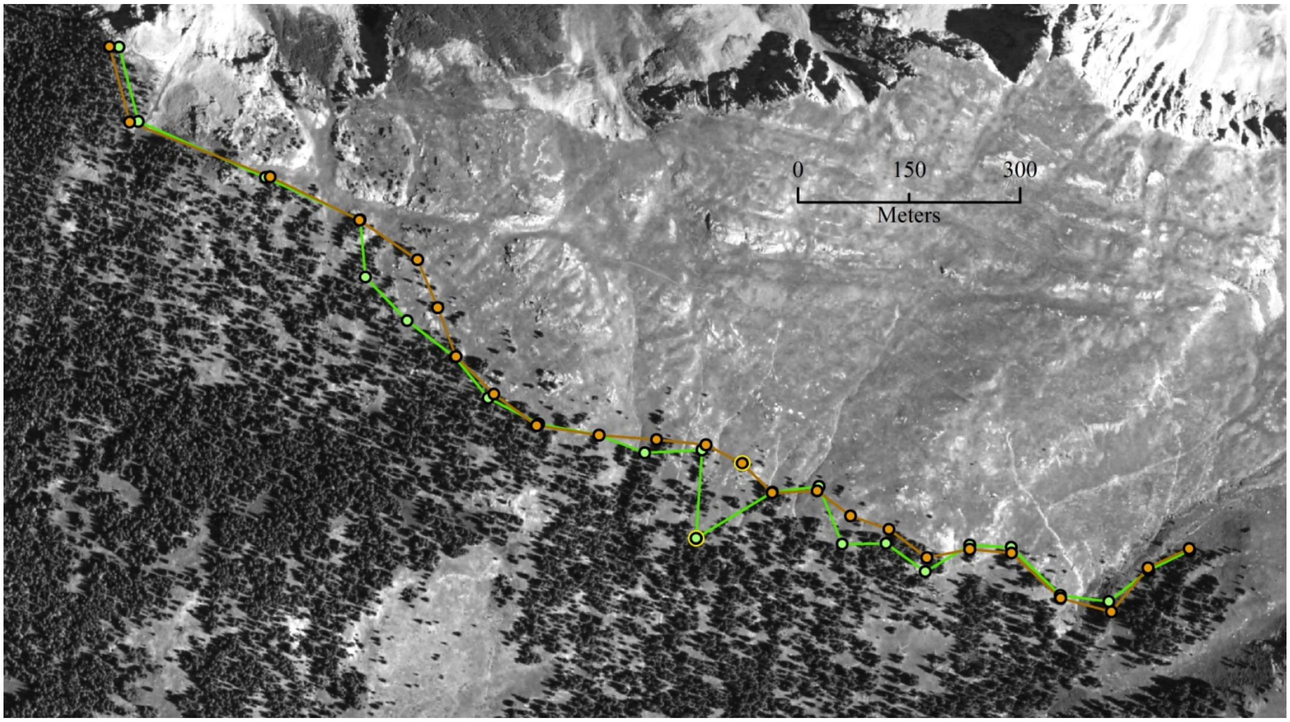

Figure 5. Results of the treeline analysis. Orange = 2011, green = 1951. The points circled in yellow represent the outlier pair. The 2011 converted black and white imagery is used for background.

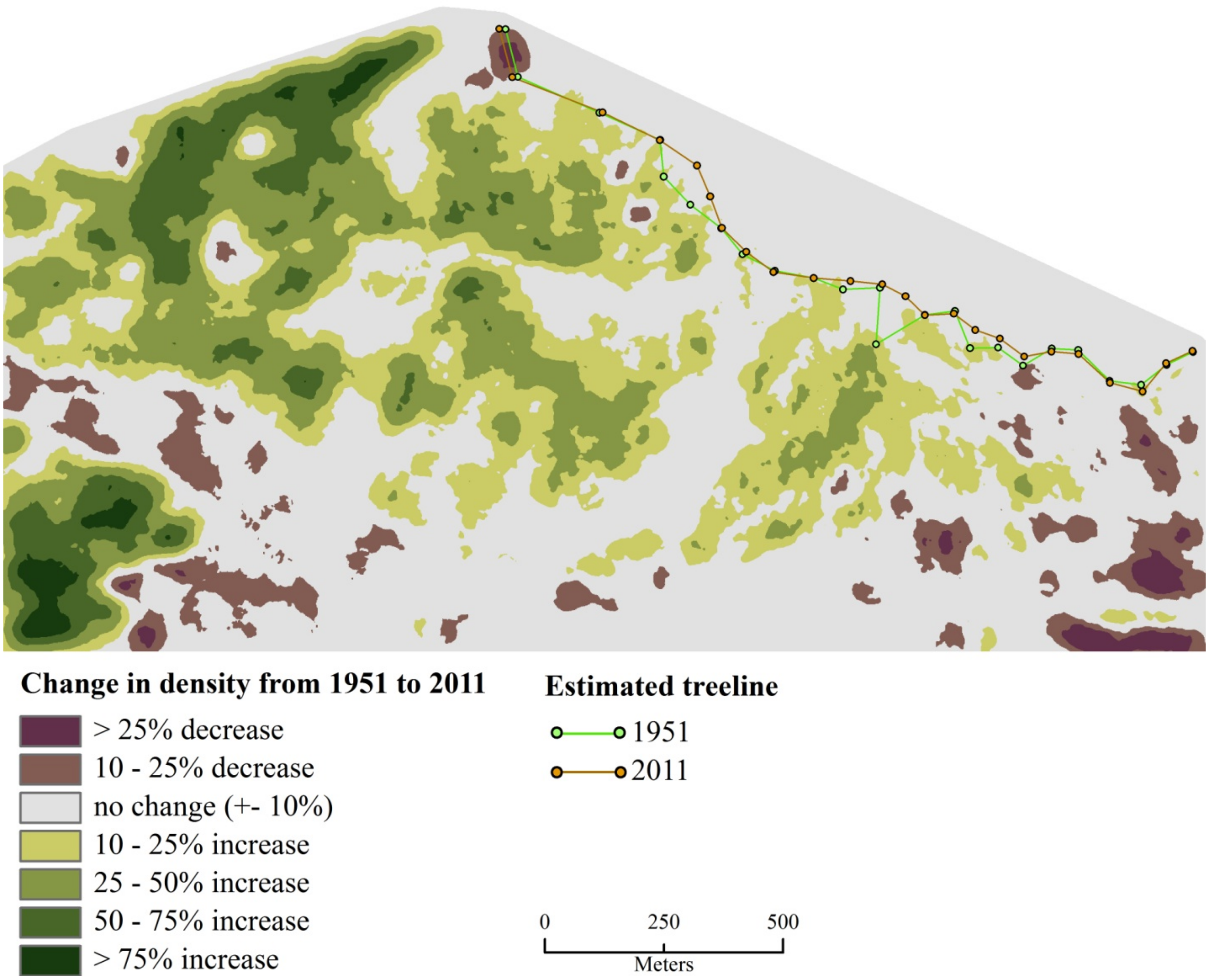

Figure 6. Change in tree density from 1951 to 2011.

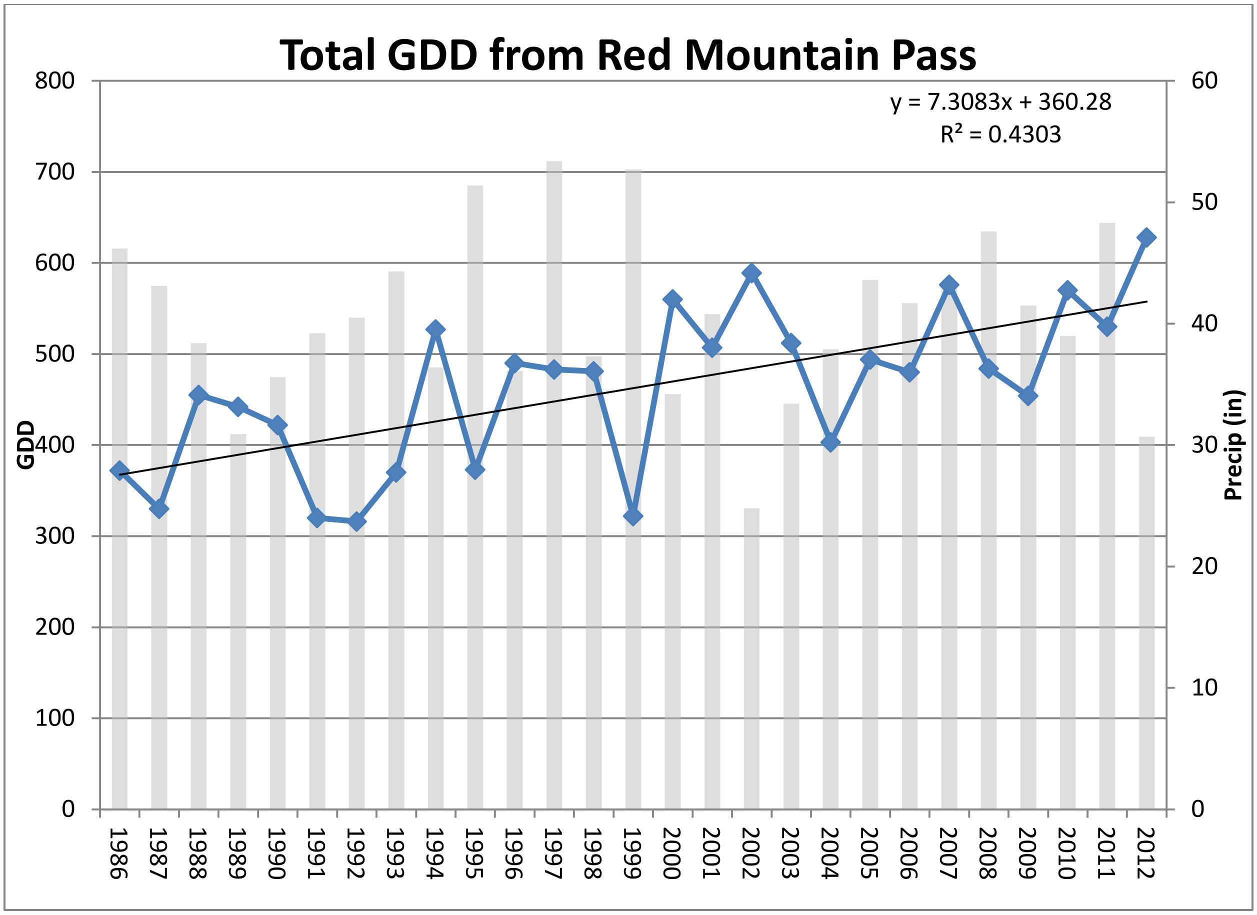

Figure 7. Growing degree days (GDD) and precipitation from the Red Mountain SNOTEL site at 11,200 feet.

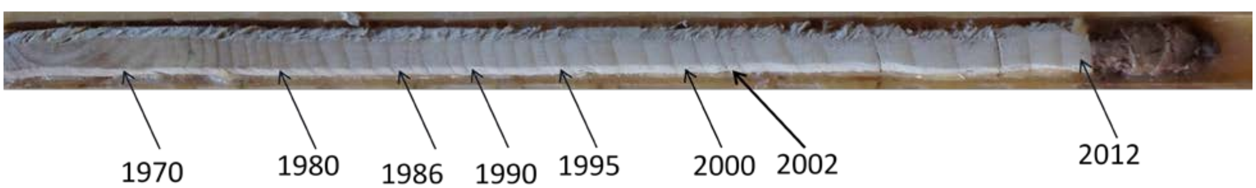

Figure 8. A tree core from 11,930 feet. The bolted Krumholtz tree was 2.8 m tall and 18.1 cm in diameter. The core was taken 28 cm above the point of bolting. Starting in 1996, tree growth increased compared to previous years. This increase correlates with an increase in summer temperatures that were recorded at the Red Mountain SNOTEL site.

Table 1. Treeline point pair distances; positive number indicates uphill change from 1951 to 2011, negative indicates downhill change.

Transect number	distance (meters) between 1951 and 2011 tree	Field Verification Distance
1	-13	Unable to measure
2	-12	5
3	6	0
4	-1	0
5	74	4
6	45	0
7	2	7
8	9	0
9	-4	0
10	0	0
11	24	0
12	9	0
13 *	118	28
14	-1	0
15	6	0
16	40	0
17	19	19
18	19	0
19	-6	0
20	-8	0
21	-4	0
22	-14	14

Transect number	distance (meters) between 1951 and 2011 tree	Field Verification Distance
23	3	0
24	2	0
Average	**8**	**3**

* Outlier pair, removed from mean calculation.

Table 2. Two different measurements of change in tree density from 1951 to 2011.

Percent of pixels in area of interest identified as "tree/shadow"		
1951	**2011**	**difference**
51.8%	64.1%	12.3%
Average density (per acre) of "tree/shadow" pixels in area		
1951	**2011**	**difference**
48.6%	60.3%	11.6%

Table 3. Mapped trees by age category.

Age	Number of trees mapped
≤20yrs old	18
>20≤30	7
>30≤50	11
>50	7

Table 4. Cored trees age (estimated and actual), height, diameter and year established.

Tree number	Estimated age	Actual age	Height	Diameter	Year tree established
3	<30	27	1.08	8.6	1985
4		25	2.05	10.3	1987
6		33	2.15	13.1	1979
7	17	33	0.9	7.0	1979
8	17	23	0.8	3.5	1989
10	20	20	0.7	5.9	1982
11	50	50	2.8	18.1	1963

A view of the mapped young trees.

Cohort of young trees near parent tree. Note that more trees are on the uphill side than downhill side.