

**Summary and analysis of vegetation data from Denali long term
ecological monitoring program permanent plots, 1992-1998**

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I. Introduction

The vegetation element of the Denali long term ecological monitoring program was originally designed to monitor the effects of climate change on the the position of the forest-tundra ecotone and to discern concomitant changes in the community structure of three major vegetation types occurring in the northern part of the Park (spruce forest, treeline spruce-birch scrub woodland, and alpine tundra). The initial effort thus established permanent monitoring sites along an elevation gradient, with a site located in each of these three vegetation types. Secondly, a riparian zone site (willow-alder thicket) was added to the study. At each site, the initial structure and composition of the tree, shrub and herbaceous strata were documented to provide baseline data for comparison in future years. A principal objective of the project was to measure differences in white spruce (*Picea glauca*) growth and reproduction in different landscape positions over time and relate trends in these parameters to changes in the position of treeline on the landscape. This monitoring program was intended to help park managers document and anticipate the direction and trajectory of major changes in ecosystems fundamental to Park resources that are expected to occur in the coming decades as a result of climate change.

Permanent vegetation plots were established at four sites in the Rock Creek watershed near Denali National Park headquarters during the years 1992-4 (forest, treeline, tundra and riparian). The measurements recorded at the installation of these permanent plots were extensive; they included mapping, tagging and measuring of all trees present, placement of twelve 1 M² cover quadrats for herbaceous vegetation and twelve 4 M² quadrats for shrub cover at each replicate plot. In addition, permanent photo points were established, dendrometers were installed to quantify yearly white spruce growth and seed traps were put in place to quantify yearly seed rain within the plots. Numerous parameters have been recorded yearly in these plots, including spruce growth and reproduction, berry productivity, and phenology. A full description of the objectives, study-design, and methods and materials, of this study are provided in the vegetation monitoring protocol document (Densmore 1997).

The considerable time and effort required for the establishment, maintenance and collection of data from the Rock Creek vegetation plots represents a substantial investment by Park staff. However, much of the information collected during the course of this project has not been summarized or analyzed. As a result, it has not been available to those who might use it (such as Park managers and other researchers). The purpose of this report is to summarize and distill the field data that has been collected in the Rock Creek vegetation plots. In addition, I present some analysis and interpretation of the data and study design. The objectives of this set of analyses are twofold: to help make this information more accessible to all concerned and to evaluate the efficacy and appropriateness of the designs of these experiments.

An important aspect of this project is its compatibility with the research at Bonanza Creek Experimental Forest outside Fairbanks. For this reason, I have compared our data with those from Bonanza Creek, where possible. Bonanza

Creek data was retrieved from the Bonanza Creek LTER website and obtained from researchers there.

Organization of this report

This report is organized into separate sections corresponding to the individual parameters that have been measured during this study. The results for each parameter are presented, followed by a discussion of those results and finally comments on the study design and recommendations for future work. There are two broad classes of parameters included in this study, those that are monitored yearly and those monitored at intervals of ten years. Accordingly, the aforementioned sections are grouped together based on their monitoring frequency.

A general note on sampling design

There are three replicate plots at each site in this study, which represents the number of independent samples ($n=3$) for the estimation of population parameters (mean, standard deviation, and others). The mean value for any parameter for a site, then, is the mean of these three plot means. There are four separate vegetation study sites that are currently monitored as part of the Denali long term ecological monitoring program: the three initial sites established along an elevation gradient, **Forest**, **Treeline** and **Tundra**. The fourth site is **Riparian**, which is an additional site established in the floodplain of Rock Creek, above the forest site).

II. Temperature, Precipitation and selected climate indices for the period 1992- 1998

The design of this monitoring program rests on the reasonable assumption that climate is an important driving variable in the ecosystem, and that differences in climate variables result in measurable variation in the vegetation parameters that are monitored. Therefore, it is critical to examine variation in climatic parameters in conjunction with analysis of the vegetation data. The following section briefly summarizes some important aspects of climate from data gathered daily at the N.P.S. kennels at Denali Park headquarters.

Precipitation

Mean annual precipitation for the years 1990 through 1997 was 41.9 cm (fig. 1). 1990 was by far the wettest year (65.1 cm) with more than twice the precipitation of 1995, which was the driest year during the period, with only 31.4 cm of total precipitation. There were also strong differences among years in the seasonality of precipitation recorded at Park headquarters (fig. 2). Mean monthly precipitation was generally highest during the spring and summer periods, and lowest during the period between February 1 and April 1. There was only one year (1990-1) when mean monthly precipitation was above the average for the

period during each of the four seasons. During the year 1996-7, mean monthly precipitation was equal to, or below, average for each of the four seasons.

Snow cover is an important aspect of precipitation in the Alaska Range. A deep, late-lying snow pack results in delayed phenology in the vegetation, but provides protection against frost and wind during the winter. Abundant winter snow often results in more moisture being available during the growing season. Mean snow depth is recorded at Park headquarters daily, and figure three shows the mean snow depth averaged for each month for the winters of the period 1991-1998. The winter of 1992-3 stands out as by far the largest snow-pack for the past 8 years; in part because 38.1 cm of snow fell very early (between the twelfth and fifteenth of September of 1992), and remained on the ground through the winter.

Temperature

An important aspect of the climate in the far north is the duration of the seasons. Summer is commonly defined as the period during which mean daily temperature is above 10° C, and winter is the period during which mean daily temperatures remain below freezing (0° C). The arrival and departure of these seasons is frequently variable among years in mountainous regions, and Denali National Park is no exception (figures 4 and 5). The mean duration of the summer season over the past eight years was from the tenth of June until the 23rd of August (fig. 4). The longest summer during this period was 1997, which lasted from June third until September twelfth. The shortest was 1996, lasting from June fourteenth until August third. Winter arrived, on average, on the fifth of October and lasted until April eighteenth (fig. 5). The variation in the duration of winter was less pronounced among years than the duration of summer, although the longest winters in this brief record bracket the "Mt. Pinatubo" year of 1992-3.

Mean monthly temperatures averaged for three-month increments over the past 8 years are presented in figure six. Mean monthly temperatures for the periods November through January, and February through March were colder than the period average during the winters of 1990-1 and 1995-6. The mean monthly temperature for the fall months (August through October) of 1992 and 1996 were below freezing, markedly colder than the average for the period.

A temperature index that is highly correlated with several aspects of plant growth and development, is the accumulation of thawing degree-days over the course of the growing season. One thawing degree day is the positive departure of mean daily temperature from 0° C of one degree Celsius. Thus, a day during which the mean temperature was 8.5° C, adds 8.5 thawing degree days. Degree days are summed for a specified period of time (commonly per month, or the growing season). A plot of monthly sums of thawing degree days for the summers 1991-1998 (fig. 7) reveals parallel patterns to the duration of summer data presented above. That is, the two shortest summers during this period, 1996 and 1998, were also the coolest. The cumulative number of degree-days per month in these two summers was below (or just equal to), the average number of cumulative degree-days per month for the entire period for each month of the growing season. The total number of degree-days accumulated per

month in the summer of nineteen-ninety seven, on the other hand (the longest summer during the period) was higher than the for each month of the summer (this was also the case in 1993 and 94).

Summary

- 1) A very early heavy snowfall occurred from 12-15 of September, 1992, and the snowpack accumulated over the winter months of 1992-3 was the deepest during this period.
- 2) Annual precipitation during the years 1990 and 1992 was above normal, and the driest calendar year during the period was 1995.
- 3) The warmest growing seasons during the period were 1993, 94 and 97; the coolest were 1996 and 98. The longest summer during the period was 1997.
- 4) The coldest winters during the period, on average, were 1990-1, and 1995-6. Mean monthly temperatures were below the average for both these periods in these two years.

III. Parameters monitored on a yearly basis

White spruce growth (diameter increase)

In 1992, dendrometers were installed on 23 trees (5 each in 3 forest plots (=15) and 8 total in the treeline plots) in order to track the yearly growth in diameter of the boles of selected white spruce trees in the forest and treeline study sites. Dendrometers require 1 year to settle before a baseline diameter can be recorded. As a result, the baseline measurement was made in 1993, and the first growth data is for the 1994 growing season.

Results

Yearly growth of spruce was, on average, slightly lower in the treeline site than in the forest site for the period 1994-98 (fig. 8). In three of these five years, however, mean spruce diameter increase at treeline was within one standard error of the mean growth in the forest site (1995-97). Spruce growth at treeline was considerably lower than growth in the forest during 1998. In fact, the difference in mean growth between sites was statistically significant only in 1998.

The amount of yearly growth of sampled trees generally increased in both sites from 1994 through 1997. Mean yearly growth reached a peak of 0.42 cm in 1997 (at the forest site). Growth rates were markedly lower in 1998 in both sites. There was negligible growth recorded for treeline spruce trees in 1998, with the mean diameter increase falling from 0.33 cm in 1997 to 0.006 cm in 1998 (fig. 8).

Discussion

The highest rate of tree growth at both sites was recorded in 1997, which was also the longest and warmest summer during the period. It is worth noting, however, that although the summer of 1994 was also very warm (fig. 7), spruce growth in this year was, on average, apparently considerably less than in 1997. Furthermore, 1996 was a very cool, short growing season but mean spruce growth was nevertheless reasonably high. In addition, the summer of 1998 was similar to that of 1996 in being short and cool, but the amount of spruce growth

was apparently much less during 1998 as compared to 1996. The above facts suggest two possible explanations. Sampling error due to our relatively small sample size may obscure the true trends in tree growth. Alternatively, factors other than the warmth of the growing season may be important in influencing the amount of yearly growth of spruce trees (which is certainly true). Examples of such influences include interactions with other climate factors, such as precipitation, and cyclical factors internal to the trees and independent of current season weather. For instance, the particularly low rate of growth in 1998 was likely due to the allocation of resources to reproduction (a bumper cone crop) instead of vegetative growth by the sampled trees.

A longer record of the interactions among climate, spruce growth, and cone production is necessary in order to tease apart the factors affecting the growth and reproduction of spruce in the study sites. In particular, a record that includes more than one occurrence of a bumper cone crop is vital to understand the causes of this important phenomenon, and its relationship to annual vegetative growth in spruce in Denali.

Recommendations

The principal weakness in the study design of the spruce growth component of the long-term monitoring program is the very low sample size, both in terms of number of trees within the plots (intensity) and the lack of spatial replication (extensiveness). It is likely that this low sampling intensity is the reason for the lack of statistical significance in the consistent difference in mean growth between the forest and treeline sites. Furthermore, the addition of sites located in a region of the Park with different climate norms (for instance, the south side of the Alaska range) would greatly amplify the both the area of inference encompassed by the study, and our ability to discern the effects of different climate factors on long term patterns of spruce growth.

Dendrometer bands are relatively inexpensive and are easy and quick to maintain and to read (once per year in the fall). As a result, adding a few more to the current sites would be an economical way to increase the quality of the data for this parameter. The addition of new sites in a different region of the Park would be more involved, and time-consuming, but if the new sites were easily accessible, their addition would not represent an unreasonable additional amount of effort.

Cone production of white spruce

Female spruce cones are counted on five trees per replicate plot in the forest and treeline sites on a yearly basis. All the trees with dendrometer bands are included in this sample. These counts have been made since the inception of the monitoring program in 1992.

Results

Mean cone production was slightly higher in the forest site than at treeline during the years 1992-7 (except 1995), although the samples are statistically indistinguishable (fig. 9). In 1998, however, mean cone production was abruptly higher in both sites, and there were significantly more cones produced by the forest trees than those at treeline. The mean number of cones produced per tree

was 390 at the forest site in 1998. This is more than four times the number of cones per tree that was observed during the previous high year for the forest site, which was 1992. The mean number of cones per tree at the treeline site was 162 in 1998. This is more than three times more cones per tree than were observed in 1993, the previous high year for cone production there.

To what is the higher cone productivity recorded in the forest site as compared to the treeline site in 1998 attributable? Hypothetically, differences in the environmental conditions between these sites might cause differential cone production by resident spruce trees. A closer look at the data belies such an interpretation, however. A plot of the number of cones produced by a tree as a function of its height reveals that higher cone production in the forest site is the direct result of the larger size of the trees sampled at this site, in comparison with those sampled at treeline (fig. 10). In fact, it appears that for a given size, treeline trees may in fact produce more cones than forest trees.

Discussion

Banner spruce cone crops such as the one recorded in 1998 are known to occur only episodically even in the lowlands, usually separated by long periods (up to 15 years) of negligible cone production. It is likely that these banner crops are even less frequent in mountainous areas such as Denali, where summers are relatively short and cool. While it is thought that warm, dry summer weather is a prerequisite for the initiation of a substantial cone crop, all the conditions that give rise to this phenomenon are not well known.

The 1998 cone crop presents a first opportunity to examine the meteorological conditions that may stimulate increased reproductive output by white spruce in the Alaska Range. Initiation of cones in white spruce takes place during the summer prior to the year in which the cones mature. Therefore the conditions that are most relevant to the formation of this year's cones are those that occurred during the summer of 1997. A plot of the accumulation of thawing degree days during June and July for the years 1991-1997 shows that warmer conditions prevailed during these months in 1997 than during any of the previous six summers, beginning on the 28th of June and lasting for the remainder of the season (fig. 11). In addition, the summer of 1997 was the longest during this period (see fig. 4). Precipitation sums, on the other hand, do not indicate that the summer of 1997 was particularly dry, as would be expected based on the hypothesis that warm *and* dry conditions are required for the stimulation of a large cone crop (fig. 12). In fact, total April-July precipitation in 1997 was the second highest noted during this period.

Comparing cone production with vegetative growth (see figs. 8 and 9), there is a conspicuous correspondence of low vegetative growth and the banner cone year in 1998. As mentioned above, this is likely due to a shift in allocation from vegetative growth to reproduction by spruce in 1998, which was caused by the initiation of the large cone crop in the summer of 1997. This effect may have been exacerbated by the relatively cool growing season conditions that prevailed during the summer of 1998.

Recommendations

A potential shortcoming in the design of the cone productivity monitoring protocol is the absence of size stratification. It is important to examine cone productivity in treeline versus forest areas within different size classes of spruce. That is, are spruce at treeline less productive, or are they just smaller, on average, at this point in time? This is not possible using data from the current protocol because of the very different size-class distribution of the sampled trees in the two areas. This could be remedied by adding randomly selected trees that meet specified size criteria to the group of sampled trees. Of course, the maximum size of treeline individuals is smaller than that in the forest, at present, so the stratification would not be entirely symmetrical for the two sites.

There is likely considerable counting error associated with recording the number of cones in the field, particularly when cones are numerous. One possible way to help reduce such error, and standardize these counts, would be to establish photo points and take wide-angle photographs in order to count cones. This would allow the collection of a larger sample size, because field-time would be diminished, and provide the added benefit of allowing the direct archiving of data.

The problems associated with low sample size that were discussed with regard to the spruce growth monitoring protocol also apply to the cone counts. Increasing the sampling intensity and extensiveness would benefit the power of this study to discern differences in cone production in different landscape positions through time. Furthermore, this could be accomplished using an adaptive sampling approach, wherein specific targets for levels precision and confidence in estimators could be set, and sampling would proceed only until these targets were met, and then terminated. However, the most important facet of the cone counts is documenting the occurrence of bumper cone crops, such as occurred in 1998, and the current protocol is adequate to this task.

White spruce seed production

There are six 0.25 m² seed traps in each replicate plot in the forest and treeline sites. These traps are patterned after those used in numerous other studies, such as the long term ecological research program at Bonanza Creek experimental forest. These traps are set out before seedfall starts in August and collected in the spring. All spruce seeds are sorted from the detritus accumulated in the traps, and counted.

Results

There was considerable year-to-year variation in the number of seeds per trap during this period in the forest site. It ranged from a mean of more than 51 seeds per trap in 1994 to less than three seeds per trap in 1995 (the mean for the entire period was in the forest site was 19.7 seeds per trap per year). Both the overall numbers of seeds and the variability in the number of seeds among years were much lower in the treeline site than in the forest. There was a range of 0.28 to 2.6 in the mean number of seeds per trap (the mean for the period was less than one seed per trap per year). The highest number of seeds per trap was

highest in 1994, for both forest and treeline. Comparing the two sites, there were significantly more seeds per trap in the forest as compared to treeline 1994 ($p=0.008$). This difference approached significance in 1995 ($p=0.075$).

I compared Rock Creek seed rain data with similar data from upland white spruce forest recorded at Bonanza Creek experimental forest. The number of seeds trapped each year at these Bonanza Creek stations from 1989 through 1996 also showed considerable year to year variation (see Fig. 14). There are similarities in the timing and patterns of seed rain in the Bonanza Creek site with those observed in the forest site in the Rock Creek drainage. Specifically, seeds were relatively abundant in traps in 1994 and 1996 in both areas, and relatively scarce in 1993 and 1995 in both areas (see figs. 10 and 12). However, the highest number of seeds was observed in 1996 at BC, while 1994 had most abundant seed rain at RC. Because the 1998 cone crop was large statewide, it will be instructive to compare the values for these two sites for this year.

There is pronounced variability in seed numbers among traps within a plot, among plots within a site and among years at both of these spatial scales (see table 1). This variability is a function of the nature of seedfall within the forest. Specifically, since many cones fall with numerous seeds still attached, there is a very clumped distribution of seedfall within these plots, and our estimators are heavily influenced by whether or not a cone falls into one of the seed traps.

Table 1. Total number of seeds in six seedfall traps in each of 3 replicate plots in forest and treeline sites in Rock Creek drainage for the years 1993 - 1996.

plot	1993	1994	1995	1996
forest 1	15	337	21	261
forest 2	8	335	15	12
forest 3	52	247	8	108
treeline 1	1	7	3	2
treeline 2	3	30	1	1
treeline 3	1	10	1	2

Discussion

Two inconsistencies arise from a joint consideration of the seed rain data and the cone production data. Specifically, the disparity in seed rain between the sites appears to be more pronounced than the disparity in cone production between the sites, and the timing of relatively high seed rain in the forest does not appear to correspond to years in which cone production was relatively high.

The probable reason for the apparent lack of correspondence in the timing of relatively high seed production and high cone production is sampling error. The nature and degree of variance in the seed rain data necessitates caution in drawing firm conclusions from it. In fact, sample size calculations based on the means and variances observed in this study show that during 1994 and 1996, it would have been necessary to have placed more than 40 traps per plot in the

forest site order to have 80% confidence that the estimator of the mean was within 20% of the true mean for the year. The strong spatial variability in seedfall may explain why the high seed years recorded in this study do not correspond with the high cone years: the estimators are strongly influenced by random sampling error, and do not necessarily closely reflect the true amount of overall seed rain for the year.

The more pronounced differences in seed production between sites as compared to differences in cone production between sites may similarly be attributable to sampling error. However, they may also reflect real differences in fecundity by spruce trees in these two landscape positions. The formation of a large cone crop is not a guarantee of abundant spruce seed the following year. The second critical step in the production of a spruce seed crop is the fertilization and maturation of the seeds within the cones. This takes place during the second summer of cone growth, and is also dependent on climatic factors. In other words, it is possible to have a large cone crop produce only a small number of viable seed, if conditions during the second summer are not favorable. Therefore conditions may uniformly cause abundant initiation of cones in both sites, but the true limiting factor on seed production may be in the seed formation stage, which is potentially more sensitive to harsh treeline conditions than is cone initiation. The large 1998 cone crop will once again be helpful in resolving this question.

Recommendations

Seed collection and sorting is a relatively time consuming aspect of the monitoring protocol. Therefore, although a larger sample size would benefit the monitoring program by making the estimator of seed rain more precise, the additional time and effort involved to effect this improvement prohibit this option. An option that would provide a measure of relative seed production by spruce cones in treeline and forest areas would be to harvest cones directly from trees in sites similar to the long term monitoring plots, and count seeds from these cones.

In order to quantify the relative productivity (in terms of viable seed) of the cones in the banner 1998 crop, for instance, we harvested cones directly from trees at eight widely scattered treeline sites at the end of the summer. These cones will be examined for the quantity and quality of seed they contain, providing a measure of the amount and variability in seed productivity and viability within and among eight different sites during a banner cone crop.

Berry productivity

There are two small, rectangular plots (0.5 m x 1.5 m) at each of the three replicate plots in the forest and treeline sites within which the number of berries are counted on a yearly basis. There are two of these “berry” plots in only one of the tundra replicates, but berry plots are absent from the other tundra replicates because there are no berry producing species present there. The principal berry-producing species monitored in this study are crowberry (*Empetrum nigrum*), blueberry (*Vaccinium uliginosum*), and lowbush cranberry (*Vaccinium vitis-*

idaea). Less prominent “berry” species include bearberry (*Arctostaphylos rubra*), dwarf dogwood (*Cornus canadensis*), and *Geocaulon lividum*.

The design of this monitoring element is aimed at quantifying the berry productivity **per unit area** of the sampled communities. The abundance of berry-producing species (in terms of cover, density, and biomass) was allowed to vary among the berry plots. Thus the proper unit of measure for the berry productivity observations is the number of berries produced per unit of ground area (m²).

Results/Discussion/Recommendations

Results of the berry monitoring study for the years 1994-1998 are presented in tables two through four (also see appendix one). A close examination of the berry data for both the forest and treeline sites, however, suggests that it is necessary to either redesign or drop this element from the monitoring program. The degree and pattern of variation in the number of berries of the different species over the past five years appears to be primarily random noise (see appendix one). The great variation in species abundance, ecological characteristics (slope, aspect, degree of shade, etc...) within and among plots in this study obscures any possible measurement of true year-to-year variability in berry productivity. For example, although the plots are meant to monitor all berry species, even the dominant berry species are absent from some plots, and abundant in others. It is my opinion that accurately measuring berry productivity with any degree of precision for this study would require a stratified approach to sample design, which is absent from the present one. In fact, the minimal requirement of random plot placement was violated in the design of this monitoring element; berry plots were sited in a way that is incompatible with valid statistical analysis of the data.

Table 2. Mean number of blueberries (*Vaccinium uliginosum*) produced by 2 “berry plots” in each of 3 plots in Rock Creek at forest and treeline LTEM sites for the years 1992 – 1998 (n=3).

Plot	1994	1995	1996	1997	1998	overall mean
Forest	8.3	16.0	33.0	39.7	22.0	23.8
std. error	2.8	5.0	23.4	17.2	12.1	5.7
Treeline	48.3	80.0	24.0	26.0	20.7	39.8
std. error	15.6	20.6	10.2	2.1	4.9	11.2

Table 3. Mean number of crowberries (*Empetrum nigrum*) produced by 2 “berry plots” in each of 3 plots in Rock Creek at forest and treeline LTEM sites for the years 1992 – 1998 (n=3).

Plot	1994	1995	1996	1997	1998	overall mean
Forest	1.3	8.7	36.3	59.7	64.0	34
std. error	1.3	4.2	15.4	31.2	40.3	12.8
Treeline	4.7	8.3	4.0	18.7	25.7	12.3
std. error	4.7	5.6	2.1	9.2	12.6	4.3

Table 4. Mean number of lowbush cranberries (*Vaccinium vitis-idaea*) produced by 2 "berry plots" in each of 3 plots in Rock Creek at forest and treeline LTEM sites for the years 1992 – 1998 (n=3).

Plot	1994	1995	1996	1997	1998	overall mean
Forest	4.0	22.3	22.3	18.7	79.3	29.3
std. error	2.6	8.6	21.3	16.2	62.6	12.9
Treeline	0	0	0.3	0	4.7	1
std. error	0	0	0.3	0	4.7	0.9

IV. Parameters monitored every ten years

At the time the permanent vegetation plots were established, various measurements were made to record the baseline conditions at the sites. These measurements included the measuring and mapping of all trees, assessing percent cover by species of the shrub layer in 12 separate 4 m² quadrats, and percent cover by species in the herb layer in 12 additional 1 m² quadrats.

Summary of stand structure of trees and tall shrubs in Rock Creek LTEM plots

In order to summarize the data collected at the vegetation monitoring sites in the Rock Creek drainage, and allow for comparison of these data to the results of similar studies (such as those at Bonanza Creek experimental forest) I calculated the following parameters for the Forest, Treeline and Riparian sites:

- 1) mean basal area by species (m² per Ha)
- 2) mean stem density by species (# stems per Ha)
- 3) size class distribution by species (summed by site: forest, treeline, and riparian)

Density and Basal area:

Tables five through eight summarize the tree and tall shrub measurements taken in the three replicate plots in the forest, treeline and riparian sites for the three most important woody plant species (*Picea glauca*, *Betula papyrifera*, and *Alnus crispa*) and for all willows taken together (*Salix* spp.). Field measurements were made in 1992 and 1993. Basal area is presented in units of square meters per hectare and was calculated assuming a cylindrical cross-section and the equation $BA = \pi d^2 / 4$ where d = diameter breast height; density is given in units of stems per hectare.

Table 5. Basal area and stem density of white spruce (*Picea glauca*) (individuals >1.3 m in height) in three vegetation monitoring sites in the Rock Creek watershed, Denali National Park.

plot	forest				treeline				riparian			
	for 1	for 2	for 3	mean (st. dev.)	trl 1	trl 2	trl 3	mean (st. dev.)	rip 1	rip 2	rip 3	mean (st. dev.)
basal area	15.2	24.3	23.9	21.13 (5.18)	0.68	2.16	2.28	1.01 (1.0)	0.00	0.00	0.00	0.00
density	256	864	560	560 (304)	240	320	64	208 (131)	0	0	0	0

Table 6. Basal area and stem density of paper birch (*Betula papyrifera*) (individuals >1.3 m in height) in three vegetation monitoring sites in the Rock Creek watershed, Denali National Park.

plot	forest				treeline				riparian			
	for 1	for 2	for 3	mean (st. dev.)	trl 1	trl 2	trl 3	mean (st. dev.)	rip 1	rip 2	rip 3	mean (st. dev.)
basal area	8.4	0.00	0.00	2.80 (4.86)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
density	336	0	0	112 (194)	0	0	0	0	0	0	0	0

Table 7. Basal area and stem density of alder (*Alnus crispa*) (individuals >1.3 m in height) in three vegetation monitoring sites in the Rock Creek watershed, Denali National Park.

plot	forest				treeline				riparian			
	for 1	for 2	for 3	mean (st. dev.)	trl 1	trl 2	trl 3	mean (st. dev.)	rip 1	rip 2	rip 3	mean (st. dev.)
basal area	0.00	0.00	1.00	0.34 (0.58)	0.00	0.00	0.00	0.00	7.5	11.00	13.5	10.67 (3.11)
density	0	0	768	256 (443)	0	0	0	0	12200	17600	7800	12533 (4908)

Table 8. Basal area and stem density of willows (*Salix* spp.) (individuals >1.3 m in height) in three vegetation monitoring sites in the Rock Creek watershed, Denali National Park.

plot	forest				treeline				riparian			
	for 1	for 2	for 3	mean (st. dev.)	trl 1	trl 2	trl 3	mean (st. dev.)	rip 1	rip 2	rip 3	mean (st. dev.)
basal area	0.00	0.09	0.32	0.13 (0.16)	0.00	0.00	0.00	0.00	15.3	4.3	22.7	14.1 (9.26)
density	0	16	224	80 (125)	0	0	0	0	9400	5000	3400	5933 (3107)

I. Forest plots

There were pronounced differences in the species composition, density and basal area of the woody plants among the three forest plots (see tables 5-8; figures 15 and 16). Plot one was mixed spruce-birch forest, with dominance shared by paper birch and white spruce. Birch was absent from the other two plots. In plots two and three, tall shrubs (alder and willow) were more dense than in plot one, but represented minor percentages of the total woody plant basal area in these plots. There was also variation in white spruce (*Picea glauca*) abundance among the plots, with a range of 15.2 to 23.9 m² per Ha in basal area and 256 to 864 stems per acre in density. The presence of 768 stems/Ha of alder (*Alnus crispa*) in plot 3 is important due to the effects on ecosystem processes contributed by the nitrogen fixation associated with alder roots. Nutrient dynamics in this plot are likely very different than in the plots without alder.

The forest plots at Rock Creek supported less basal area, but somewhat higher stem density of white spruce than did the mature upland white spruce forest plots ("Upland 3") at Bonanza Creek experimental forest (in 1993 measurement). Basal area measurements for the Rock Creek sites were close to the range of variation for the same measurements at BC sites, (a range of 15.2 to 23.9 m² per Ha at Rock Creek vs. 22.8 to 32.3 m² per Ha at Bonanza Creek). Stem densities of white spruce in the three Upland 3 plots at Bonanza Creek were 493, 330, and 373 stems per Ha, which is at the low end of the range of variation for white spruce stem density at Rock Creek forest site (256 to 864 stems per Ha).

Another difference between BC Upland 3 plots and RC forest plots is the virtual absence of aspen and poplar from the RC forest plots, whereas these species were present, although in relatively low abundance, at the BC Upland 3 plots. However, the overall ratio of spruce to deciduous tree basal area summed for the three RC forest plots was 7.55, closely resembling the mature upland spruce community at BC (UPLAND 3) which had a ratio of white spruce to deciduous tree basal area of 6.27 in 1993.

II. Treeline plots

All the trees recorded in the treeline site were white spruce (*Picea glauca*). Both basal area and density of trees were considerably less at the treeline site as compared to the forest site (see figures 15 and 16). The most noticeable difference among the three treeline plots themselves was that treeline plot 3 had fewer, larger diameter trees than the other two treeline plots, which support more numerous, generally smaller trees. Plots one and two supported similar basal area and density of white spruce (see table 5). There are no equivalent stands at Bonanza Creek that compare with treeline sites, because of the high elevation of these plots.

III. Riparian plots

The species that are dominant in the forest plots are essentially absent from the plots located in the riparian zone (see figures 15 and 16). The principal

tall woody plant taxa in the riparian plots were alder (*Alnus crispa*) and Alaska willow (*Salix alaxensis*), which formed dense stands with a maximum density of 17600 stems per Ha of alder in plot 2 (see Fig. 2).

IV. Summary

The density and basal area summaries presented above provide a basis for judging the degree to which the chosen plots are representative of the vegetation of significant sections of the landscape. By comparing these data with similar measurements made in other locations, we can assess whether these sites are reasonably typical of spruce forest, treeline and riparian communities in the Park, or whether they represent unusual ecological situations. If they are typical, we can be more confident that the measurements taken there are representative of processes occurring at more widespread spatial scales. However, if these data represent atypical values for density and basal area of woody plant species their “representativeness” for larger scale processes would be highly questionable.

These summaries represent baseline metrics for the long term monitoring plots. The primary usefulness of these data will be in comparing subsequent measurements to these baseline values. Such comparisons will reveal trends in the dominance and growth patterns of different segments of the vegetation.

Size class distribution of white spruce and paper birch

A comparison of the size class distribution of white spruce individuals at the forest site versus those in the treeline site reveals several differences in the population structure of spruce between these two sites (figs. 19 and 20). Most notably, these histograms indicate that significant seedling establishment occurred within the forest plots (prior to 1992, when these measurements were taken; fig 19) compared to little, if any, recent establishment of spruce in the treeline plots (fig. 20). This is evidenced by the large numbers of individuals in the less than 0 cm diameter (at 1.3 m above the ground) size class in the forest site and the very low number of individuals in these size classes at treeline. Furthermore, the size-class histogram for the treeline site shows that a majority of the trees in these plots are of a similar size. Thus these treeline stands may be formed by one relatively even-aged cohort dating to a specific pulse of establishment (perhaps derived from a particular banner seed crop in the past). A project designed to determine the age-structure of the spruce trees in this area has been undertaken by a researcher from the University of Alaska.

The relative scarcity of seedlings and saplings in the treeline site could be due to few viable seeds being produced there, low germination, or seedlings being unable to survive and become established. In contrast, white spruce seedlings/saplings are more abundant in the forest site and there is a pronounced drop in numbers of individuals moving into the larger size classes. This diminution in numbers within the larger size classes suggests high post-establishment mortality, perhaps as a result of resource limitation and competitive interactions. That is, establishment of seedlings may be less difficult for spruce at the lower elevation site. Once established, however, these

seedlings may face strong competition for resources (particularly light). As a result, mortality would be concentrated in the several years following establishment in the forest. In contrast, mortality at treeline may be concentrated in the embryo, seed or young seedling life stages, due to the harsher microclimate conditions prevalent there. Monitoring of the consequences of the banner cone crop of 1998 should provide insights into the different spruce establishment conditions in these two sites, over the long term.

The size class distribution histogram for birch (*Betula papyrifera*) in the forest site shows that there is a relatively old cohort of similarly-sized trees and that few birch have been established there recently (note the absence of individuals of less than 9 cm in diameter; fig. 21). It is probable that the birch trees in these plots are relatively even-aged, dating to the most recent disturbance event, and that this population is gradually aging, with little recruitment due to the inhospitable seed bed characteristics on the forest floor and competition with spruce for light. Birch are dependent on fire (or other disturbance) for establishment, and there has been no significant disturbance in the vicinity of the plots recently. Birch trees are absent from treeline plots

These baseline size class histograms are likely very important to track over time. Presumably, trends in mortality or establishment rates should first be reflected in this basic population structure parameter. For example, climatic warming might result in a wave of seedling establishment in the high elevation plots, or increased mortality of moisture-stressed seedlings in lower elevation plots. Only by recording these observations over repeated sampling intervals will the long-term trends in spruce forest dynamics in the study sites become evident.

Herbaceous cover quadrats

The structure and composition of the herb layer of the vegetation was quantified using twelve one meter square quadrats in each replicate plot at the forest, treeline, riparian and tundra sites. The percent cover of each species was estimated within these quadrats. The percent cover of each species was averaged within each plot, and the mean of these three plot averages was taken for the mean cover by site for each species. The herb layer was dominated by a different group of species at each site (see figs 22 through 24), although *Vaccinium uliginosum*, *Vaccinium vitis-idaea*, and *Empetrum nigrum* were among the dominants in both the forest and treeline sites. Not surprisingly, the tundra site shared none of the dominant species with the forest and treeline sites. In fact, there are only four vascular plant species that occur in the herb quadrats at all of the three sites along the principal landscape gradient in this study (elevation): The four species that occur in the herb quadrats at all of the three sites along the principal landscape gradient in this study are: *Empetrum nigrum*, *Festuca altaica*, *Vaccinium uliginosum* and *Vaccinium vitis-idaea*, and *Vaccinium uliginosum*.

Gradient analysis allows for the examination of species responses to environmental or topographic variables. For example, gradient analyses of the cover of the four vascular plant species that occur at all three sites along the

elevation gradient show that the cover of *Empetrum nigrum*, *Festuca altaica*, and *Vaccinium vitis-idaea* decline with increasing elevation. In contrast, *Vaccinium uliginosum* reaches its highest abundance in the treeline site (see figs. 25-28). Numerous tundra species, such as *Dryas octopetala*, are absent from treeline and forest plots, showing a gradient response highly skewed towards increased cover in high elevation sites (fig. 29). Dwarf birch (*Betula glandulosa*), the dominant plant in subalpine situations through much of the north side of the Park, shows a gradient response of maximum cover at the treeline site (fig. 30).

These gradient “signatures” can provide a valuable measuring stick for monitoring changes in the vegetation in Rock Creek drainage. For example, it is possible that, with warming, shrub birch cover will increase in the tundra sites, at the expense of typical tundra dominants such as *Dryas*. Tracking the potential changes in abundance of dominant species over time should yield insights into changes in the community structure of vegetation in these three landscape positions. These gradient responses should be looked at with caution, however, due to the small amount of variation that is captured within each of the three community types, and the lack of spatial replication of the experiment outside this small drainage. It is very likely that a set of plots in a different set of places would, for some species, yield very different gradient signatures. For instance, *Empetrum nigrum* is very abundant in certain tundra facies, but due to the particular location of the Rock Creek plots, it appears to decline precipitously in cover with increasing elevation.

Over the long-term course of the monitoring program, comparing changes in gradient signatures of important taxa in the permanent plots, such as those shown here, will portray an important facet of vegetation dynamics over time within the Rock Creek watershed. However, “noise” in this data due to local succession patterns, stochastic variation and other localized phenomena may make landscape-scale interpretations of these data unwarranted. Greater replication of quadrat sampling (extending it to other areas of the park) would facilitate comparisons between areas and potentially make the findings more general in nature. In addition, more intensive sampling of gradients in the vegetation within vegetation types would allow more sophisticated and detailed community-level analyses of these data.

The best way to capture more variability within these broad vegetation types would be to sample topographic gradients (slope/aspect/elevation) within the “forest”, “treeline” and “tundra” categories. Sampling of topographic gradients in this way would not only give a more precise and accurate picture of the composition and structure of these vegetation types, it would allow analyses that would show the factors that cause differences in the abundance of different species on the landscape. As a result, we would be able to monitor not only a periodic, static “snapshot” provided by the four permanent plots, but the differing contributions of the causal factors that produce these snapshots. For instance, with climatic warming, the importance of aspect in determining the vegetation pattern on the landscape may decrease because frozen soils on north slopes would thaw. Alternatively, drier summer conditions might increase the importance of slope in causing vegetation patterns because of the magnified

importance of drought, hence drainage patterns on slopes, as a determinant of vegetation. Determining the underlying landscape-vegetation relationships should be a priority because they operate at several spatial scales, and are fundamental to the rate and pattern of processes within the ecosystem.

Species richness of herb layer

I generated species-area curves for each of the long term monitoring sites using the herb layer quadrat data (fig. 31). Species-area curves indicate whether the amount of area sampled in a sampling plan is adequate. If the number of species encountered in each new sample is still rising sharply when sampling is terminated, the area sampled is not extensive enough to encompass important aspects of the plant community. In the case of Rock Creek, this is not a problem because the species-area curves have leveled out within the allotted sample size.

One very obvious aspect of the species-area curves for these sites is the considerably higher species richness of the tundra site as compared to the other three sites. This is a significant result that has several important implications. This diversity trend is surprising from a theoretical standpoint. Species richness generally decreases with increasing elevation, a trend parallel to the global trend of reduced species richness with increasing latitude (global diversity gradient). However, these curves may reflect a real pattern within Denali National Park and subarctic Alaska in general. Plant inventory work in Wrangell-St. Elias NP and other areas of the state has suggested that endemic and uncommon or "rare" plant species richness, in particular, is much increased in alpine areas.

These species richness data suggest that significant expansion of forest and shrub-dominated vegetation in the Park, at the expense of alpine tundra, could have strong deleterious effects on vascular plant diversity in Denali National Park. If the area supporting tundra does not increase at a similar pace to the (hypothetical) expansion of woody-plant dominated vegetation, then the area available to most of our rare and endemic flora will decrease appreciably over time, possibly resulting in local extinctions.

Plant biodiversity is an area worth focusing on in the context of long-term ecological monitoring, particularly since climatic warming is expected to increase the area covered by the relatively species-poor birch shrub, treeline and spruce forest plant communities, at the expense of alpine tundra in some cases. Testing whether the patterns in species-richness observed in this very limited data set are in fact general ones throughout the Park could be accomplished with relatively little additional work. Such work could also be used towards modeling the distribution of rare and sensitive plant taxa on the landscape within the Park, linking landscape scale vegetation processes with population-level species conservation concerns. In addition, basic information on the composition, distribution, habitat preferences and other important characteristics of the endemic and rare flora within the park is almost entirely lacking.

V. Summary

This document provides summaries for a majority of the data-sets collected during the course of the long term monitoring of vegetation project in the Rock Creek watershed of Denali National Park for the years 1992-1998. It shows that some aspects of the program are providing relatively sound data that is useful in meeting the original goals of the program. The dendrometer tree-growth monitoring, yearly cone counts, and many of the baseline plot (ten year remeasurement cycle) monitoring protocols appear essentially sound, although recommendations were provided to augment and improve the sampling design for these elements and for the collection of these data. On the other hand, several aspects of the study were shown to require substantial reworking. The berry productivity protocol, for instance, needs to be entirely redesigned, or eliminated.

There are two significant areas of concern that pervade all aspects of the design of the vegetation monitoring program. First, the area of inference of any statistical tests performed with this data is limited (at the maximum) only to the Rock Creek watershed, and in some cases it is not even that extensive. Secondly, the amount of variation captured within the sites is not sufficiently inclusive of the variation inherent in these community types on the landscape. The tundra replicates, in particular, do not encompass a large proportion of the variation in tundra vegetation present even in the Rock Creek watershed. The tundra plots are all located in a relatively mesic swale area, and do not capture examples of drier facies of alpine tundra, which is common in the watershed, and in the Park generally. This should be remedied if we continue collecting data in the tundra in the Rock Creek drainage. Furthermore, the nature of the variation that is captured by the established plots is haphazard in some cases. For example, two of the forest plots are on a dry hillside and the third is on the relatively level valley floor. Thus, these replicate plots represent areas with different ecological conditions, and as such, are not necessarily true replicates.

The vegetation monitoring study should be adjusted to include more of the variation inherent in the sampled vegetation types, integrating topographic gradients within these broad types into the sampling design. This would serve to benefit both the accuracy and precision of the results of this study, and would provide data on the *causes* of vegetation patterns and processes within the Park.

Literature cited

Densmore, Roseann, 1997. Inventory and Monitoring Project Vegetation Protocol, internal document, Denali National Park and Preserve.

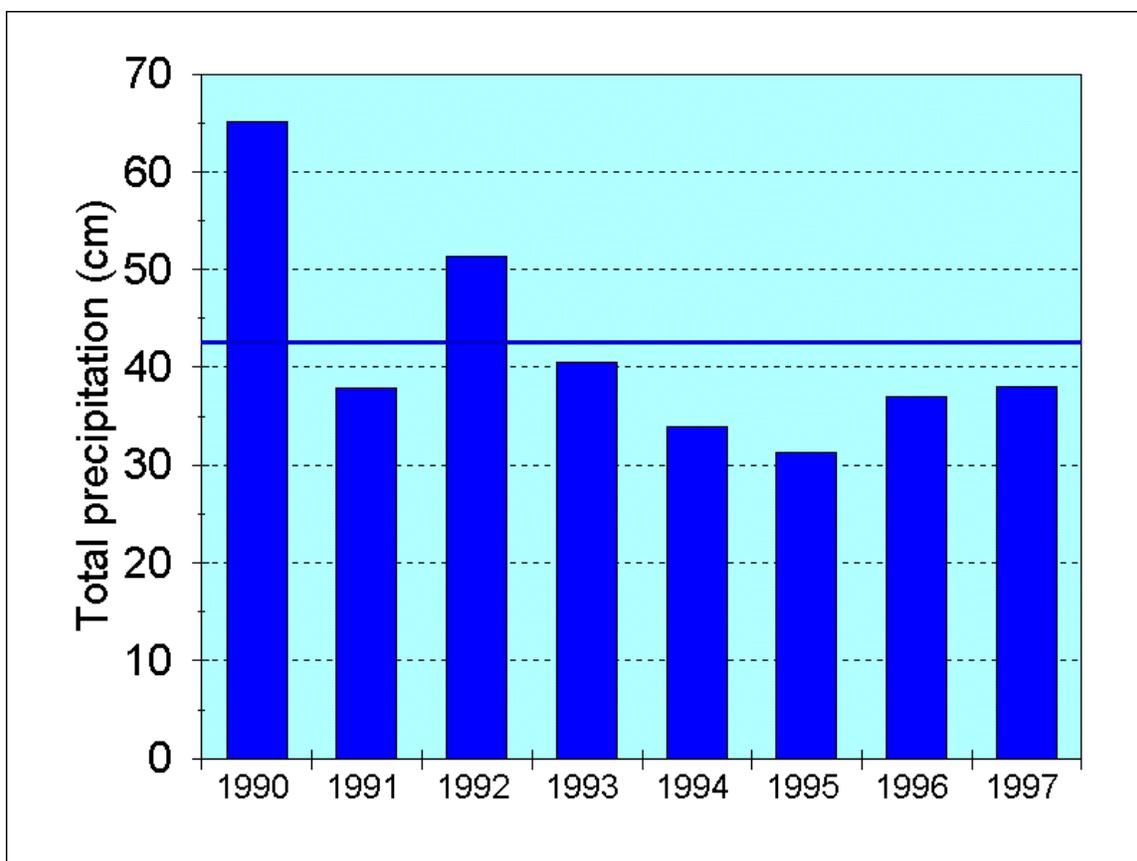


Figure 1. Annual precipitation recorded for the years 1990-1997 at Denali National Park headquarters, Alaska. Horizontal blue line shows the mean annual precipitation for this period of time.

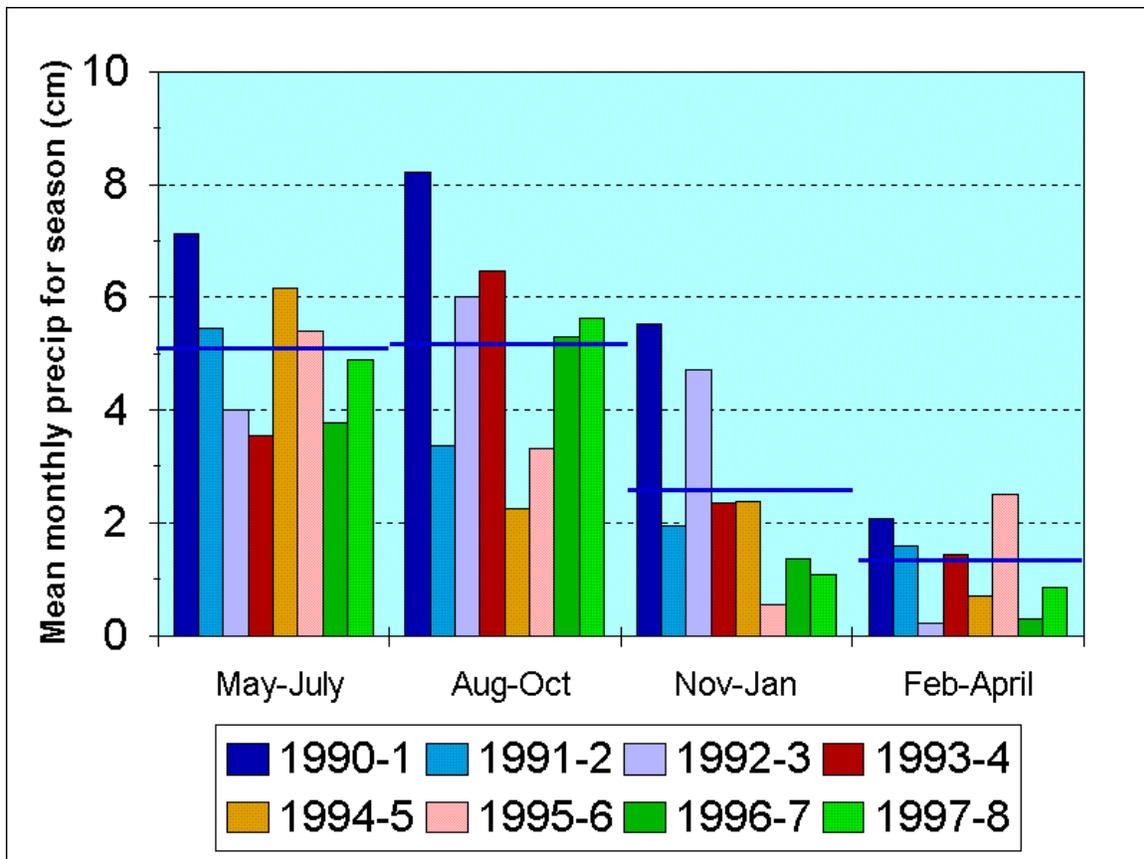


Figure 2. Mean monthly precipitation for three-month time increments, for the years 1990 through 1998. Horizontal blue lines show the mean annual precipitation for the same period of time.

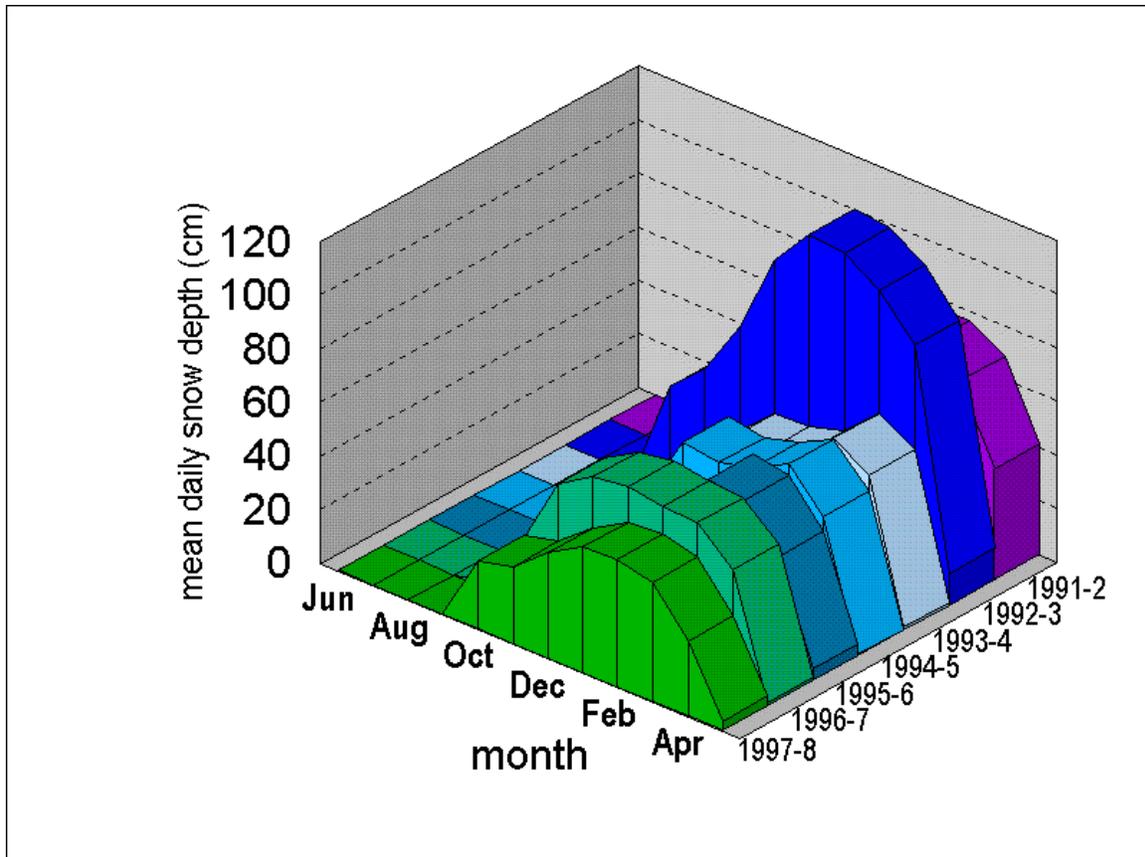


Figure 3. Mean daily snow depth recorded at Denali National Park headquarters, Alaska, for the years 1990 through 1998.

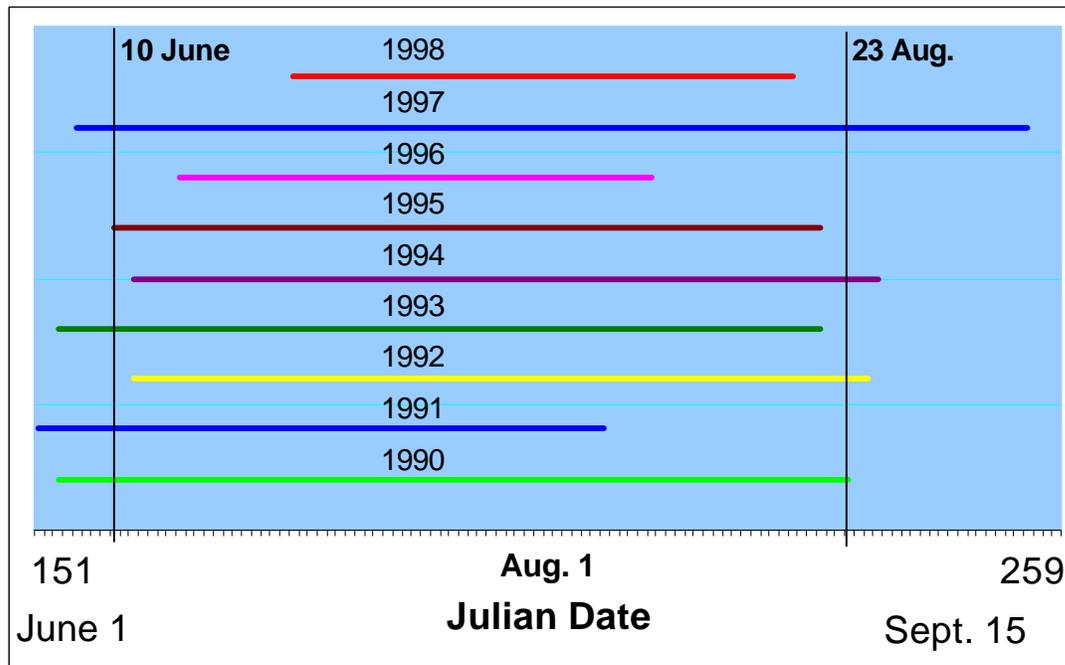


Figure 4. The duration of summer for each year between 1990 and 1998, tabulated from temperature records recorded at Denali National Park headquarters, Alaska. . Vertical lines show mean start and end dates for summer during this period.

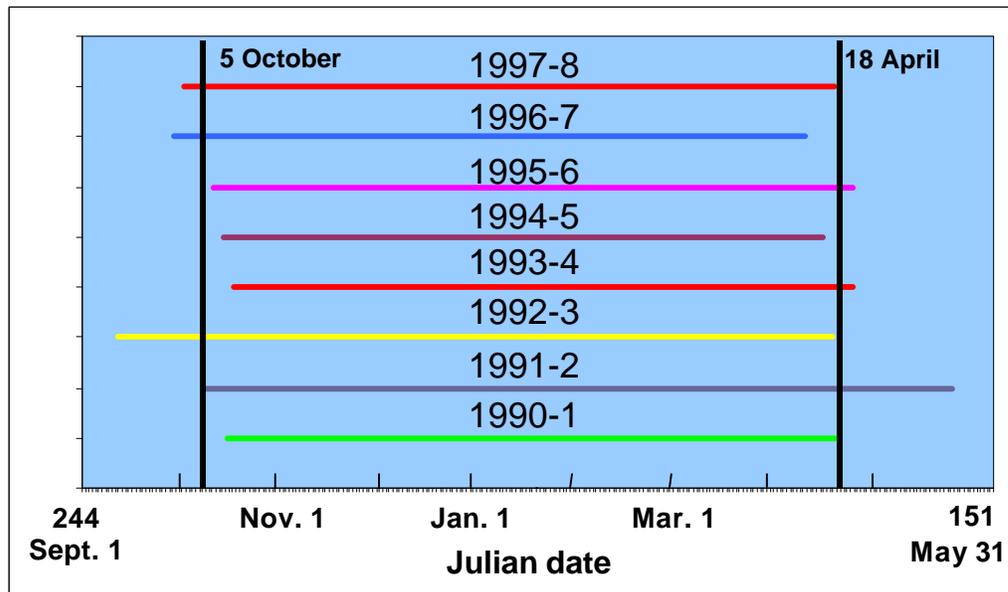


Figure 5. The duration of winter for each year between 1990 and 1998, tabulated from temperature records recorded at Denali National Park headquarters, Alaska. Vertical lines show mean start and end dates for winter during this period

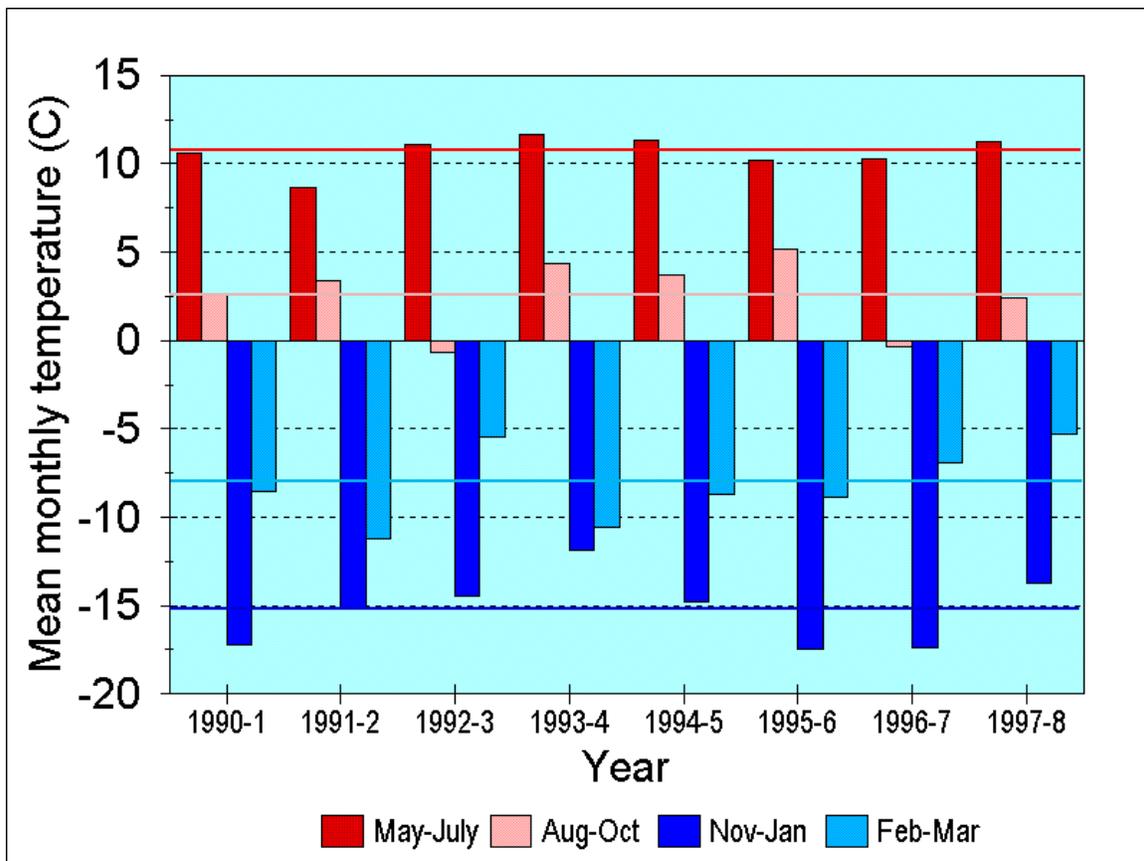


Figure 6. Mean monthly temperature for three-month time increments, for the years 1990 through 1998. Color-coded horizontal lines show the mean temperatures for each interval during this eight year period of time.

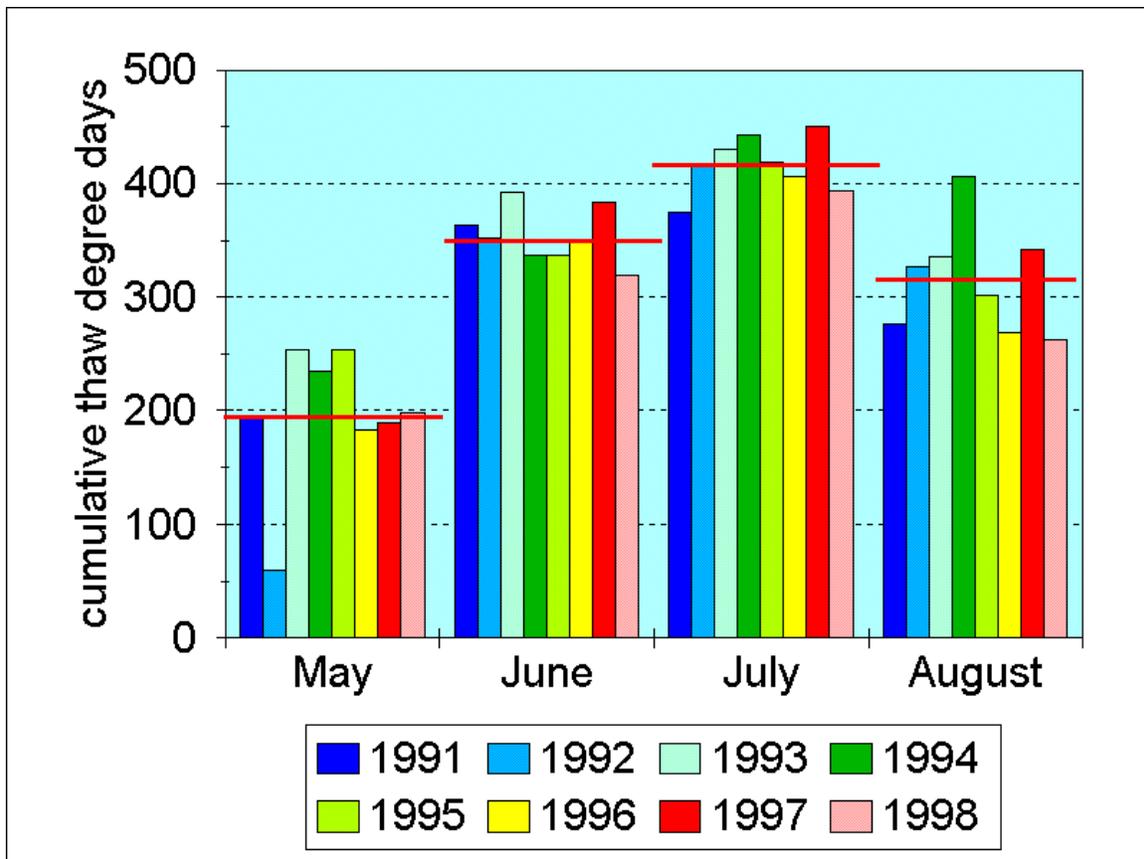


Figure 7. Monthly cumulative thawing degree days for May through August, for each year between 1991 and 1998. Red horizontal lines show mean value for each interval over for this eight-year period of time.

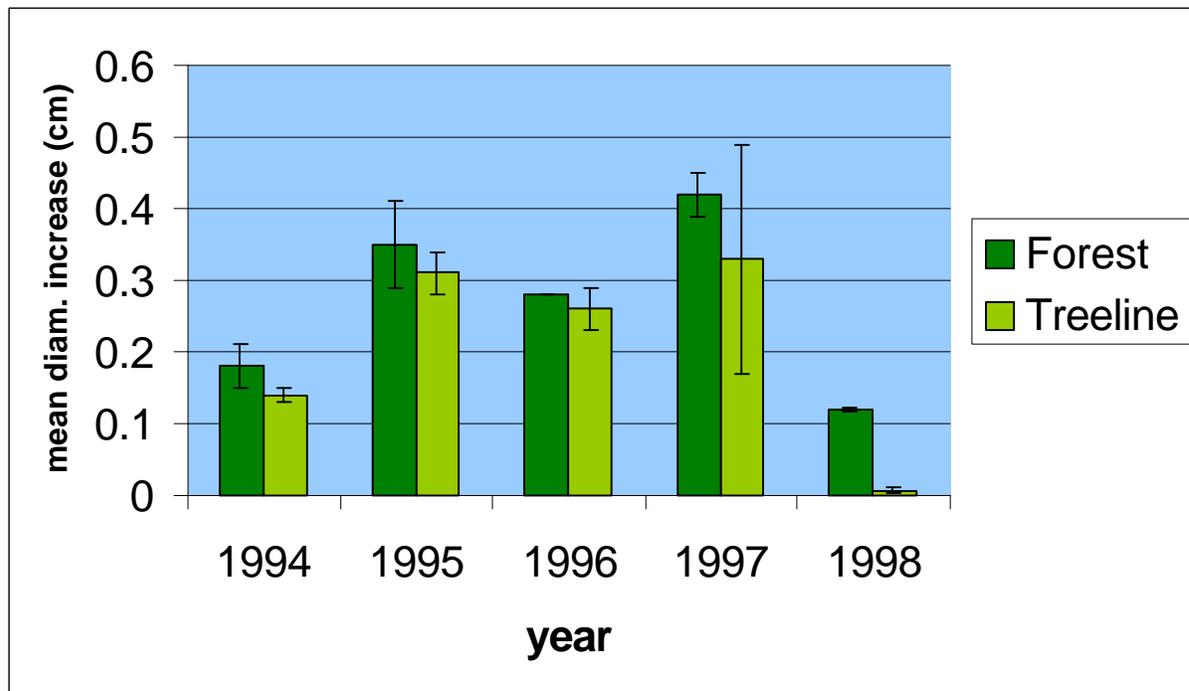


Figure 8. Mean increase in diameter of selected trees in forest and treeline sites Rock Creek watershed, Denali National Park, Alaska (error bars give standard error).

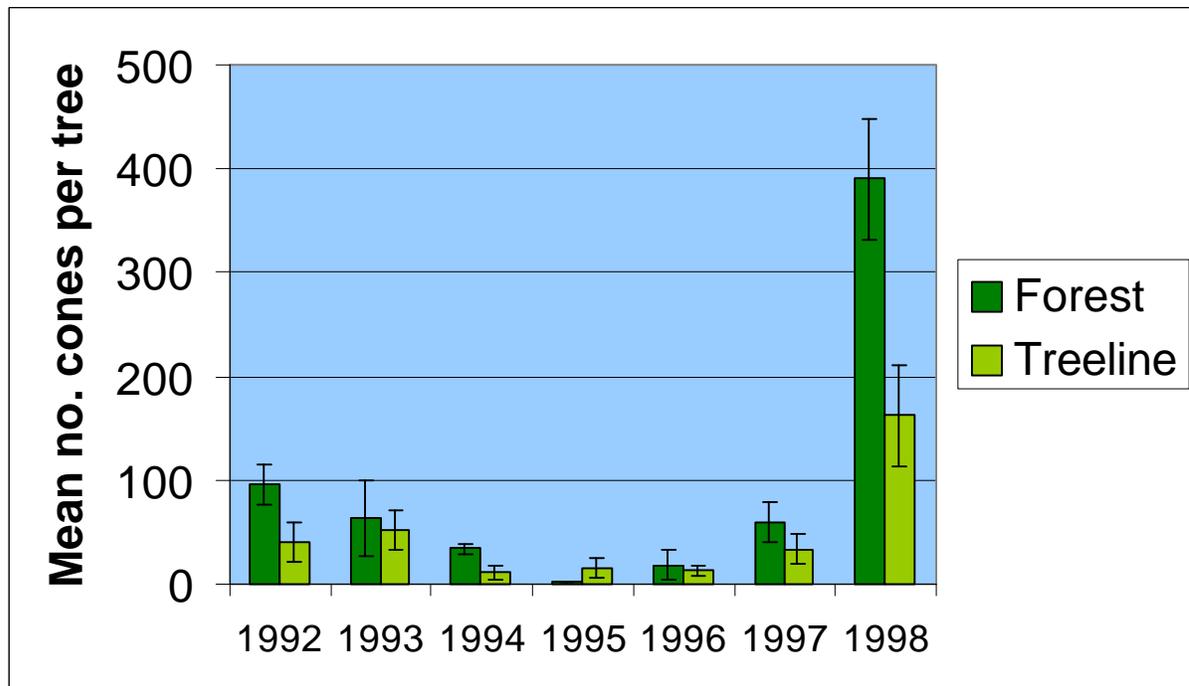


Figure 9. Mean number of cones per tree in forest and treeline sites in Rock Creek watershed, Denali National Park, Alaska (error bars give standard error).

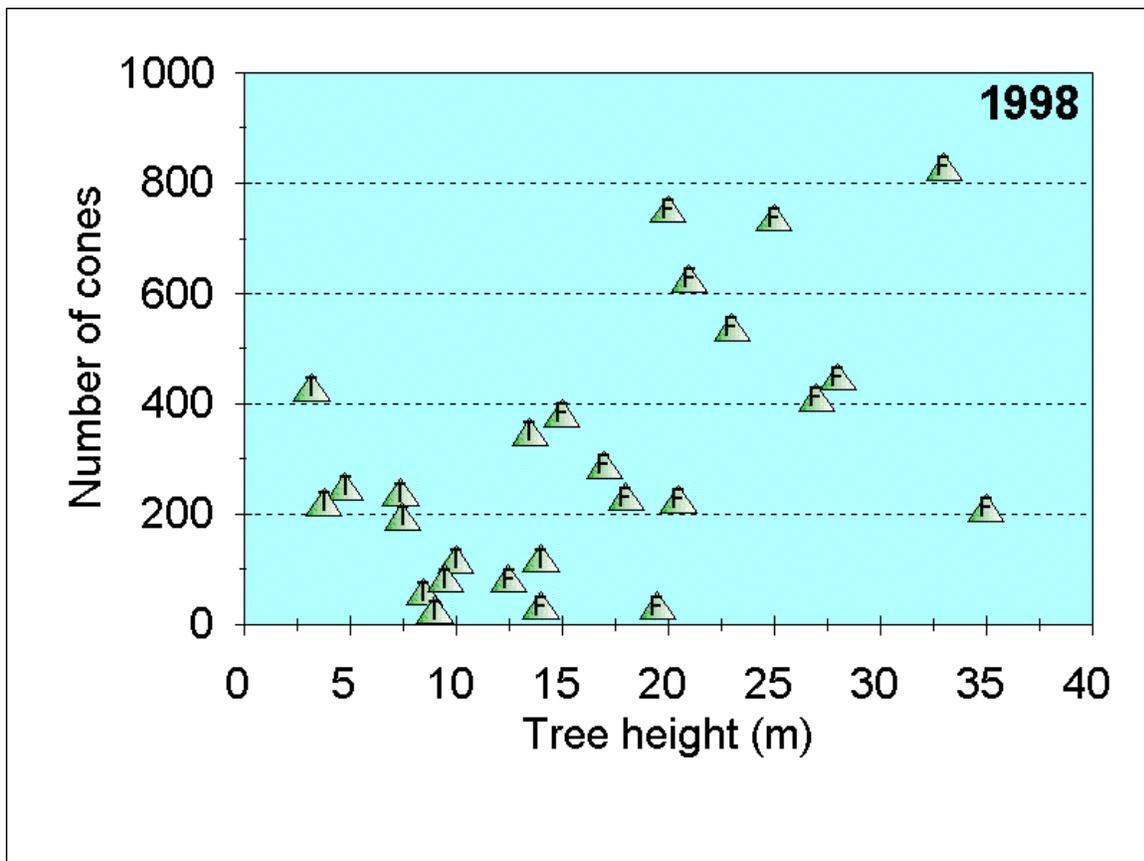


Figure 10. Number of cones produced per tree as a function of tree height for selected trees in the forest and treeline sites in Rock Creek watershed, Denali National Park, Alaska (letters in symbols indicate whether tree is located in Forest (F), or treeline (T) site).

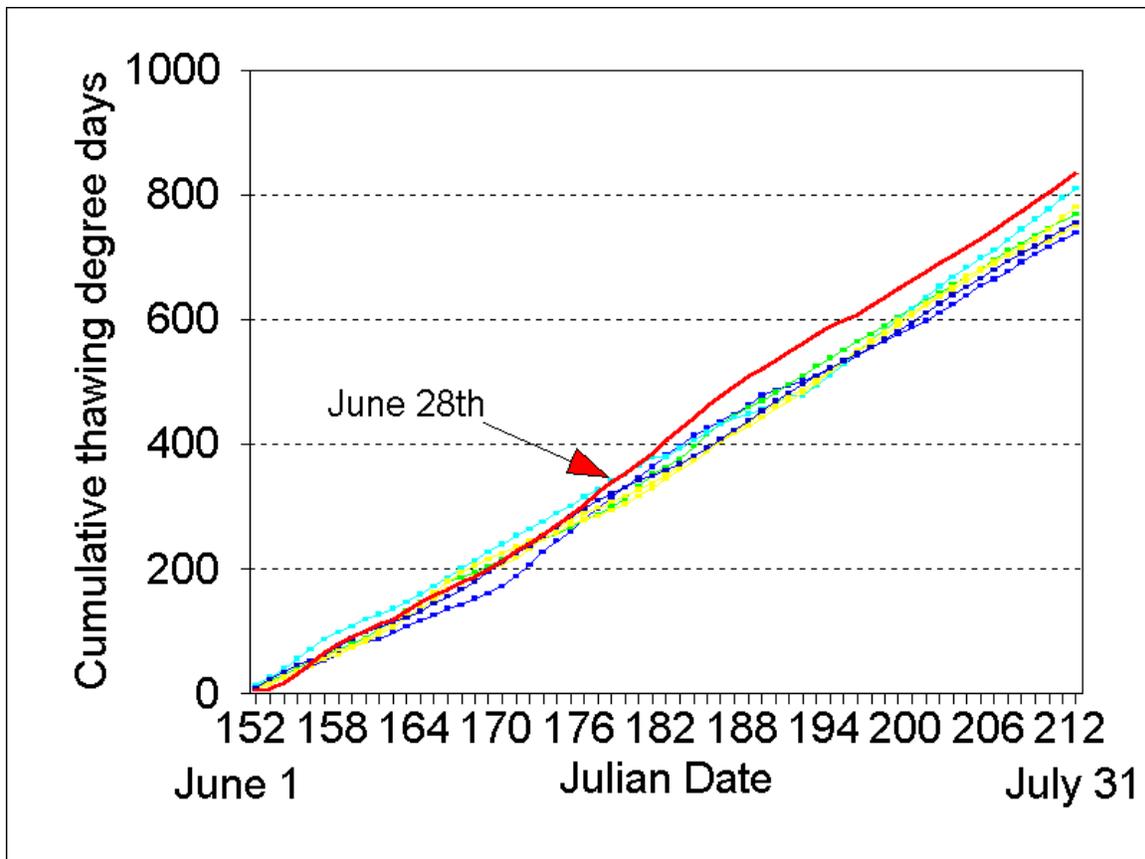


Figure 11. Cumulative thawing degree days for the years 1991-1998, tabulated from temperature data collected at Denali National Park headquarters, Alaska. Red line shows values for 1997.

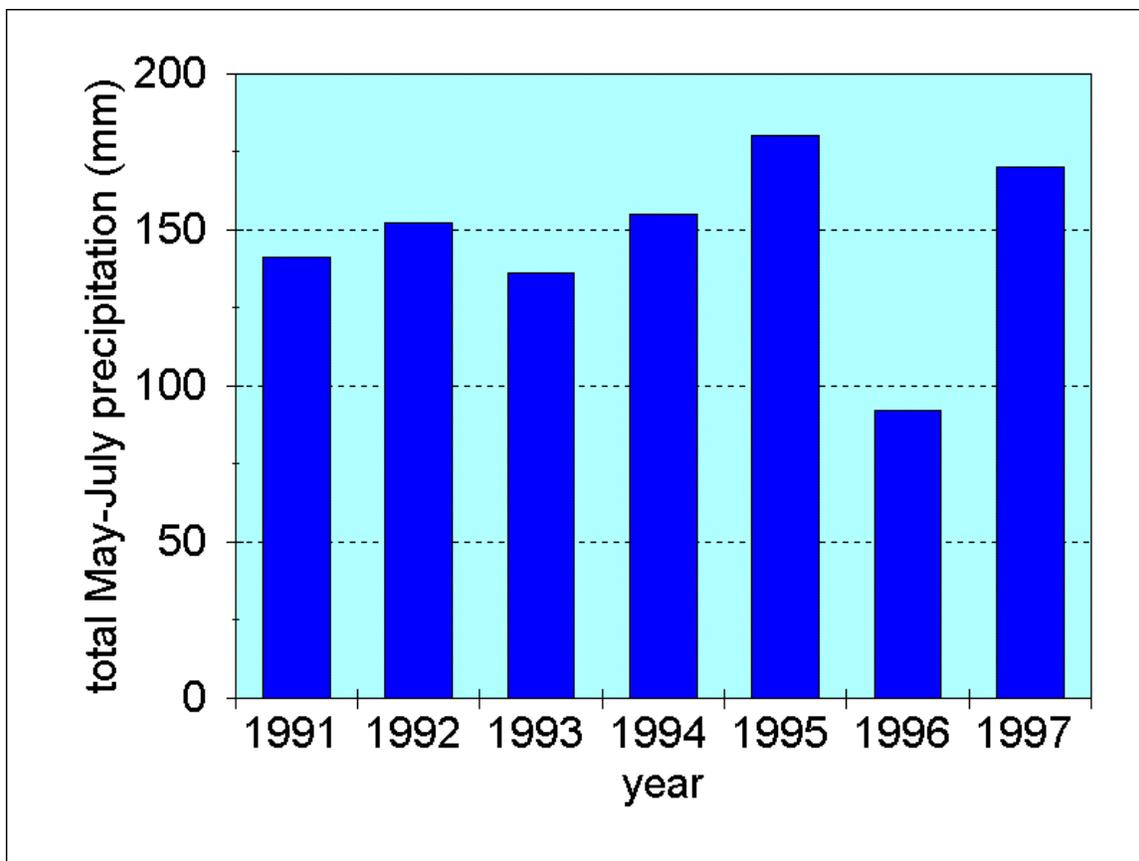


Figure 12. Total precipitation recorded for the period May through July for each year between 1991 and 1997.

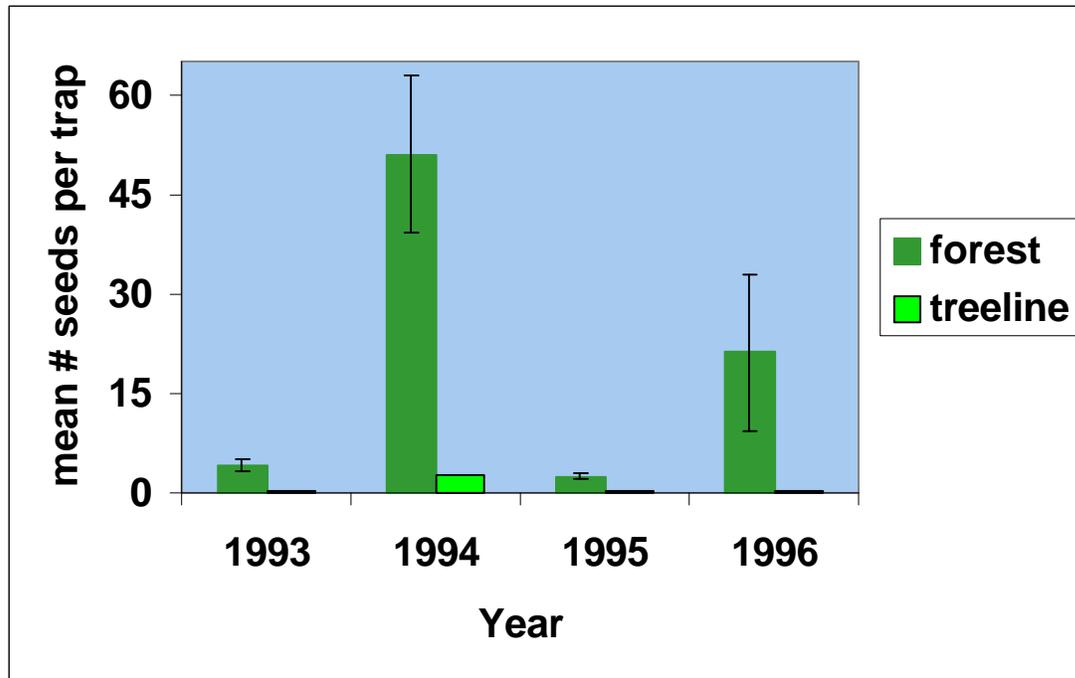


Figure 13. Mean number of seeds per trap for the forest and treeline sites in the Rock Creek watershed, Denali National Park, Alaska (error bars give \pm one standard error).

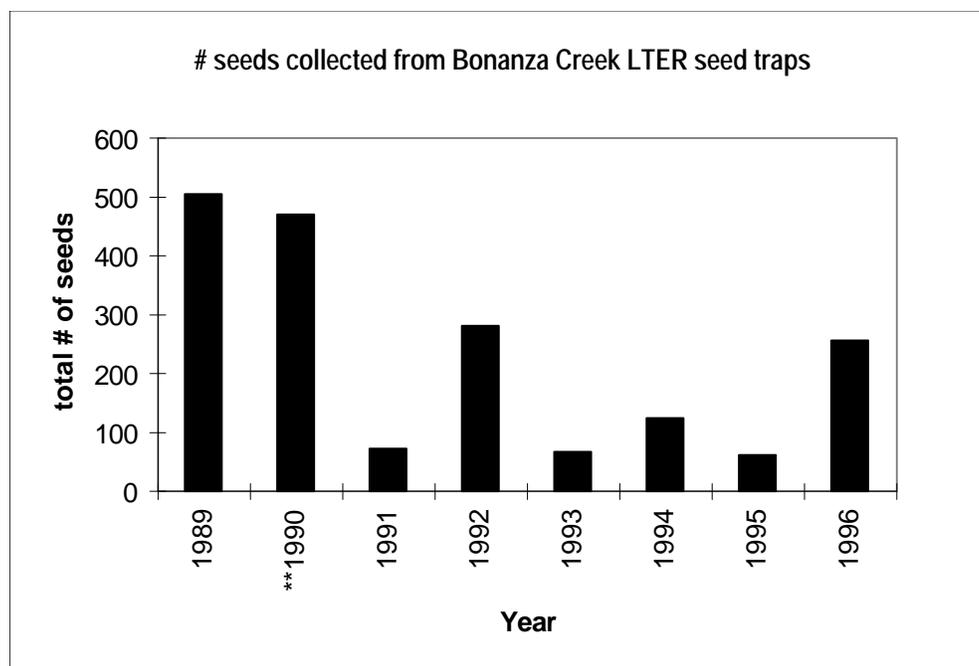


Figure 14. Total number of *Picea glauca* seeds collected in seed traps at Upland sites of Bonanza Creek experimental forest during the years 1989-1996. * one trap missing from 1990 data. Data retrieved from Bonanza Creek web page, and summarized and graphed here.

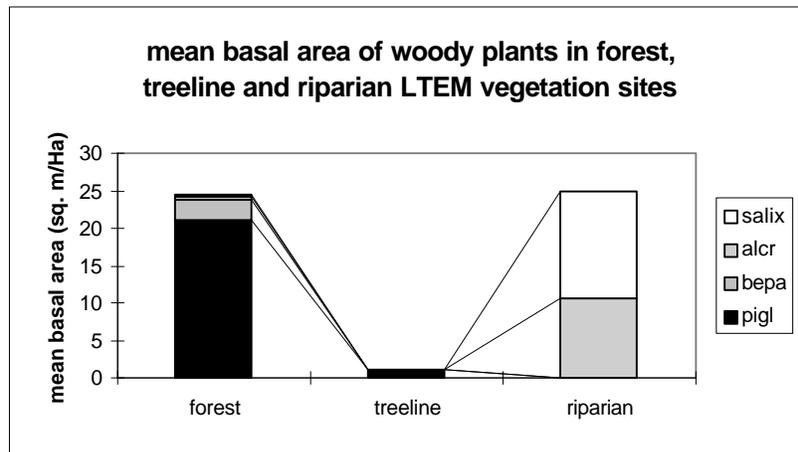


Figure 15. Mean basal area of woody plant species in three sites in the Rock Creek watershed, Denali National Park, Alaska.

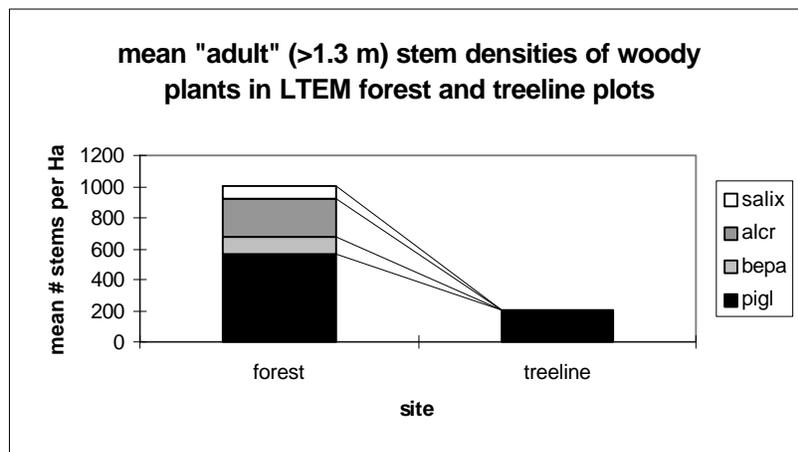


Figure 16. Mean number of stems per hectare of woody plants in the forest and treeline sites in the Rock Creek watershed, Denali National Park, Alaska.

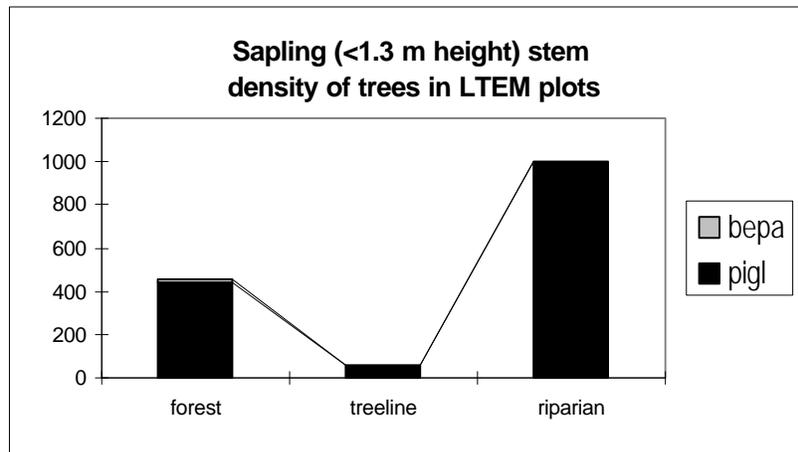


Figure 17. Mean number of stems per hectare of tree saplings (less than 1.3 m tall) in three sites in the Rock Creek watershed, Denali National Park, Alaska.

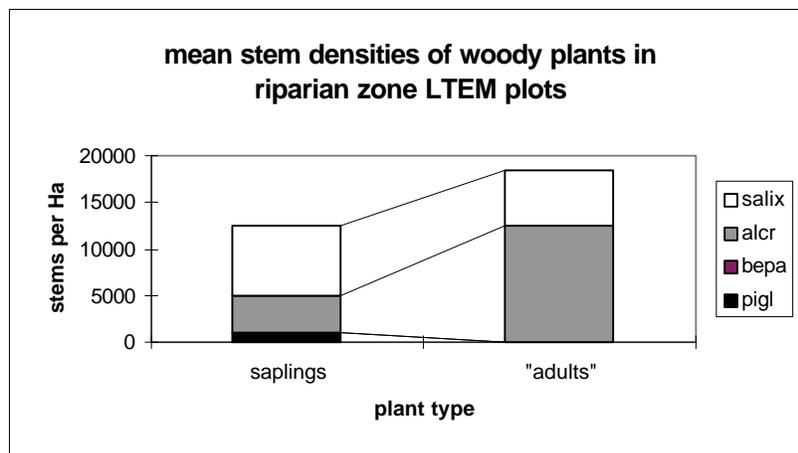


Figure 18. Mean stem density of woody plants in the riparian site in Rock Creek watershed of Denali National Park, Alaska. Saplings are individuals of less than 1.3 m in height, adults all others.

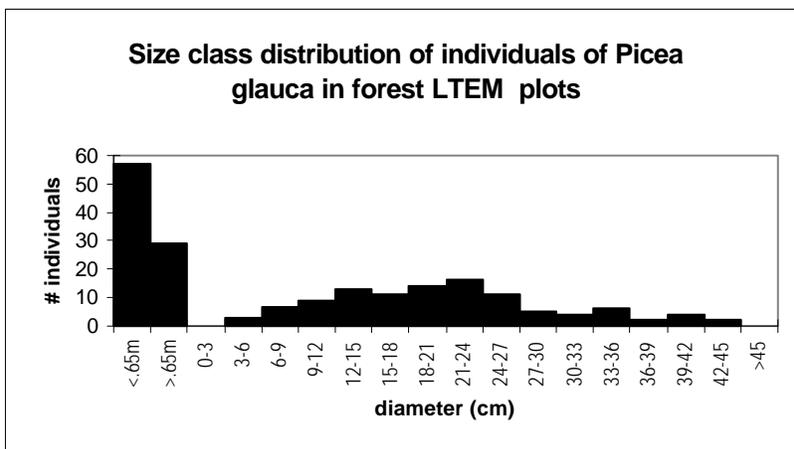


Figure 19. Histogram of size class distribution of white spruce individuals in forest site in Rock Creek watershed, Denali National Park, Alaska.

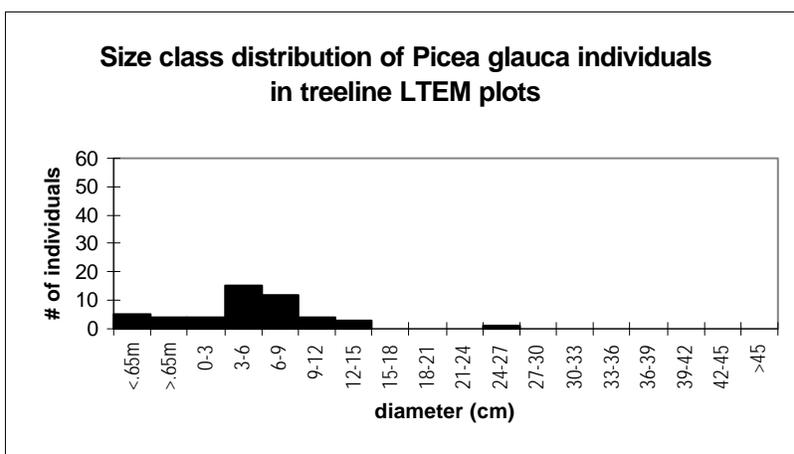


Figure 20. Histogram of size class distribution of white spruce individuals in treeline site in Rock Creek watershed, Denali National Park, Alaska.

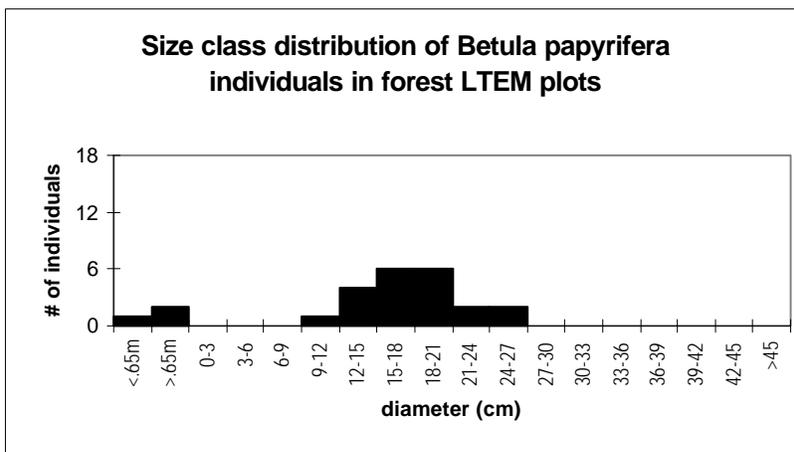


Figure 21. Histogram of size class distribution of paper birch individuals in forest site in Rock Creek watershed, Denali National Park, Alaska.

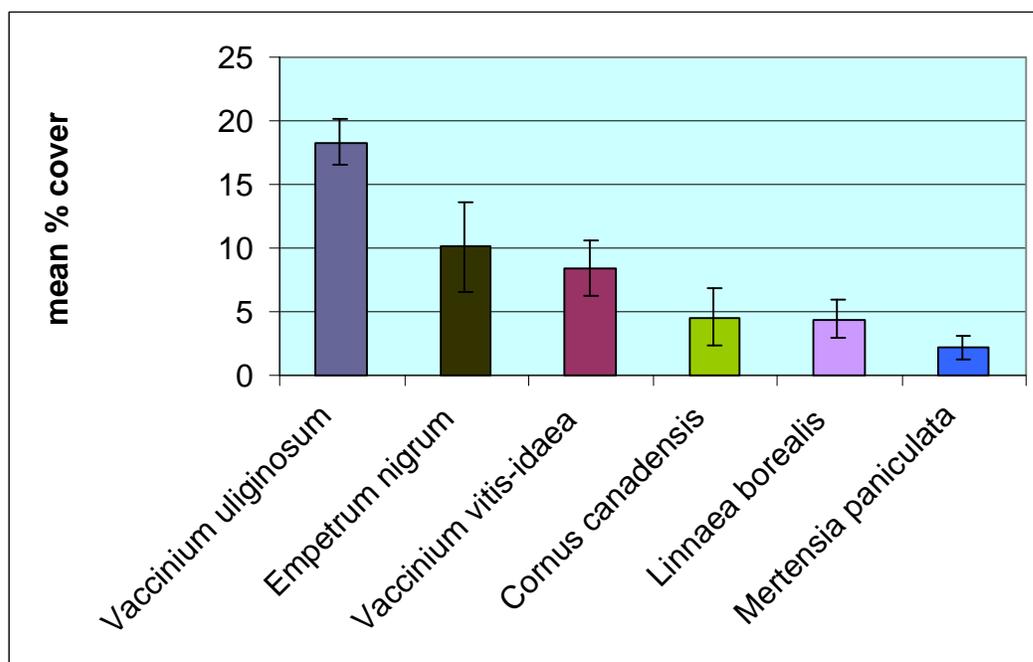


Figure 22. Mean percent cover of the six most abundant species in herb layer quadrats recorded in the forest site in Rock Creek watershed in Denali National Park, Alaska.

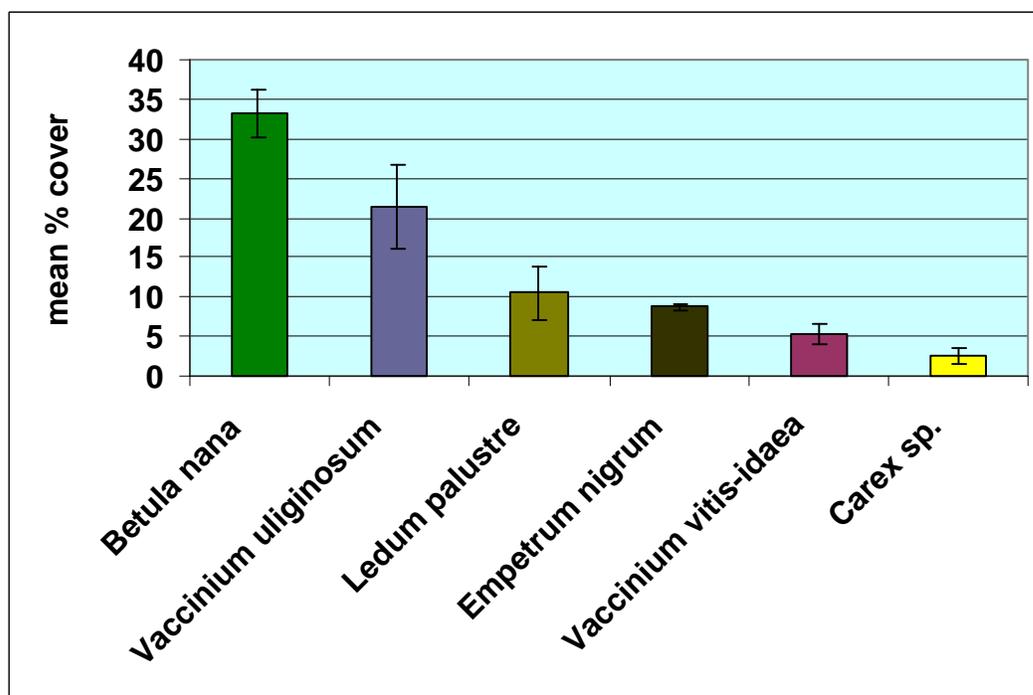


Figure 23. Mean percent cover of the six most abundant species in herb layer quadrats recorded in the treeline site in Rock Creek watershed in Denali National Park, Alaska (error bars give \pm one standard error).

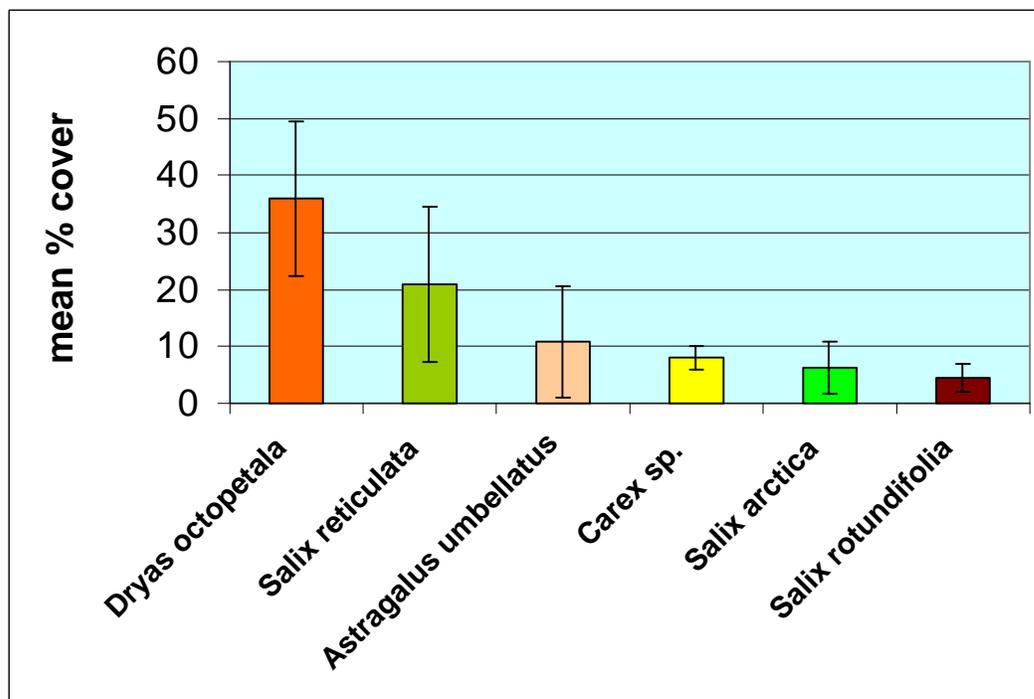


Figure 24. Mean percent cover of the six most abundant species in herb layer quadrats recorded in the tundra site in the Rock Creek watershed in Denali National Park, Alaska (error bars give \pm one standard error).

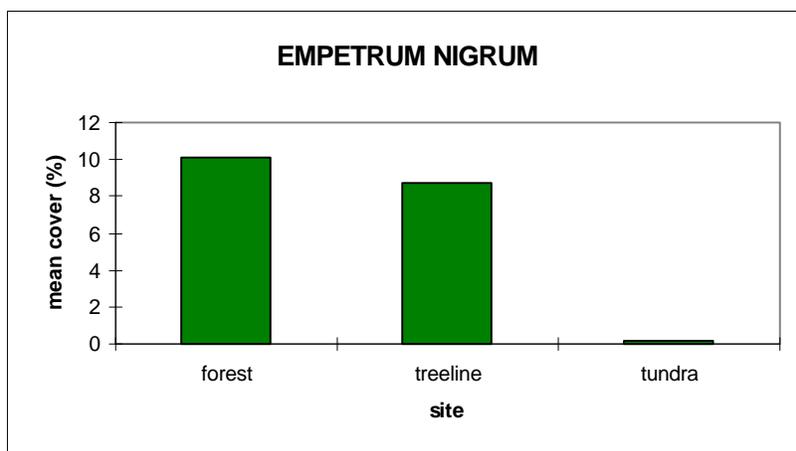


Figure 25. Gradient analysis of *Empetrum nigrum* cover in herb quadrats at three sites in the Rock Creek watershed, Denali National Park, Alaska.

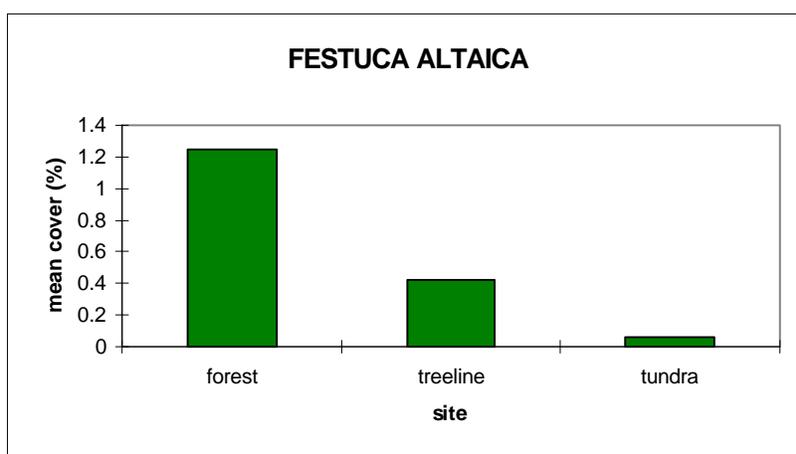


Figure 26. Gradient analysis of *Festuca altaica* cover in herb quadrats three sites in the Rock Creek watershed, Denali National Park, Alaska.

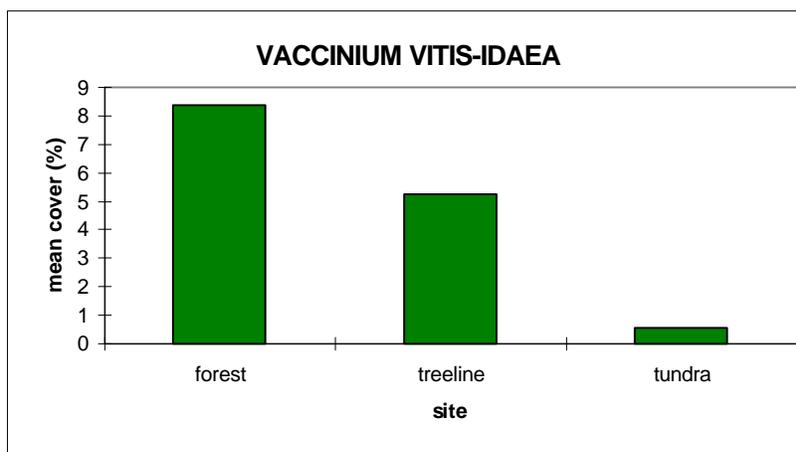


Figure 27. Gradient analysis of *V. vitis-idaea* cover in herb quadrats at three sites in the Rock Creek watershed, Denali National Park, Alaska.

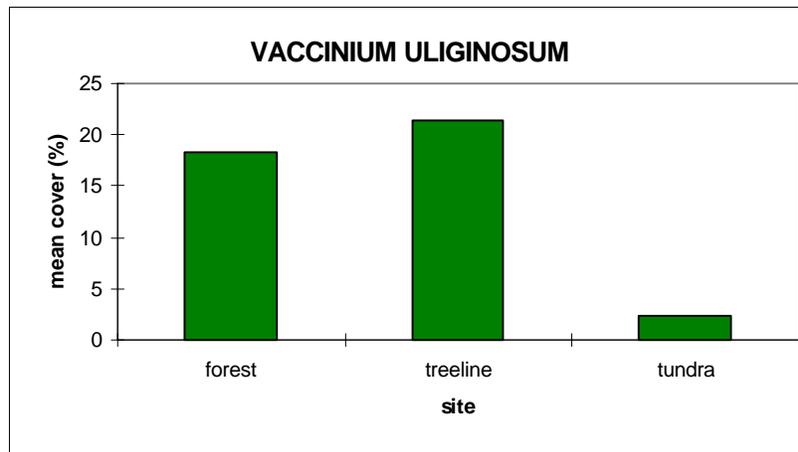


Figure 28. Gradient analysis of *V. uliginosum* cover in herb quadrats at three sites in the Rock Creek watershed, Denali National Park, Alaska

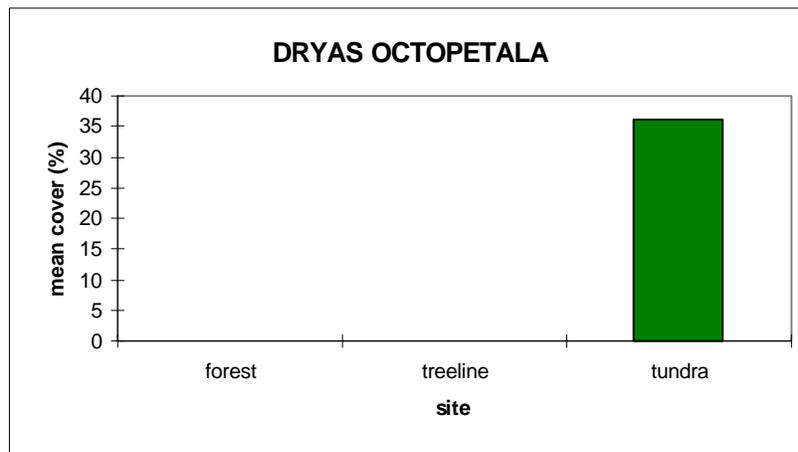


Figure 29. Gradient analysis of *D. octopetala* cover in herb quadrats at three sites in the Rock Creek watershed, Denali National Park, Alaska.

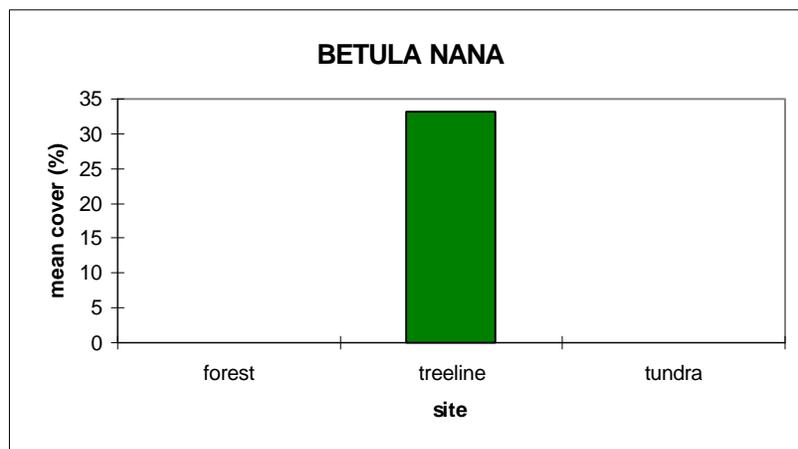


Fig. 30. Gradient analysis of shrub birch (*B. nana*) cover in herb quadrats at three sites in the Rock Creek watershed, Denali National Park, Alaska.

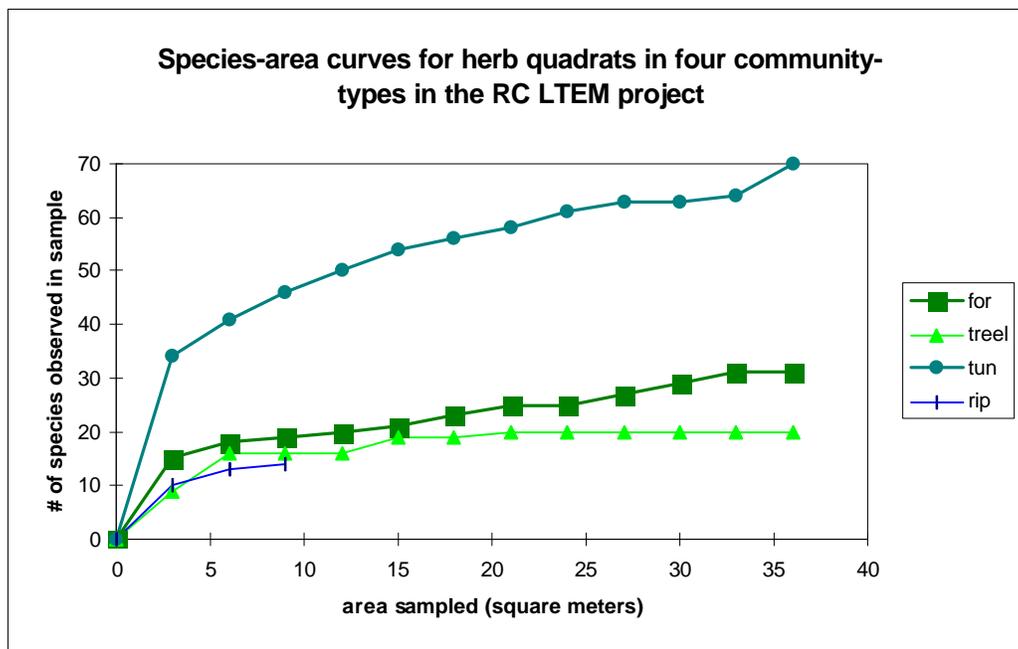


Figure 31. Species-area curves for four sites (forest, treeline, tundra, riparian) in the Rock Creek watershed, Denali National Park, Alaska.