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4 **Dendrochronological patterns of white spruce in the Noatak National Preserve in**
5 **northwestern Alaska.**
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9 Michael J. Arbaugh*

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11 *USDA Forest Service, Pacific Southwest Research Station,*
12 *4955 Canyon Crest Drive, Riverside, CA 92507, U.S.A.*
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14 Frank Suarez
15 Dan Binkley
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17 *Department of Forest Sciences, Colorado State University, Fort Collins, CO. 80523*
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39 *Corresponding author:
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41 Telephone: 303-491-7076

42 Internet: mikea@larix.cfnr.colostate.edu

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Historical growth patterns were studied at 10 tree line sites in the Noatak National Preserve in Alaska to examine the role of geography and topography on climate response. Six sites were located along the Agashashok River (80 kilometers north of Kotzebue) and 4 sites were located along the Kugururok River (200 kilometers northeast of Kotzebue). Three sites were on terrace areas of sediment deposited by historical flood events; three sites were located on hillsides adjacent to the river; and four sites were located at the forest-tundra ecotone on hillsides adjacent to the river valleys. Principal component analysis indicated that plots within drainages were similar, and that terrace sites differed from hillside sites.

Climate information from the seven nearest weather stations was used to examine the patterns of monthly and seasonal climate variations as a function of residual ring-width for each of the sites. Ring-width correlations with multiple station averages were more consistent across sites than correlations using individual weather station records. Ring-widths correlated positively with June temperature and negatively with previous July temperature for all sites. Each drainage showed characteristic climate correlations. The Agashashok sites correlated positively with November temperature and February precipitation, while Kugururok sites were positively correlated with September precipitation. There were also differences in climate correlations for the terrace sites relative to other sites within each drainage.

These results indicate that geographical and topographical characteristics may influence tree response to climate at the northern tree line. It is also possible that the precipitation response observed, and some temperature responses, may indirectly influence growth through modification of soil conditions.

Introduction

Ecotones are potentially the most sensitive portions of ecosystems, and as such they are valuable early indicators of the effects of climate change (Neilson, 1993). This is especially true for areas which are primarily temperature limited, such as the northern white spruce-tundra ecotone in Alaska and Canada. Extremely cold winters and short growing seasons may make this area sensitive to climate changes. This area may also have a more direct response to temperature changes than more southerly ecosystems where evapotranspirational stress may obscure the estimation of direct temperature-growth effects.

Several studies (Garfinkel and Brubaker 1980; Cropper and Fritts 1982; Jacoby and Cook 1982) linking ring widths with summer temperatures and growing day sums have been conducted. These studies generally agree about the significance of present and past growing season effects; however, little agreement has been reached about the importance of precipitation on tree growth for this area.

Most of these studies consider sites located over large areas (Garfinkel and Brubaker 1980; Cropper and Fritts 1982; Jacoby and Cook 1982), typically with short weather records are used from a few locations. This makes it difficult to determine the confidence in the correlations due to remoteness of the weather stations from study sites (Cropper, 1982). Little is known about the role of geography or topography on climate response for this area.

In this study we sampled 10 stands at two river drainages in the southern Brooks Range as part of treeline expansion study. The sites were used as 'replicates' for a climate analysis with single weather station records, and multiple weather station averages. Site chronology response to individual weather stations and averages of stations was examined. Differences in response of the individual sites to the climate series selected was then examined, to determine if topographical or geographical differences influence the climate response.

Study sites

Two river basins, the Agashashok and the Kugururok (68° 20' N Latitude, 117° 7' longitude), were selected as representatives of tundra-white spruce forest ecotones. The forest is mostly continuous along the river basins, but becomes increasingly patchy towards the sides of the basin. The forests did not extend past the top of the basin for either area, although it did extend for several kilometers up tributary washes. The Kugururok basin was approximately 120 km further north than the Agashashok sites.

White spruce dominated the forests of both areas. Shrub forms of Balsam poplar (*Populus balsamea*) and Willow (*Salix spp.*) occasionally were found in the plot areas. The understory of hillside plots consisted of *Lupinus arctus*, *Cassiope tetragona*, *Salix spp.*, *Eriophorum spp.*, *Equisetum spp.* and feather moss (*Hylacornium splendens*). The understory of terrace stands consisted primarily of feather mosses, *Lupinus arcticus*, and *Equisetum sp.* Many of the trees in the terrace stands had some degree of bole deterioration.

Stand ages were comparable for most sites. The oldest trees at the sites ranged from 1708 to 1797 for 8 sites, with the median age ranging between 1812 and 1868. Two sites (KUT-2 and KUH-2) were younger; the oldest trees being 1842 and 1816 respectively. Median tree ages for these two sites were within the range observed for the other sites.

Climate data

Long term climate records are sparse for north Alaska. Both river basins were located in Division 9 (Arctic Drainage) of National Oceanic and Atmospheric Administration weather records (NOAA Climatological Data 1991). This division contains nine stations and only two are interior locations. Division 8 (Interior West)

1 stations were included as candidate climate stations to increase the number of stations in
2 the analysis.

3 Monthly climate data were obtained for 7 stations nearest to the study sites (Fig.
4 1) or at equal latitude. Monthly mean temperature and total monthly precipitation were
5 obtained for each individual station, for several station averages, and for 5 x 10 degree
6 grid-box values. Grid-box values are temperature values developed for large regions
7 from temperature anomaly information using all available climate data. All records
8 were acquired from the World Climate Disc (Chadwyck-Healey, 1992). This package
9 includes information from World Weather Records, Monthly Climatic Data for the
10 World, U.S. Weather Bureau and the World Meteorological Organization. Grid-box
11 temperatures were developed at the Climatic Research Unit, University of East Anglia,
12 UK.

13 The examination of both individual station climate data, averages and grid-box
14 values was included due to the uncertainty related with using remote weather stations.
15 The nearest weather station to the sites is in Kotzebue, however this station is located at
16 the end of a peninsula and may represent marine sea surface conditions more accurately
17 than inland weather. It also receives only about half the precipitation relative to inland
18 stations, but has similar evapotranspiration rates (Patric and Black, 1968). Similar
19 latitude stations were 10° - 15° east in longitude but past studies (Garfinkel and
20 Brubaker 1980; Cropper and Fritts 1982; Jacoby and Cook 1982) indicate these may be
21 more relevant than coastal data.

22 The climate at this area is the most severe weather tolerated by forest tree
23 species. Long winters with temperatures of -75° C occur (NOAA, 1991). This severe
24 cold contributes to shallow rooting zones over permafrost soil conditions on hillsides.
25 The growing season at this latitude may be as little as 6-8 weeks and occurs June to
26 August (Marr 1948; Oswalt, 1960; Larson 1980).

Methods

Six sites were sampled in the Agashashok river basin (Ag) and 4 sites were sampled in the Kugururok basin (Ku). Two sites in the Kugururok basin and one from the Agashashok basin were located on terraces composed of sediment deposition from old flood events. The other sites were located on hillside slopes of the basin areas. Two sites at the Agashashok were located adjacent to the river, and the others were located at the forest-tundra ecotone of the basin areas. Whenever possible these were located directly above the lower stands.

Trees were sampled only in continuous white spruce stands, on slopes of 0 to 50%. Trees were cored at each site along a 20 m wide transect; the length of the transect varied between 10 and 30 m, depending on the density of trees that fit the sampling criteria. All trees within the transect were sampled that were at least 50 years old at 1.4 m., did not have major crown or stem deformities or scars, and were not suppressed, based on crown classification (Spurr and Barnes 1980). Dbh (at 1.4 m), height and bark thickness were measured for each tree. Stem density and basal area at each site were determined with 5 circular 0.03 ha quadrats; only trees taller than 1.4 m were included in the sample.

Two cores were extracted from each sample tree at 1.4 m. with an increment borer. Cores were taken from the cross slope sides of the tree and stored in paper straws until they were processed. Cores were glued into wood mounts and sanded with successively finer grades of sandpaper until individual tracheids were visible under a microscope.

Ring widths were measured to the nearest 0.01 mm with an incremental measuring machine equipped with digital encoder. This machine is connected to a microcomputer that stores ring widths by year for each core (Robinson and Evans 1980). A video camera attached to a binocular microscope is used to transmit the core image to a monitor.

1 Cores were included in the database only if they could be confidently crossdated
2 (Fritts 1976) by accurately associating the rings of each core with a specific year. The
3 last ring measured was formed in 1991, because cores were collected during the
4 growing season of 1992. Cores were initially crossdated visually by indicating dates
5 directly on the core (Stokes and Smiley 1968). All rings were measured and recorded.
6 Following ring measurement, crossdating was verified with the program COFECHA
7 (Holmes 1983), which calculates correlation coefficients between the time series of ring
8 widths for a single tree, and for an entire collection of trees.

10 *Chronology Development*

11 Individual ring width series were standardized to remove variation associated
12 with increasing bole size, disturbance and forest dynamics processes. A cubic spline
13 curve was fitted (Cook and Holmes 1985) for trend removal. A 50-year spline stiffness
14 was used for standardizing after several spline stiffnesses were examined. This spline
15 may remove some of the longer term climate affects identified in past studies (Jacoby
16 and D'Arrigo, 1989), but resulted in larger climate correlations in this study due to the
17 lack of trend in growing season temperatures or annual precipitation (Fig 2).

18 Series were further detrended by fitting an autoregressive function to the ratio
19 residuals from spline curve fit. This resulted in individual series which had no residual
20 trend remaining in the series (Fig. 3). Series from each site were averaged using the
21 Tukey's Bi-weight estimator of the average into a single mean site chronology. The
22 mean sensitivity of the chronologies averaged 0.162 and the signal-to-noise ratio
23 averaged 13.3 (Table 1). These values are comparable to those reported in previous
24 studies in this area (Cropper 1982; Cropper and Fritts 1981).

26 *Principal Components Analysis*

Principal component analysis (Jolliffe 1986) was used to examine the patterns of common variation among the sites. This technique transforms a group of variables into a set of variables that have decreasing amounts of variance, and are mutually independent. This generally results in the first PC being roughly equivalent to an overall average of the sites, and the following PC's being group differences from the mean response. Loadings, or weighting coefficients, reflect the correlation of the individual site with the PC. The sign and size of these correlations may indicate groups of similar sites.

In this study the site chronologies were entered as variables in a principal components analysis with years as observations. The analysis was based upon the correlation matrix of the common period of 1903-1991, and was conducted using the PRINCOMP procedure (SAS Institute Inc., 1988). The first five components were retained for examination, and accounted for 91 % of group variation. Graphs of PC loadings were constructed to suggest groupings of sites. The first three PC's were retained for analysis (73%, 8% and 5% of group variance); higher order PC's were observed to have little meaningful information about site chronology groupings.

Climate Analysis

Pearson correlations were calculated for single station climate records and residual ring width series for a 16 month period beginning at the previous June and ending with current September. This period is similar to Cropper and Fritts (1982) and Garfinkel and Brubaker (1979). A Bonferroni adjustment (Samuel, 1989) factor was used to obtain the group significance levels for all correlations. This correction factor reduces the p-value associated with the confidence level when groups of variables are used, to reduce the incidence of spurious correlations associated with random matches. In this study 16 candidate variables were used. Because the Bonferroni procedure may result in conservative confidence intervals for large groups a 90% confidence level was

selected. This resulted in a minimum significant correlation coefficient (r) of > 0.28 (< -0.28).

Results

Structural Characteristics

Trees varied in dbh and height between sites (Table 2). The Ag sites were generally more variable in diameter and height than the Ku sites. The terrace sites generally had taller trees than hillside sites with large, but not the largest diameters. Among the hillside sites, there was considerable variability in the diameter and height of the trees.

The terrace sites also generally had high densities resulting in large basal areas per hectare. In contrast the Ku-hillside sites had the smallest basal areas per hectare. Among the lower and upper hillside sites of the Ag there was no apparent pattern for dbh, height, density or basal area.

Principal Component Analysis

The first PC is usually a weighted average of the series. For these sites the loading values were positive and roughly equal across stands, and the proportion of variation explained was 73%. This is similar to values found by Jacoby and D'Arrigo (1989). The second and third PC had mixes of positive and negative loadings that revealed group structure among the sites. PC2 loadings reflected differences between the two drainages that were apparent in a scatter plot of the loadings (Fig. 4a). PC3 loadings generally reflected differences between terrace and hillside sites (Fig. 4b). This difference is very strong for the Ku sites, but is much less for the Ag terrace site.

The analysis indicated that there was no separation of lower hillside and upper hillside Ag sites. This may indicate that specific microsite conditions rather than slope location influence growth and climate response for white spruce stands in this area.

1 This is supported by the broad differences in the structural and sample measurements
2 observed for these sites (Table 1, 2). On the basis of this analysis the original site
3 groupings were reformed into three groups of sites; Ag-hillside, Ku-hillside and all
4 terrace sites.

6 *Climate Analysis*

7 The months with significant climate correlations varied across the sites when
8 individual climate station records were used for the analysis (Fig. 5). Many of these
9 differences may be spurious associations resulting from modeling non-climatic variance
10 unique to individual site chronologies. This idea is supported by the lack of similar
11 correlations within the tree groups of sites determined by the principal components
12 analysis. Grid-box and several station averages were also correlated with the site
13 chronologies due to the results from individual stations. Four regionally averaged
14 climate series were developed. Series 1 contained all candidate sites, series 2 omitted
15 the coastal Barrow stations, series 3 omitted the coastal Barrow and Kotzebue stations,
16 and series 4 omitted Barrow, Kotzebue and the southerly McGrath station.

17 The four regional climate series indicated similar patterns of correlations with
18 the site chronologies. Series 3, containing all interior sites, was chosen for the final
19 analysis because it had the most consistent correlation pattern across site locations and
20 positions. Grid-box temperatures based upon regional temperature anomalies resulted
21 in low correlations with the site chronologies. Their use was not recommended by
22 Chapman-Healy, nor did it result in correlations consistent with the groups defined by
23 the principal component analysis.

24 All chronologies correlated positively with present June mean temperature.
25 Significantly larger correlations were observed for the slope sites at the Agashashok
26 River, smaller for the Ag terrace plot and the smallest were all at the Kugururok river

1 sites (Fig. 6a). All sites were also correlated negatively with previous July
2 temperatures.

3 The Ag slope sites also had positive correlations with November temperature,
4 that was absent for the Ku sites. The Ku terrace sites, however, were positively
5 correlated with present year August temperatures, while the Ku terrace plot was not .

6 There were no precipitation correlations that were common for both river
7 basins. The Ag was consistently associated with February precipitation, while the Ku
8 sites were associated with present September precipitation (Fig. 6b). The Ag terrace
9 plot was also positively associated with September precipitation.

10

11 Discussion

12 Climate correlations were consistent for the groupings determined by principal
13 components analysis. The two temperature correlations common to both basins were
14 similar to those observed in past studies of this region (Cropper and Fritts, 1981,
15 Cropper 1982, Garfinkel and Brubaker 1980). The large June correlation is likely due
16 to increasing the rate and duration of the growing season by initiating photosynthesis
17 and soil warming earlier. The negative effect of the previous July has been associated
18 with allocation changes associated with compensation for short growing seasons
19 (Garfinkel and Brubaker, 1980). It also may be due to allocation to height growth after
20 a long growing season (Mikola, 1962).

21 Positive correlations with previous November temperatures have been associated
22 with bud formation (Heide, 1974), or additional carbohydrate storage associated with
23 longer growing seasons (Garfinkel and Brubaker, 1980). The absence of significant
24 correlations for the Ku sites may imply that some other moderating factor, such as
25 topography or proximity to the coast allows the Ag trees to utilize warm autumn
26 conditions.

Precipitation correlations were consistent within river basins, however, had less obvious explanations as direct growth factors. February precipitation may contribute to increased water availability during the growing season, however it is not typically the month with the largest precipitation. September precipitation at the end (or past) of the growing season is the most surprising result. It is possible that trees may continue growing during September (Oswalt, 1960) although it has not been widely documented. It is unlikely that the correlation was spurious, however, because it was significant for 3 of 4 Ku sites (and positive nonsignificant for the other) and the Ag terrace site.

Although evapotranspiration rates of the arctic indicate that only a small amount of the available water is used by plants (Elliot-Frisk, 1988) over the entire year, it is possible that water stress effects may prolong growth at the end of the growing season for some soil conditions. Our work on irrigation of non-tree vegetation on a terrace beside the agashashok river indicates a McGrath water limitation on growth (D. Binkley Unpub.)

Direct effects of precipitation for both of these months may also interact with temperature stress (air or soil) on growth. This area needs much more study, however, before the exact mechanisms can be understood.

Conclusions

The sites studied showed strong and consistent positive correlations with current June temperature and negative correlations with past July temperature. These correlations are likely to be true climatic responses by trees, since they occurred for all sites, match known physiological growing season information, and have been reported in most past studies.

Climate response also partially depends on the location and topography of the site. Differing river basins, and differing slope (terrace or hillside) within drainages, exhibited consistent differences in climate correlation patterns that matched site

1 groupings suggested by the principal component analysis. The results of both analyses
2 indicate a hierarchical relationship exists among the sites that consists of: common
3 regional response, then drainage response, then topographical position (although
4 topographical position response is much stronger for the Kugururok than for the
5 Agashashok drainage).

6 The non-intuitive pattern of correlations with precipitation may indicate that a
7 complex or indirect effect of precipitation on growing conditions is occurring. More
8 work on water limitations, and soil and permafrost conditions at treeline sites are
9 needed.

10 The use of single station weather records (from 200km or farther away) was
11 found to result in inconsistent correlations, especially with precipitation. This may
12 partially account for the results of other studies (Garfinkel and Brubaker, 1980;
13 Cropper and Fritts, 1982; Jacoby 1982) that found inconsistent results that were
14 difficult to interpret. This study had the advantage of using sites as 'replicates' to
15 examine the consistency of the climate response patterns.

17 Acknowledgments

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1 Table 1. Summary forest information for sample sites. Ba/ha is basal area (white
 2 spruce) per hectare.
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 4

Site	Density		Basal Area		Chronology Mean Sensitivity	Signal-to- Noise Ratio
	Mean	SD	Mean	SD		
	(#/ha)		(m2/ha)			
AGH-1	770	218	12.8	3.6	.189	19.8
AGH-2	702	328	22.0	8.3	.160	3.8
AGH-3	941	234	12.2	3.5	.169	16.6
AGH-4	968	200	10.5	4.6	.147	14.0
AGH-5	892	233	16.5	3.5	.173	17.6
AGT-1	805	239	29.3	10.7	.168	15.6
KUT-1	994	221	31.6	8.1	.150	8.7
KUT-2	1217	189	21.9	4.1	.172	13.8
KUH-1	936	324	10.3	0.97	.155	13.2
KUH-2	707	269	6.4	1.9	.139	9.9

1 Table 2. Summary statistics for study sites. Ag - Agashashok, Kug - Kugururok.
 2 High slope is hillside treeline, Low is hillside near flood plain and terrace is on flood
 3 plain terrace.
 4

Site	River Basin	Slope Type	Dbh Mean	Dbh SD	Height Mean	Height SD
AGH-1	Ag	High	27.6	7.9	40.5	17.4
AGH-2	Ag	High	19.7	4.7	34.8	9.3
AGH-3	Ag	High	18.2	3.6	32.4	8.7
AGH-4	Ag	Low	16.1	5.8	28.9	9.4
AGH-5	Ag	Low	20.3	5.3	38.2	9.2
AGT-1	Ag	Terr	25.0	5.2	46.6	9.0
KUT-1	Kug	Terr	28.0	6.4	49.8	7.2
KUT-2	Kug	Terr	23.7	4.5	45.3	11.2
KUH-1	Kug	High	20.8	4.8	42.6	11.6
KUH-2	Kug	High	24.0	5.0	28.6	13.9

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 6
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Figure Captions

Figure 1. Map of Alaska state showing study locations (round symbols), and climate stations used in the analysis (square symbols).

Figure 2. Average growing season temperature for mean interior station values (A) and total annual precipitation (B). Growing season was defined as June, July and August. The regional climate average used all interior stations (Fig. 1), but not Kotzebue or Barrow.

Figure 3. Residual ringwidth chronologies for three sites. The UP site is a hillside site at the Agashashok river, and 2UK and 1LK are a hillside and terrace site, respectively at the Kugururok river.

Figure 4. Scatter plots of principle component loadings. The two drainages show clear groupings in (A) that are reflected in differences in PC2. (A - Ag sites K - Ku sites). PC3 (B) reflects differences between terrace and hillside slope position (T - terrace sites, H-hillside sites).

Figure 5. The number of significant monthly climate correlations obtained between individual weather stations and the study sites. The five interior weather stations were correlated with each of the 10 study sites. Correlations had to be greater than 0.28 or less than -0.28 to be significant. Bars above the line indicate the number of significant positive correlations and bars below the line indicate the number of significant negative correlations.

- 1 Figure 6. Average correlations for significant months of temperature (A) and
- 2 precipitation (B) for the three groups identified by the principal component analysis.
- 3 Ag- hillside consists of 5 sites, Ku-hillside of 2 sites, and terrace of 3 sites. *'s
- 4 indicate significant correlations for each site in the group at the 90% confidence level.
- 5

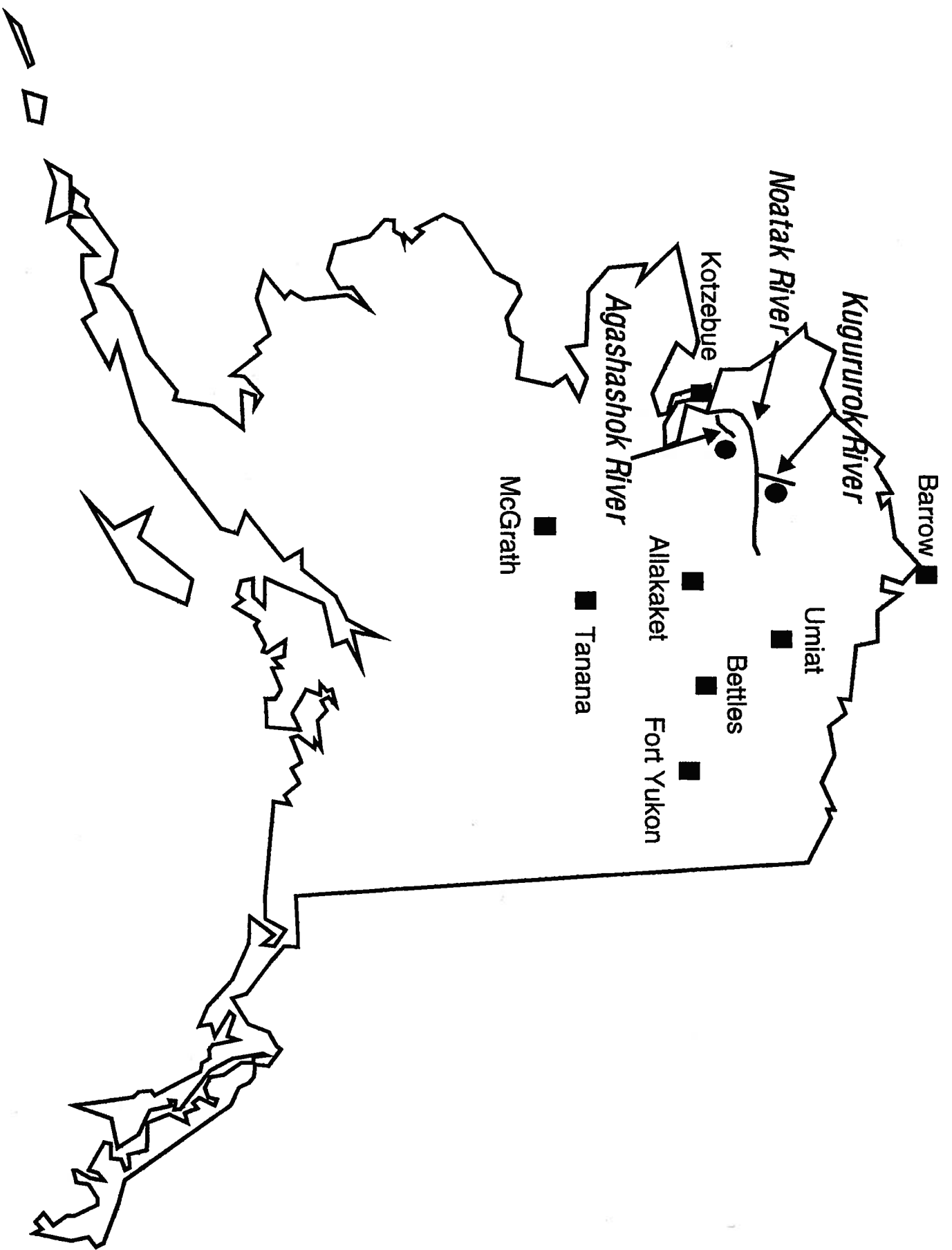
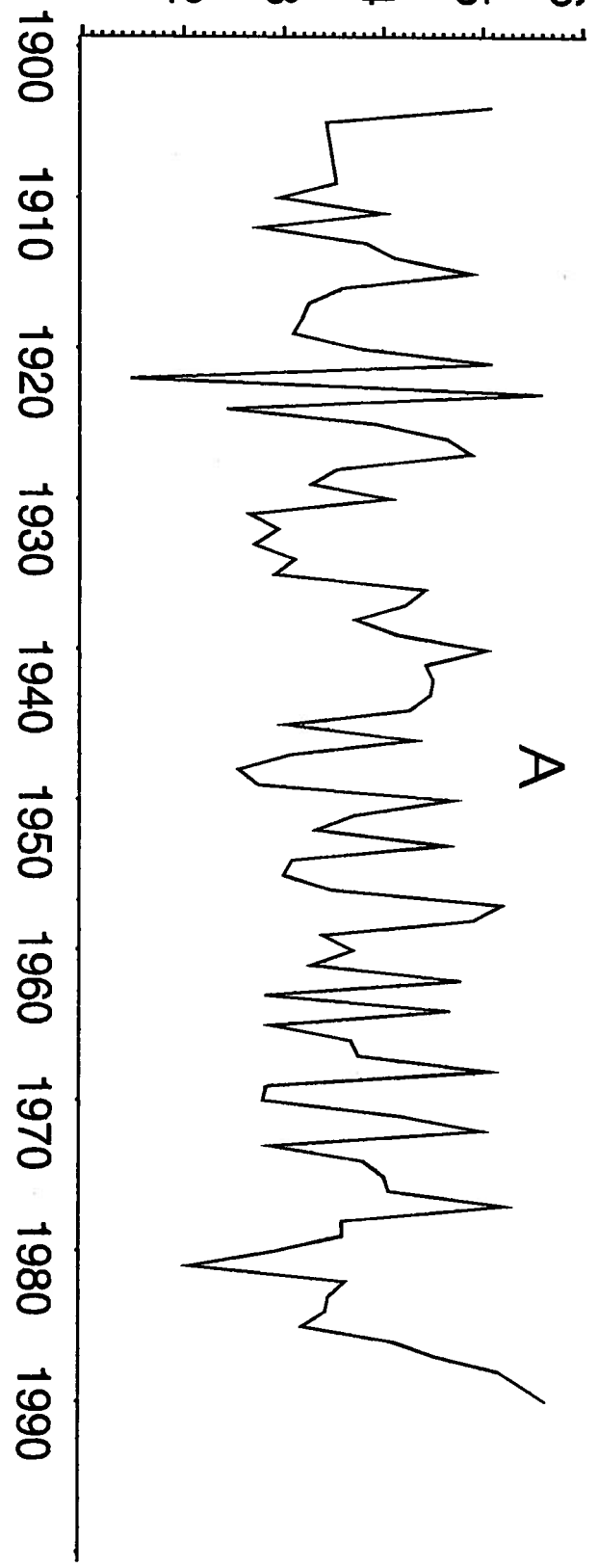


Fig. 1

Average Summer Temperature (C)

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Annual Precipitation (mm)

400
350
300
250
200
150

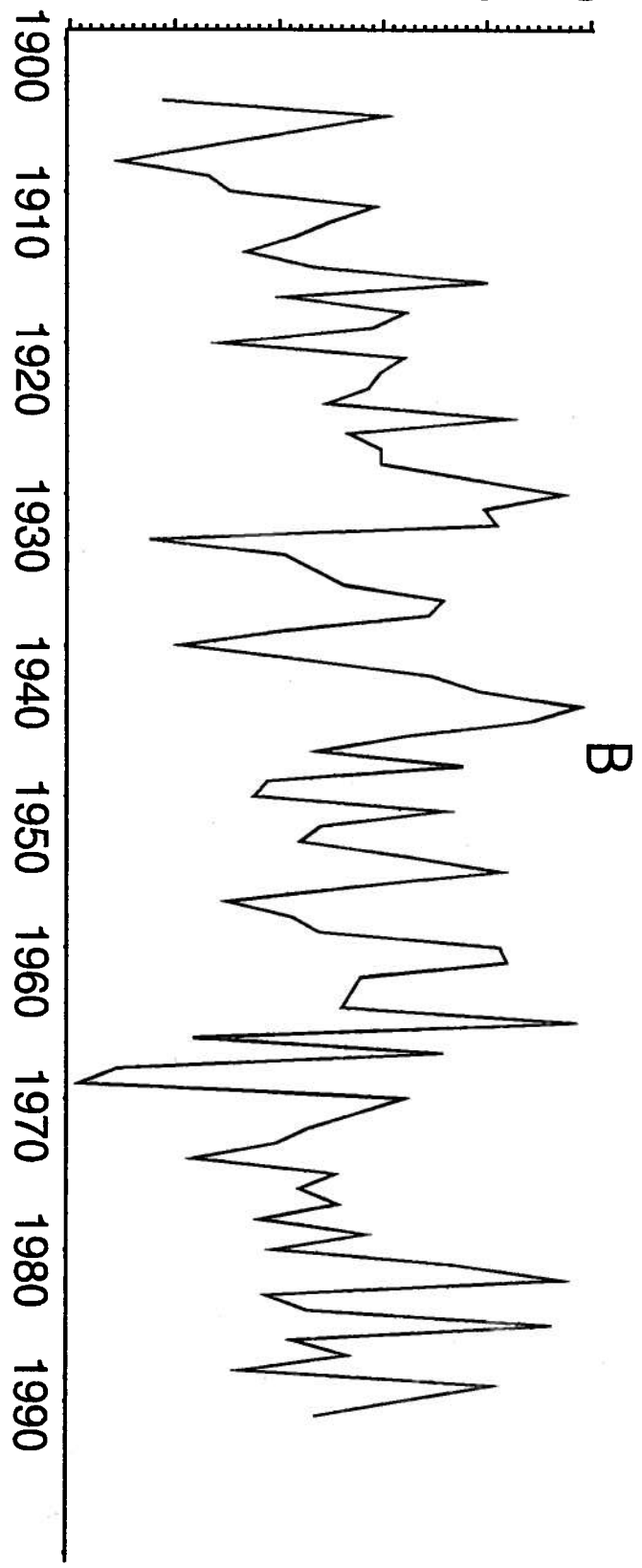


Fig 2

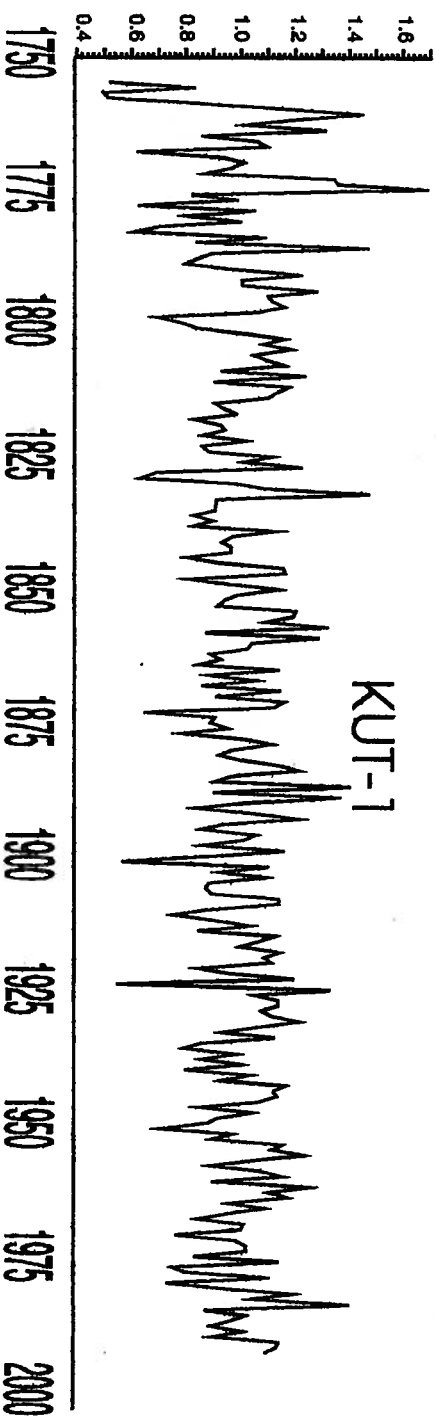
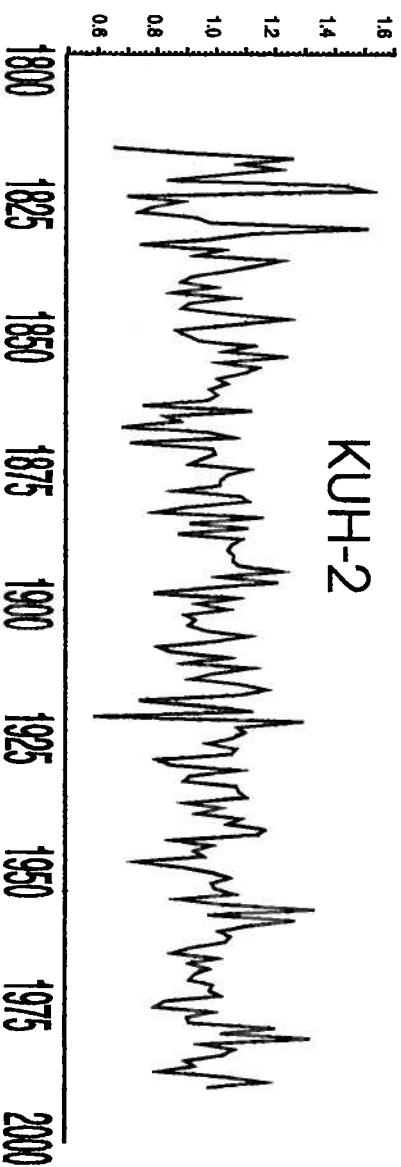
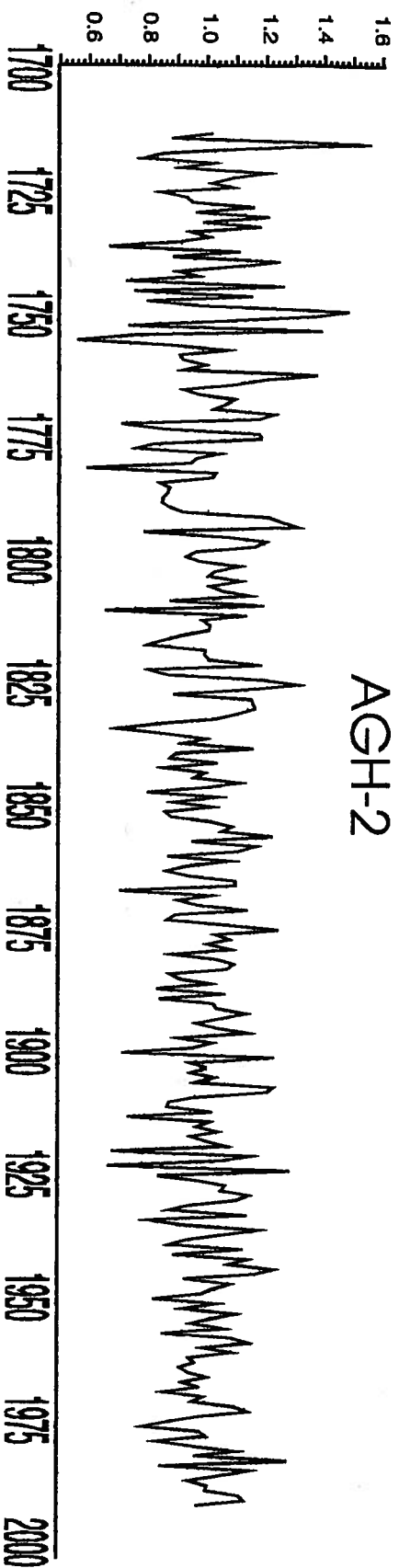


Fig. 3

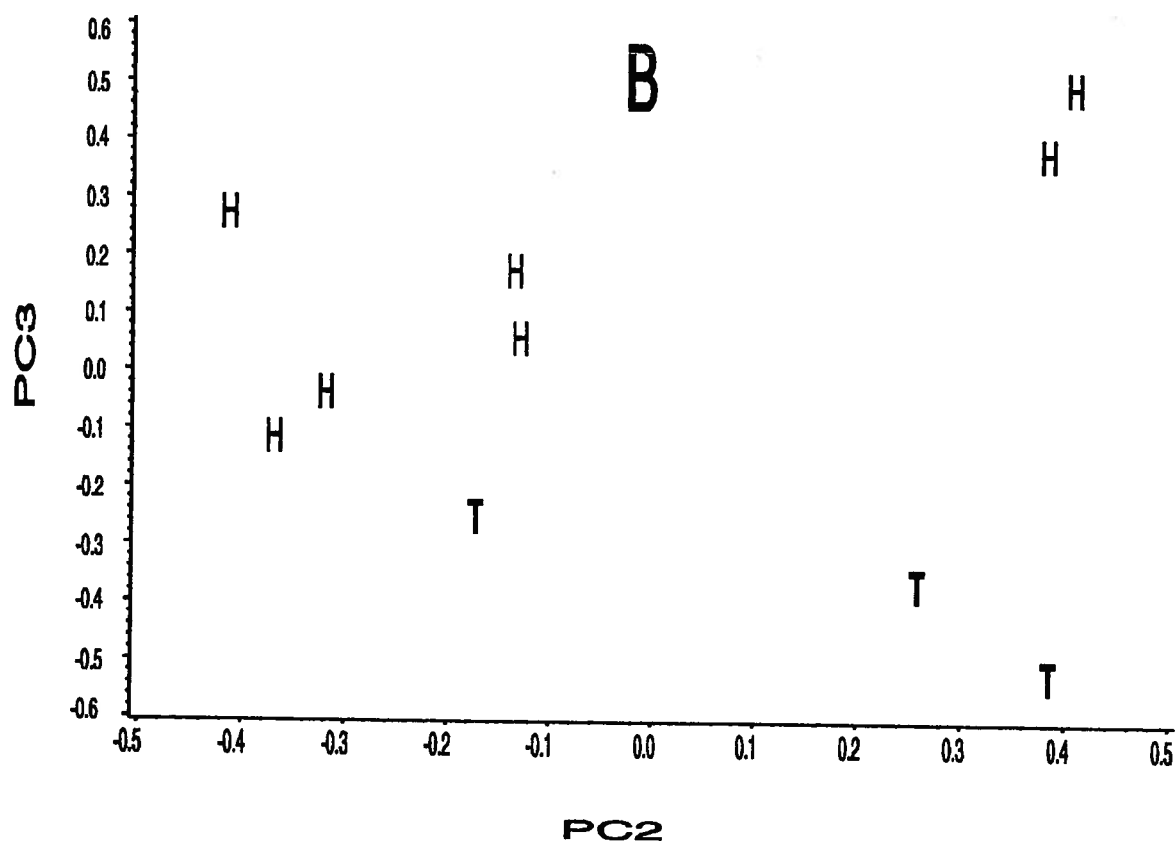
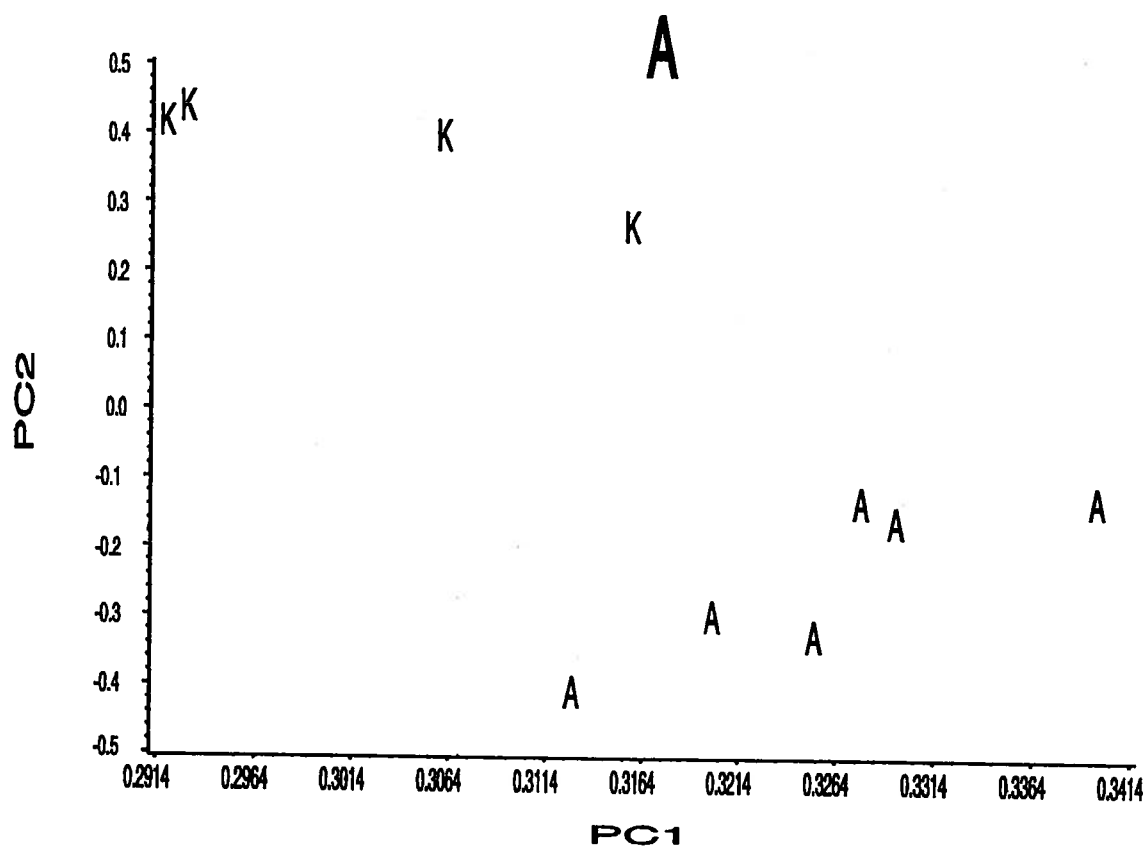
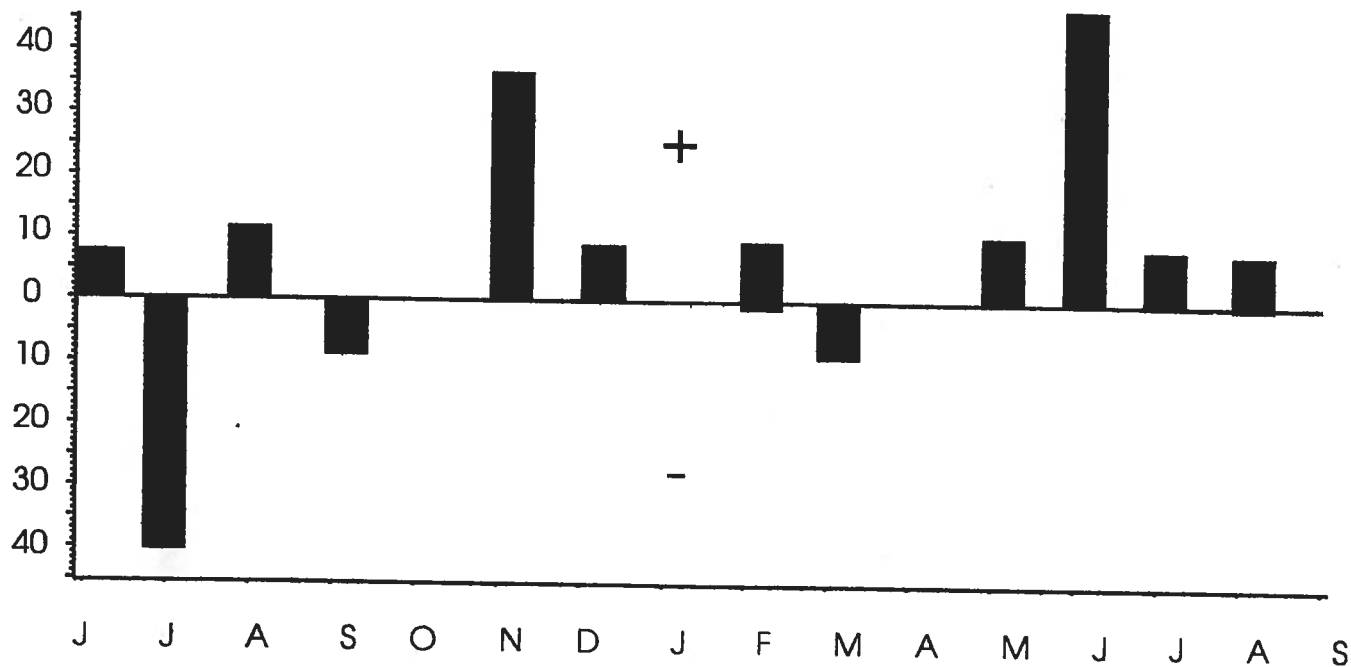


Fig. 4

Temperature



Precipitation

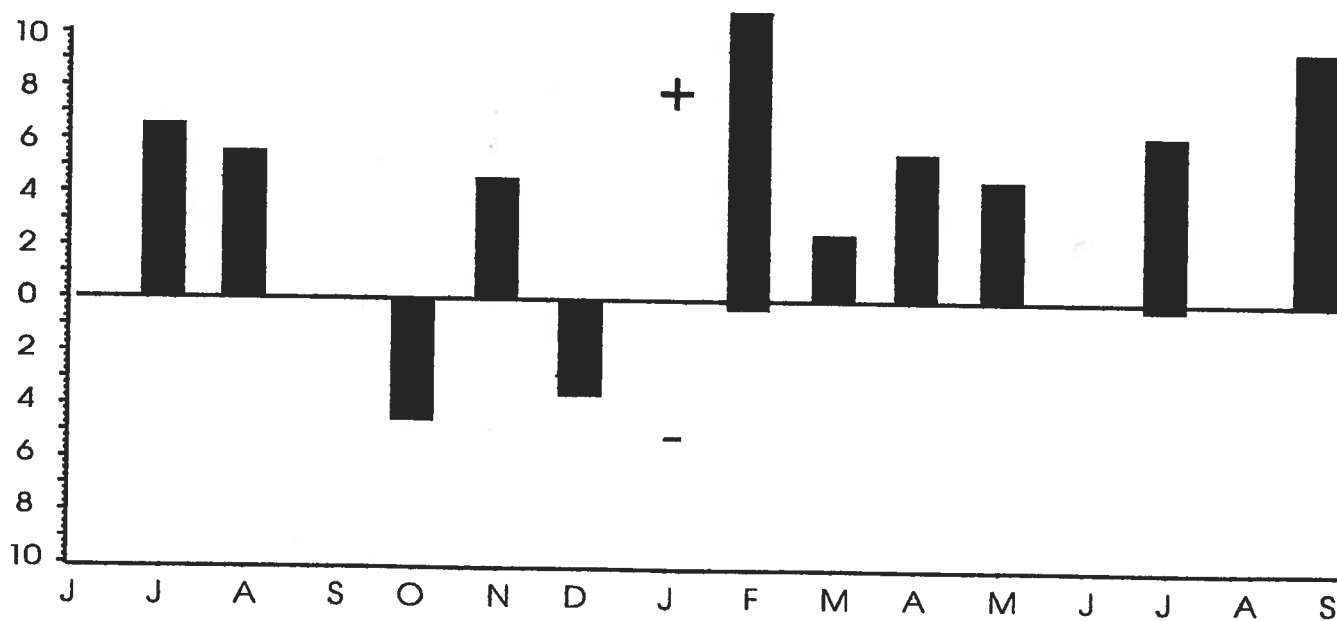


Fig. 5

Average Pearson Correlation

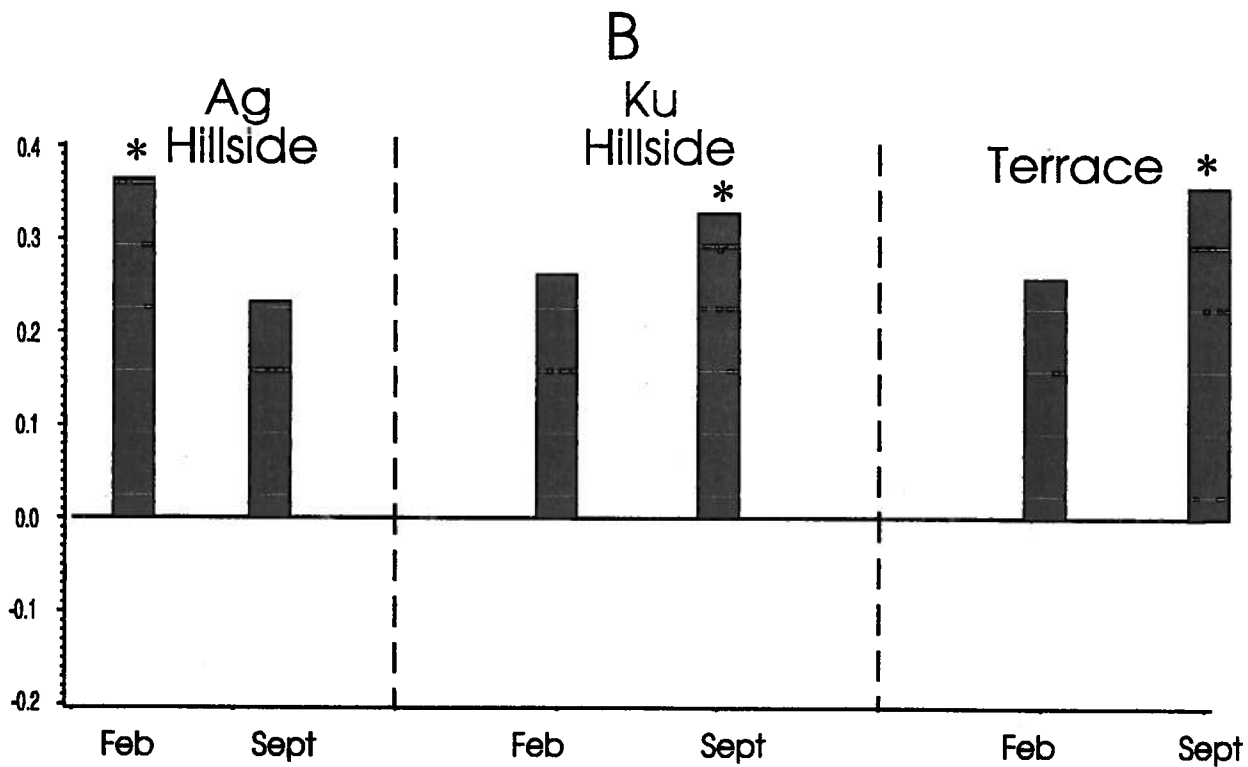
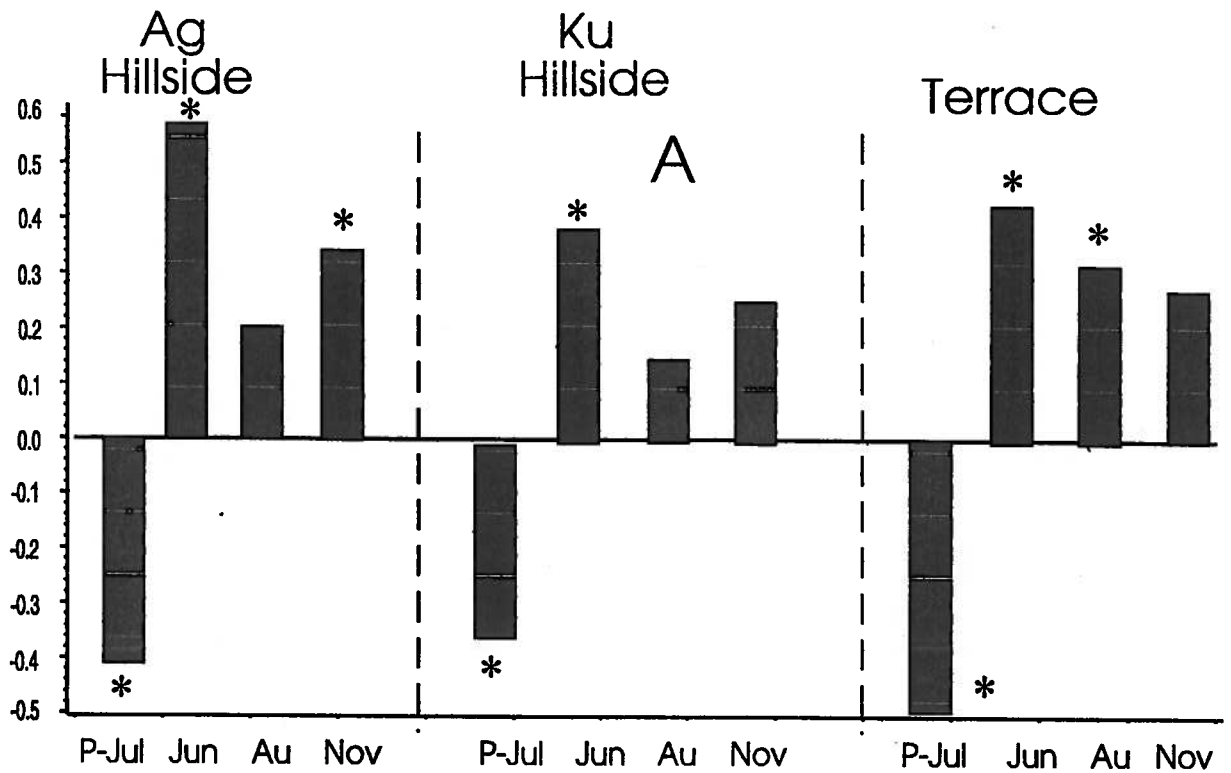


Fig. 6