

**The Effect of Climate Change on the Germination and Growth Rates of Young
Subalpine Fir (*Abies lasiocarpa*)**

Erica Staaterman^{1,2}

John Harte^{1,3}

¹Rocky Mountain Biological Laboratory, Gothic, CO

²Duke University Department of Biology, Durham, North Carolina, USA

³Energy and Resources Group, University of California at Berkeley

Email: ers16@duke.edu

Abstract.

At the Rocky Mountain Biological Lab in Gothic, Colorado, there has been a change in the timing of snowmelt over the last decade. From 1999-2003, snow melted earlier on average than in 1993-1997. I measured the effect of this climate change on the growth rates and germination success of young subalpine fir (*Abies lasiocarpa*). I estimated annual growth as the distance between branch nodes on the main stem of trees in ten different habitats surrounding RMBL. The growth of trees could be expressed as a function of age multiplied by a function of year, allowing me to eliminate the effect of age and thus determine the effect on growth of temporal climate variability alone. In most habitats, the fir trees responded negatively to earlier snowmelt; germination success also generally declined in recent years. My results imply that under continuing early snowmelt, inhibition of fir recruitment will be pervasive but not ubiquitous.

Introduction.

The Rocky Mountain ecosystems have seen a change in climate in the last five years which may be indicative of future climate under global warming. In particular, snow has melted earlier in the spring in recent years (billy barr). In this high-elevation climate, plants are generally susceptible to changes in the length of their already short growing season (Peterson) and the timing of snowmelt is known to affect the growth of native shrubs and forbs (Harte et al 1995). Less understood is the long-term effect of earlier snowmelt on conifer community structure. My goal is to investigate the effect of the observed trend in the timing of snowmelt on conifer recruitment.

To this end, I have divided the years into five year increments: 1993-1997 and 1999-2003. On average, from 1993-1997 complete snowmelt (measured next to billy barr's house) occurred on the 153rd day of the year, while the average snowmelt date from 1999-2003 was significantly earlier at 134 days. Within these five-year intervals, I examined the growth and germination patterns of the native subalpine fir, *Abies lasiocarpa*, at study sites ranging from 2,956 to 3,230 m in elevation. Because fir seedlings are more abundant than spruce seedlings, and the saplings are easier to age (see Methods), I chose fir as the focal species for this study.

The specific objectives of this experiment were to observe the way climate change has affected the germination success of fir and the growth rate of fir seedlings and saplings. Studies have shown that pines have responded positively to warmer temperatures because of a longer growing season, but firs were not examined (Peterson). Additionally, dendrochronology on high-elevation mature fir and spruce showed no relation to climate change (Kueppers and Harte). Young trees, however, may be more susceptible to climatic changes but have not yet been studied. By examining germination and growth of young fir in a variety of habitats, I was able to determine the site specificity of snowmelt effects on fir recruitment.

Methods and materials.

The study sites were located near the Rocky Mountain Biological Lab, Gothic, Colorado, in Gunnison County (2895 m). To obtain a broad set of data which included the variety of habitats in which fir trees grow, I used 10 different sites, ranging in size from 8 to 150 square meters and 2,956 to 3,230 m in elevation. The characteristics of these sites are explained in figure 6.

The first site, called the “401 trail forest,” was located northeast of Gothic, off of the 401 trail which runs parallel to the Gothic road. This site was inside a mature, nutrient-rich conifer forest located on the west side of the trail, facing Gothic mountain. The aspen2 site was about 45 m south of the 401 forest and was on a steep hill facing W/NW. The “conifer into road” site was located 90 m before the old Virginia mine, on the edge of the old mining road.

The “aspen1” site was located halfway up the Jeep trail, heading towards the 401 trail, on the north side of the road. Close to “aspen1” was the “clearing” site, located directly across the Jeep road. I was interested in determining the importance of shade provided by a dark forest, so I divided the transition area between a forest and a meadow into two adjacent sites. Approximately 100 meters east of the clearing was where these “sunny” and “shaded” sites lay.

“Meadow1” was close to the warming meadow next to the Gothic townsite, in between a conifer forest and an aspen grove. The second meadow site, “meadow2,” was approximately half a mile Northeast of Judd falls, off of the Copper Creek trail. It lay between the river and the trail, on the edge of the conifer forest that was adjacent to the river. Lastly, the “avalanche” site was located on the north side of RMBL, across the east river at the base of Gothic mountain.

To collect data at each of these sites, I used the “internode” method of counting tree age. Fir trees produce one set of lateral branches per year. As the trees age, however, these branches fall off and leave behind a scar on the trunk, or a “node.” The distance between nodes, or the internode, represents the amount the tree grew in a given year. Because young fir trees are too small to core, and I wanted to avoid cutting them down to measure rings, I counted the number of nodes on the trunk of the tree, which represents the total age. This method has been tested several times and has been shown to be as accurate as tree coring for young trees (Aplet et al 1988). I also measured the distance between these whorls to determine how much the tree had added to its height in each year. I ignored the tips of the trees which were still light green because this is the growth for 2004, which will not be complete until autumn.

The two parts of this study were the examination of 1) fir growth rates, and 2) germination success, or the ability of the seed to produce a shoot and establish roots. To determine the germination success, the number of trees that were less than 5 years old was compared to the number of trees between 6 and 11 years old. I hypothesized that if there were fewer trees in the first category than the latter, the seeds must be having difficulty germinating because of the different climatic conditions in the two five-year periods (1993-1997 and 1999-2003).

Fir trees’ growth depends not only on the climatic conditions in a given year, but also their natural growth rate based on their age. Age detrending was necessary to isolate and examine the

effect of climate on the growth rates of fir trees (Perfors et al 2003). I had hoped that the growth of a fir tree would fit the model of a function of age times a function of year:

$$\text{growth} = A(\text{age}) * Y(\text{yr})$$

Because I only wanted to examine the differences between the climate years, it was important to divide out the function of age. For each site I plotted the age of the tree in a given year versus the amount of growth (in cm) added in that year. I then had ten different regressions, one for each year (1993-2003, excluding 1998). The most important step was to determine the degree to which the slopes of these regressions differed from year to year and how to account for this variation. As long as the slopes were similar, I could take the average of the slopes and the intercepts to derive the “age-function,” $A(\text{age})$ for that site. To ensure similarity, I plotted the slopes of $A(\text{age})$ with their standard errors and observed that for almost all of the sites their 95% confidence intervals overlapped. This allowed me to take the average slope, M , and average intercept, B , for a given site. This equation, in the form of $y = Mx + B$, represented the “age function,” $A(\text{age})$, which describes the rate at which the fir trees at that site grow based on their age. This “age-factor” then had to be eliminated in order to determine if climate alone had an effect on the trees’ growth.

Using the average function for a given site, I substituted the age of the tree in a given year for x to get the expected growth. Then the actual growth that was collected (in cm) was divided by this expected growth to get the “age-detrended growth.” In this step, I started with:

$$\text{actual growth} = A(\text{age}) * Y(\text{yr})$$

$$\text{and divided: } \text{actual growth} / A(\text{age}) = Y(\text{year}).$$

In this equation, Y represents the age-detrended growth of a given tree in a given year regardless of its age. I was then left with this number which represented age-detrended growth for each year that the tree was alive.

Then, for each tree, I took the average of this age-detrended growth from 1999-2003 and 1993-1997. I wanted to know if the difference between these means was significantly different from zero, so I subtracted the 1993-1997 value from the 1999-2003 value. If this number was less than zero, I would know that the growth had decreased in recent years and visa versa. To test the statistical significance of this difference, I used a paired t-test.

Results.

The first step of data analysis showed that fir trees' natural growth throughout their lifetime is linear in age. The functions representing $A(\text{age})$ showed that the trees grow slower at the beginning of their lives. For all of the sites I was thus able to age-detrend as described above. Once I eliminated the age factor, I saw that there was a significant difference between the age-detrended growth from 1993-1997 and 1999-2003 for almost all of the sites. The difference between these means for all of the sites, with the exception of the avalanche and shaded edge, showed a significant ($p < .01$) difference from zero. Almost all of the sites' differences were negative, representing less growth in recent years. The trees at the road site and Aspen2 site, however, showed significant increases in their growth from 1993-1997 to 1999-2003.

For the germination study, there was a general trend of less germination in recent years, but there was a high degree of variation in age distribution between sites. There were very few trees less than five years old in the two aspen groves and the clearing on the hill. In the 401 forest and the meadow2 site, however, there were more trees that were less than five years old than those that were between 6-11 years old (figures 4 & 5). A reason for this discrepancy could be explained by the fact that some trees died after they had reached the age of five, which would mean that they had successfully germinated but did not survive.

Discussion.

Soil moisture is crucial for the establishment of firs, so I hypothesized that young seedlings may have more trouble germinating and surviving in drier conditions. As a result of earlier snowmelt, I would expect to see fewer trees under five years old than 6-11 years old. Although at seven out of ten sites there has been this expected decline in germination success, there was also a large degree of variability amongst sites. It is possible that many 6-11 year olds may have died after their first five years of growth, which explains why at some sites the number of very young trees is greater than the number of 6-11 year olds. This possibility is still important because it means that there is something that has been preventing the trees from surviving past the age of five.

The growth rate study generally showed a significant decline in the growth during recent years, but not for every site. Most of the t-values are significantly negative, meaning that the difference in the average growth during the earlier time period was significantly greater than the growth in the later time period. The increased length of the growing season, then, does not appear to be helping the trees grow more per year, but rather the earlier snowmelt is inhibiting the growth of fir trees.

Each site provided a unique set of results which is shown in figure 6. Although the general trend is that these trees have been growing less per year in the recent years, not all sites fit this trend. The two main outliers are the road site and the Aspen2 site. Perhaps these sites have a later snowmelt date than the other sites and the extra moisture later in the season has allowed for these trees to grow more than expected. Another factor that could explain the extra growth at the road site is that it lies close to an old mine. The runoff from the mine may be mineral-rich and could actually be helping these trees grow faster rather than harming them. Further study is needed to better explain these results.

The clearing site, which is south-east facing, has had a decline in growth rates and a drastic decline in germination success. There weren't any trees that were less than five years old at this site. At the other east-facing sites, the Northeast sunny and shaded edges of a neighboring meadow, there were also drastic decreases in the germination success in recent years. Perhaps trees facing this aspect are more susceptible to drought and germination failure. Consistent with this result, at some of the sites that were facing West the trees grew more in recent years. The trees in both the road and the aspen2 sites, which faced NW and W, respectively, experienced more growth from 1999-2003.

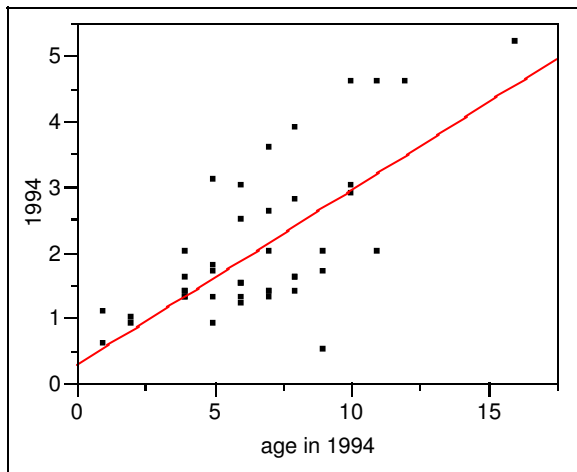
Overall, in recent years characterized by a significantly earlier snowmelt date, fewer fir trees have germinated and fir tree growth rates have decreased. These trends are clear from my data, but more information would make this study more complete. A further study should include soil data, including moisture and nutrients. It would be important to have information about which specific sites experience earlier snowmelt than others. Examining genetic information of the trees at different sites could also yield information that better explains the variation in growth at different sites.

Tables and Graphs.

Figure 1.

Aspen1 site, correlation between age of the tree in 1994 and the amount the trees grew in 1994. Older trees have grown faster than younger trees.

Bivariate Fit of 1994 By age in 1994



$$\text{Growth in 1994} = 0.296 + 0.267 * \text{age in 1994}$$

$$R^2 = .479$$

Figure 2. Each point represents the slope of the regression (see figure1) for the given year. The standard error bars are included to show that there is 95% confidence in the overlap between slopes.

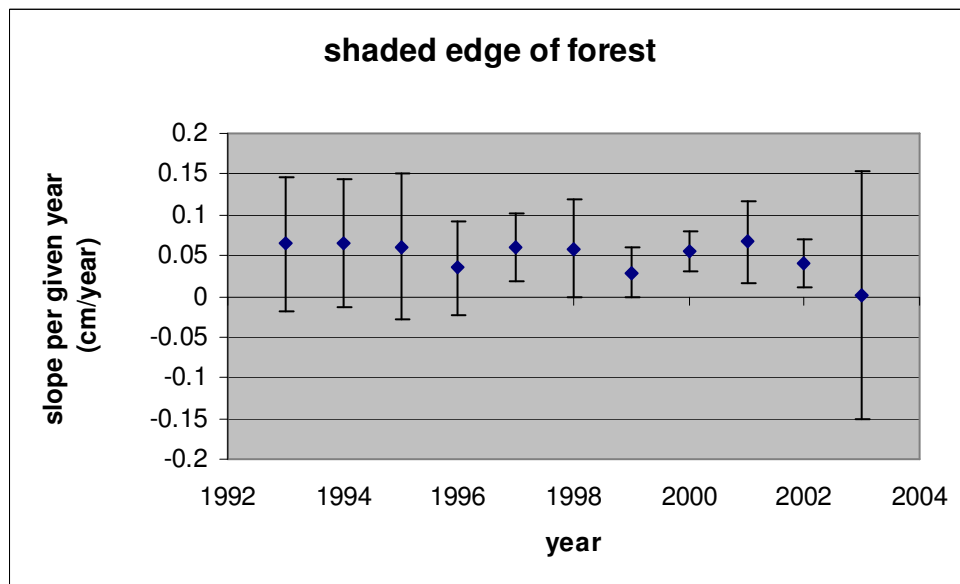
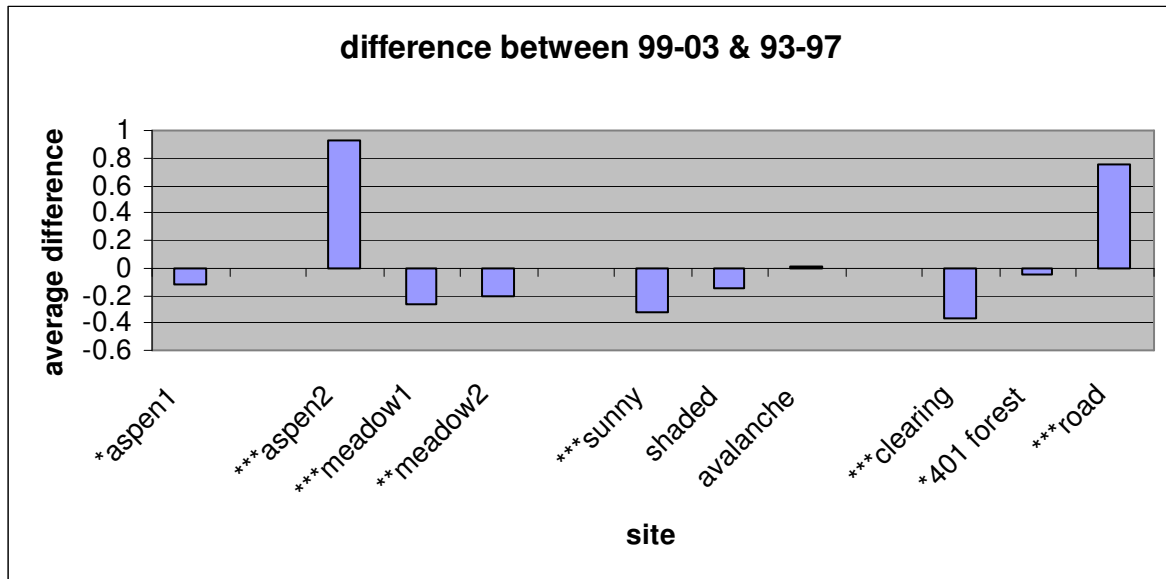


Figure 3. difference in growth from 93-97 and 99-03. Negative numbers represent a decrease in growth in the more recent years.



- * P < .05
- ** p < .01
- *** p < .001

Figure 4. The mean growth compared against the two time periods for each site. In general, there was less absolute growth from 1999-2003 than for 1993-1997.

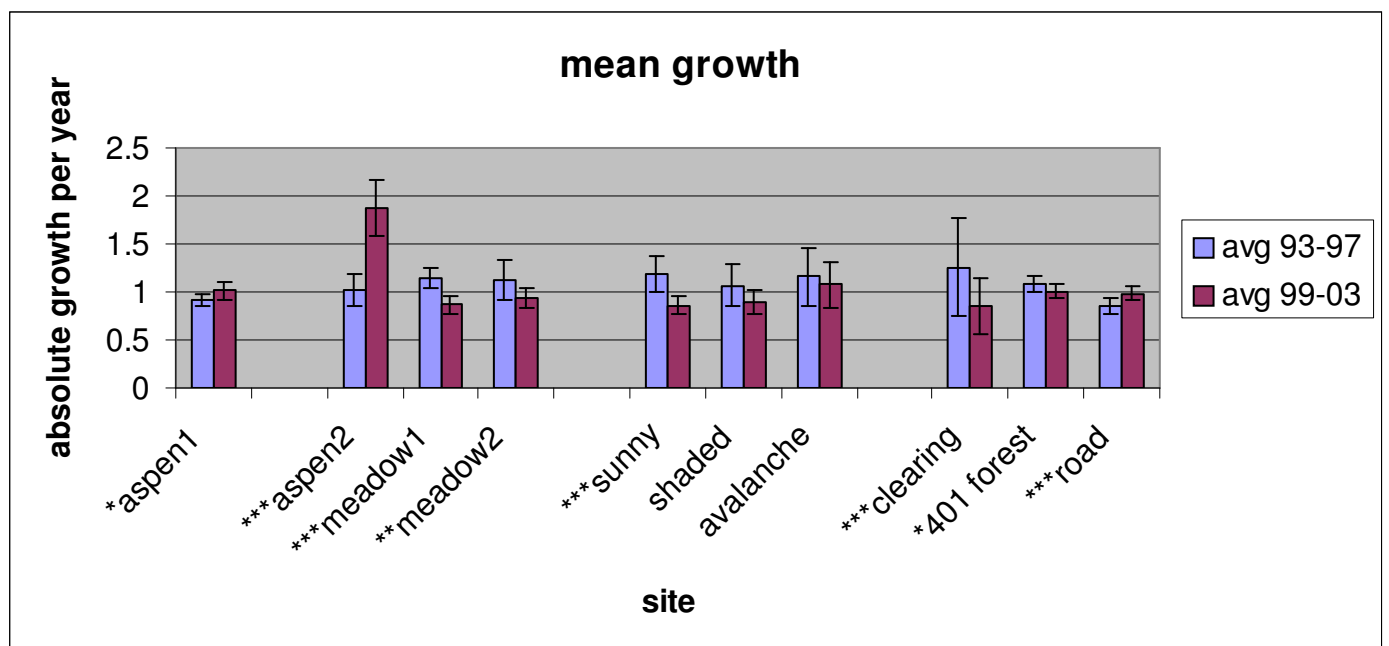


Figure 5. age distribution in the first aspen grove and in the 401 forest.

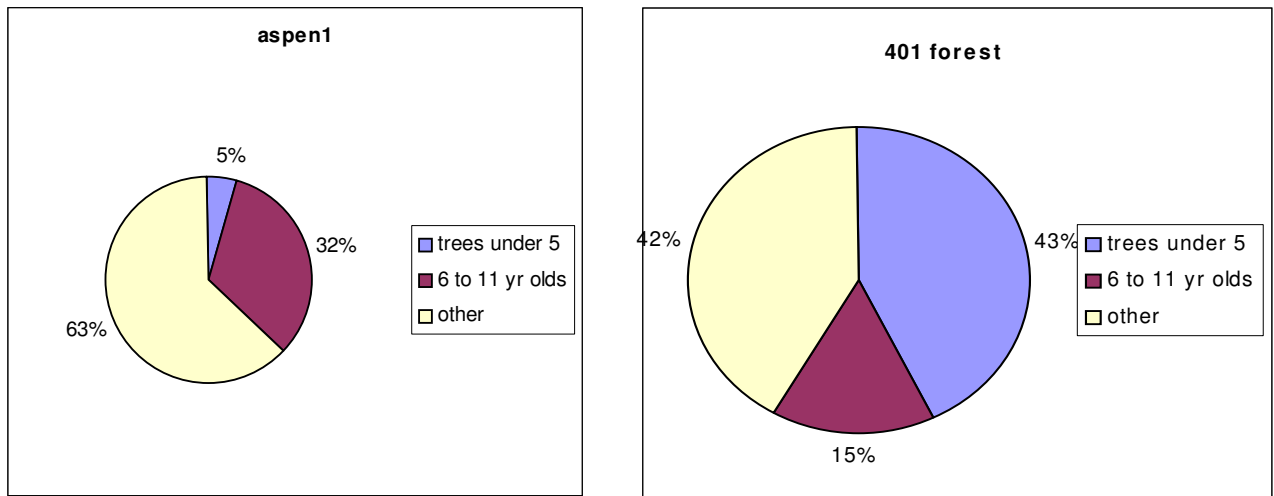


Table 1. Summary of variables at sites.

Site	Meadow 1	Meadow 2	road	Aspen1	Aspen2	avalanche	clearing	401 forest	sunny	shaded
Soil moisture	moist	Very moist	Moist	Very moist	medium	Dry	medium	medium	Dry	medium
Aspect	N	N	NW	NW open	W	N Open	SE	N/NW	NE	NE
sunlight	Fairly open	Shaded on 2 sides	shaded on one side	More shaded	More open, patches	Shaded on 1 side	Shaded on 1 side patchy	dark	Shaded on one side	Sunny on one side
Rocky soil?	no	no	yes	no	yes	no	yes	no	Yes	yes
Elevation ft	9500	10000	10600	9920	10000	9700	9920	10000	9920	9920
% under5	25	58	27	5	2	39	0	43	9	4
% 6-11 years old	48	25	64	32	8	17	19	15	30	33
p-value	.0005	.0025	.005	.01	.0005	Not sig.	.001	.05	.0005	.1
T-value	-5.824	-3.21	2.163	-2.521	8.53	0.129	-3.66	-1.767	-6.086	-1.350
Slope age function	.150	.0482	.052	.183	.0546	.261	.0802	.027	.0911	.0489
St. error on slope	0.0020	0.0012	0.002	0.016	0.0022	0.005	0.0040	0.0004	0.003	0.0055
intercept	.427	.408	.648	.655	1.31	.740	.754	.588	.426	.728
St. error on intercept	0.0612	0.034	0.049	0.089	0.146	0.172	0.103	0.052	0.048	0.079
R²	.41	.32	.35	.35	.07	.23	.08	.18	.26	.18
R² min	.3	.3	.08	.13	.001	.08	.01	.08	.18	.00026
R² max	.55	.46	.58	.48	.17	.39	.33	.25	.39	.48
Area of site m²	45	28	150	40	30	10	8	80	30	30
# trees (n) w/data	75	71	65	61	59	25	27	75	60	24
# trees counted	100	165	89	65	60	41	27	131	66	25
Density <5	.556	3.39	.16	.075	.033	1.6	0	.7	.2	.033
Density age 6-11	1.067	1.5	.033	.525	.167	2.1	.625	.25	.667	.267
density	2.22	5.89	.593	1.63	1.97	4.1	3.38	1.63	2.2	.8

Caption:

- R² is average R² from the regressions for each years at each site
- The number of trees with data are the trees for which I could read the distance between nodes. There were some trees that were so small that I could not collect data, but I counted them in the “under five years old” category.
- Density is number of trees per square meter. The last density row represents the total number of trees counted divided by the total area.
- the soil moisture was a vague estimate, in further studies the moisture should be examined more accurately

Literature cited:

- (1) Aplet, Gregory and Laven, Richard, and Smith, Frederick. 1988. Patterns of Community dynamics in Colorado engelmann spruce-subalpine fir forests. *Ecology* 69: 312-319.
- (2) billy barr, unpublished data collected at the Rocky Mountain Biological Lab.
- (3): Harte, John and Shaw, Rebecca. 1995. Shifting Dominance Within a Montane Vegetation Community: Results of a Climate-Warming Experiment. *Science* 267: 876-880.
- (4) Kueppers and Harte, unpublished data
- (5) Perfors, Tracy, Alter, S.E., and Harte, John. 2003. Enhanced Growth of Sagebrush (*Artemesia tridentata*) in Response to Manipulated Ecosystem Warming. *Global Change Biology* 9: 736-742.
- (6) Peterson, David. Subalpine Forests of Western North America. National Biological Service. <http://biology.usgs.gov>
- (7) Oosting, Henry and Reed, John. 1952. Virgin Spruce-Fir forest in the Medicine Bow Mountains, Wyoming. *Ecological Monographs*, 22: 69-91.