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Stein Johansen

DENDROCLIMATOLOGICAL STUDY OF LARIX GMELINII *AT THE FOREST BORDER IN THE LOWER KOLYMA RIVER REGION NORTH-EASTERN SIBERIA*

TRONDHEIM 1995

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Starting at No 26 the name of this series is changed from Miscellanea to GUNNERIA. The numerical order will continue (see cover page 3). The name Gunneria is in memory of Johan Ernst Gunnerus (1718-73), one of the founders of this institution, professor of theology at the University of Copenhagen, bishop in Trondheim from 1758, vice president and Director Perpetuus of the Society from 1767-73, scientist with basic research in zoology and important botanical publications ("Flora Norvegica").

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ABSTRACT

Johansen, S. 1995. A dendroclimatological study of *Larix gmelinii* at the forest border in the lower Kolyma river region, northeastern Siberia. *Gunneria 69*: 1-20.

Dendrochronological synchronization of increment cores from *Larix gmelinii* trees growing near Kolymskaya in the lower Kolyma River region, yields a tree-ring chronology covering the period 1631-1991. The Dahurian larch, growing here near the tree limit, prove to be a sensitive indicator of changes in summer temperatures. June temperatures have a significant positive influence on the width of ring growth during the growing season. Prominent periods of increased and suppressed growth are to some extent synchronized with chronologies from other Siberian localities. The high frequency of missing tree-rings in 1822 is attributed to the severe climate of that and the preceding summer.

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CONTENTS

1 INTRODUCTION

Increment borings were obtained from Dahurian larches, *Larix gmelinii* (Rupr.) Kuzen. (*L. dahurica* Turcz.), along the lower reaches of the River Kolyma. The samples were collected by an ornithological expedition from the Museum of Natural History and Archaeology at the University of Trondheim. To facilitate dating of driftwood specimens collected in the Arctic, tree-ring chronologies from different parts of the circumpolar forest zone are useful. Recent results show that the large Siberian rivers are important driftwood sources (Eggertsson 1995). More dendrochronological data from these areas are thus of interest. The initial purpose was therefore to provide a tree-ring chronology in a research project aiming at dating driftwood collected on Norwegian arctic islands. The study could test the suitability of *L. gmelinii* growing at the border of the northern forests for dendrochronological and dendroclimatological work. A tree-ring chronology constructed from this location could contribute to the network of chronologies being established across the Eurasian forest border (Mazepa & Shiyatov 1994, Shiyatov et al. 1994).

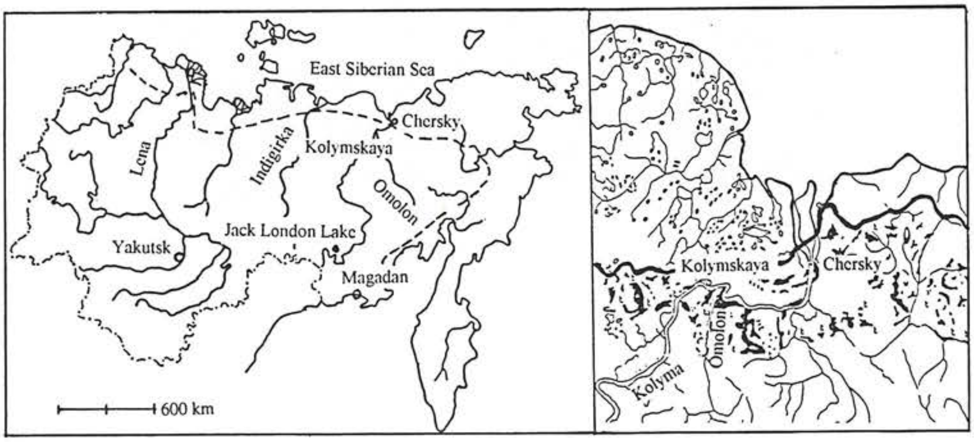

Fig. 1. Geographical overview (left) of eastern Siberia showing the tree limit of *Larix* spp. (---). The sampling site and other locations mentioned are indicated. Modified after Shcherbakov (1975). Distribution of *Larix gmelinii* in the lower reaches of the River Kolyma (right). Areas having massive forests or forest islands are indicated with black figures and the tree limit is shown by a black line. Modified after Naumenko (1966).

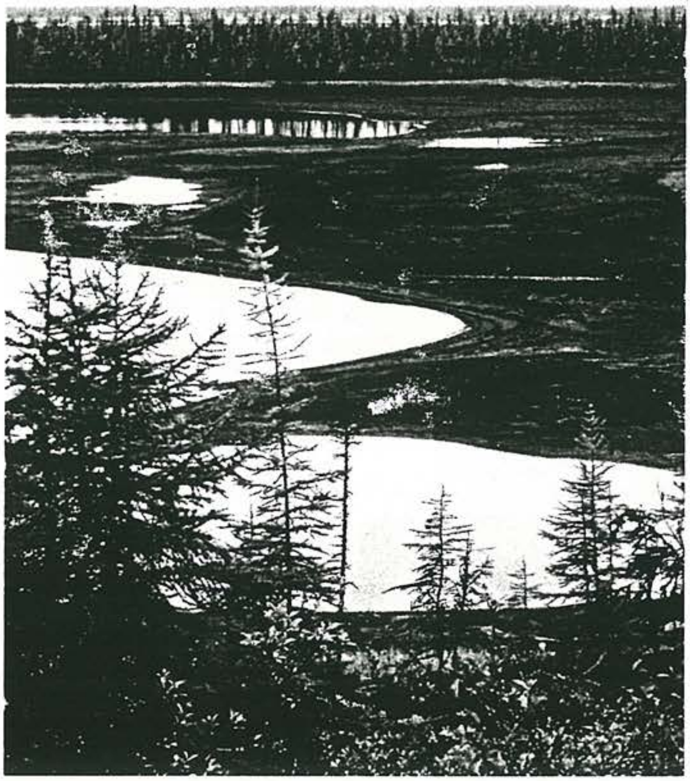

Fig. 2. Outlook from the sampling site near Kolymskaya, photo by O. Frengen on 7th September 1991.

1.1 SAMPLING SITE

The 17 increment borings from Dahurian larch, *Larix gmelinii*, were collected near the Kolyma River in Magadan Oblast, northeastern Siberia, at 68°50'N 158°35'E (Fig. 1). The site is near the confluence of the rivers Omolon and Kolyma, opposite the settlement of Kolymskaya, approximately 160 km from the East Siberian Sea. The western bank of the lower Kolyma consists of a lowland plain, with elevations reaching 100 m a.s.l. The landscape east of the Kolyma is more mountainous. The vegetation is characterized by forest tundra intermingled with mires. The site is about 50-100 m from the present-day river. The actual sampling site was a hillside or "yedoma" (A.V. Andreev pers. comm. 1995). The river bank, which rises to about 10-15 m above the present-day river course, has slopes heavily eroded by thermokarst working on the loess which is filled with ice wedges (Walter & Breckle 1989). The exposed river-side ice is warming up in summer and melting. The soil collapses and slides into the river taking trees with it.

1.3 CLIMATE

Eastern Siberia is characterized by the highest degree of continentality on earth (Lydolph 1977). Although the summer is short in eastern Siberia it is generally warm, but night temperatures are usually quite low. However, in areas east of the River Lena, such as the lower Kolyma region, the low arctic coastal plain to the north experiences considerably milder winters and cooler summers than the interior basins (Walter 1985).

The narrow belt of forest tundra at Kolymskaya is characterized by severe climatic conditions, where the yearly mean temperature is about -11.6° to -13.6°C and the mean temperature in the summer months is about 8.6° to 11.3°C, with a frost-free period of around 61-81 days (Naumenko 1966). The yearly average temperature for Chersky (68° 45'N, 161° 17'E) located 110 km east along the Kolyma river, measured in 1882 through 1960 is -11.6°C (A.V. Andreev pers. comm. 1993). However, even in July there may be significant frosts in many lowland areas north of about latitude 60°N (Walter 1985). The yearly precipitation at the sampling site is very low, 169-182 mm, but relative humidity is quite high, 63-78% (Naumenko 1966). The records available from Kolymskaya reveals that most precipitation arrives in July and in August. Very little falls during March to May.

In these regions, permafrost can be observed down to 250-400 m (Walter 1985). The depth of the seasonally thawed layer at the river port of Chersky is 0.4-1.3 m (Zimov et al. 1993). The thermokarst causes the larch trees in some locations to resemble a "drunkards forest" (Walter 1985). This may produce growth distortions (reaction wood) and consequent serious difficulties in measuring year rings. Although precipitation is very low in these regions, slow thawing of the upper soil may compensate for this.

1.4 VEGETATION

Larix gmelinii along the lower reaches of the Kolyma is growing near the northernmost limit of its distribution (Fig. 1), and is scattered sparsely as small islands surrounded by tundra, mires and bare hills (Naumenko 1966). Forest fires are an important ecological factor in the area and create extensive open clearings. The local forest is also highly influenced by geomorphological, cryogenic and soil conditions.

The overall characteristics of these larch forests are; the mean height of the trees is 4-8 m, the mean diameter of their trunks is 8-13 cm and the maximum diameter 16-24 cm, and there are 100-300 larch trees per hectare (Naumenko 1966). The vegetation at the sampling site is characterized by an open forest of thin specimens of Dahurian larch 8-10 m tall, with shrubs, grasses, mosses and lichens in the understorey (Fig. 2). The shrub layer at the sampling site consists mainly of *Betula glandulosa*, *Ledum palustre* and *Vaccinium uliginosum* along with scattered *Salix* sp.

1.5 METHODS

The samples were collected at breast height using a 5 mm diameter, 25 cm long, Suunto increment borer. They were stored in plexiglass tubes. The very thin larch trees made it possible to bore right through the trunk, thus enabling two opposite radii to be collected. Before examination, each core was cut with a sharp razor blade and coloured with white zinc paste to expose the very narrow rings. All measurements were performed with an ADDO X Tree Ring Machine (Parker Instrument, Sweden) with an accuracy of 0.01 mm. The respective curves were synchronized using the CATRAS statistical program package (Aniol 1983). This program performs the t-test (Baillie & Pilcher 1973) and the percentages agreement test (Eckstein & Bauch 1969). The t-test indicates whether two curves are related, i.e. it gives the synchronous position of two curves indisputably when the level of statistical confidence is high enough. Problems with missing year rings prevented the utilization of both radii in the building of the chronology. Hence, only the one radius from each tree showing the broadest rings and least growth distortions was used. It was possible to synchronize radius curves from 16 of the 17 trees investigated (Fig. 4). Construction of the chronology started with 5 cores which showed a combination of long record, broad year rings and no growth distortions. Careful comparison enabled the remaining 11 curves to be incorporated into this chronology. Missing rings during 1820-1823 were identified on cores and designated with a zero value. Other segments of these 11 curves with missing rings or other irregularities were avoided. Curves showing high intercorrelation were checked visually by comparing their graphical plots before being used for the chronology. Segments containing missing rings were located with the COFECHA program, which was also used to test the intercorrelation of the final chronology (Holmes et al. 1986). Chronology indices were computed with the CRONOL program, which is part of the Dendrochronological Program Library (DPL). This procedure removes the trend consisting of nonclimatic ring-width variations and enhancing the common climatic signal. The standardization used was negative exponential, negative trend line or horizontal line, cf. Fritts (1976).

The climate of a given year is known to have an effect on the ring width not only of the current year, but also on the ring widths in the following years.

This association in the time series is denoted autocorrelation, cf. Fritts (1976). After standardization, the remaining autocorrelation was removed from the tree-ring series by fitting a simple autoregressive model using the CRONOL program. A mean chronology was produced on the basis of the standardized, autoregressively modelled time series. Principal component analysis and response functions (Fritts 1976) were computed with the empirical model PRECON (Fritts et al. 1991). The technique of response function analysis, based on multiple regressions, has become widely used for studying how growth responds to such aspects as variations in monthly climate parameters over a year or more. In several respects, this technique is superior to a simple correlation (Fritts & Wu 1986). The PRECON program uses the bootstrap method to test the significance of the regression coefficients and the stability of the estimates in response functions (Guiot 1991). In older studies of response functions the number of variables being significant were often very large and the errors were underestimated (Fritts et al. 1991).

A tree-response period of 14 months was considered, beginning with July and ending with August. A detailed description of the statistical parameters used is given by Fritts (1976) and Guiot (1990).

Calibrating the tree-ring indices with mean monthly temperature data from Kolymskaya for the time span 1950-1991 proved difficult as altogether eight of the months in the instrumental period were lacking such data. The PRECON

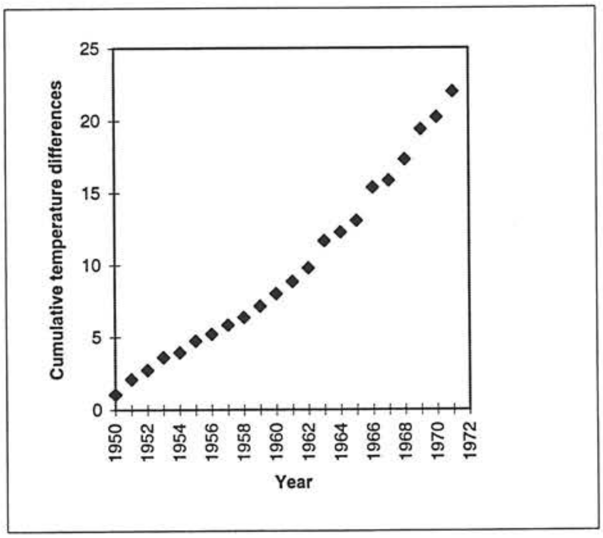

Fig. 3a. Scattergram of cumulative temperature differences between station Chersky and Kolymskaya 1950-1971.

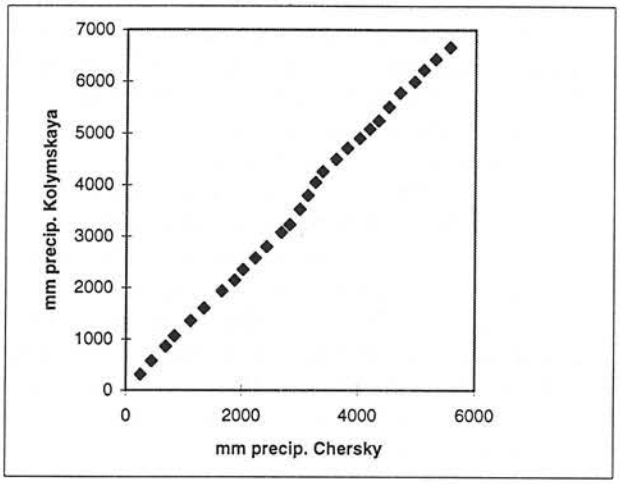

Fig. 3b. Scattergram of cumulative precipitation of station Chersky versus Kolymskaya 1962-1989.

PRECON program requires a complete data set for analysis. A comparison was therefore made between Kolymskaya temperatures and the monthly temperatures available at the site Chersky, about 110 km east along the River Kolyma. Station Chersky has a complete temperature record covering 1945-1990. A scattergram was made to assess the relationship between the two stations. By plotting the year versus the cumulative temperature differences, the homogeneity of the temperature data is visualized (Fig. 3a). As the values fall close to a straight line, this indicates that the stations are relatively homogenous.

Complete monthly precipitation records are available for Kolymskaya only for a short period, namely 1962-1989. The nearby station Chersky has a complete precipitation record covering a longer period, 1945-1990. A scattergram (double mass plot) made by plotting the cumulative precipitation of station Kolymskaya versus that of Chersky, reveals a constant relationship (Fig. 3b).

The standardized and autoregressively modelled chronology was therefore regressed against a complete set of monthly temperatures and monthly precipitation available for 1945-1990 at Chersky using the PRECON program.

2 RESULTS AND DISCUSSION

2.1 CROSS DATING

The samples were obtained on 7th September 1991 and the year ring for the current year had been formed on all the trees cored. The mean age of the 17 trees investigated is 279 years. A total of 10 of the 17 samples were older than

300 years. The mean radius of the cores was approximately 12 cm. The mean ring width of the 17 trees cored was 0.27 mm. Dendrochronological synchronization, using the CATRAS program and visual comparison followed by a quality test with the COFECHA program, gave a mean curve consisting of 16 radius curves. The chronology covers 361 years, extending from 1631 to 1991 (Table 1).

Table 1. Characteristics of the *Larix gmellinii* chronology from Kolymskaya (measurement data)

Number of dated series	16
Master series of 1631-1991	361 yrs
Internal correlation	.744
Average mean sensitivity	.346
Autocorrelation	.629
Standard deviation	.143

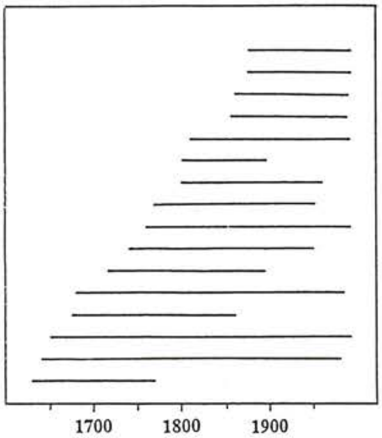

Fig. 4. Time plot of the individual tree-ring series included in the chronology.

2.2 THE KOLYMA LARCH CHRONOLOGY AND CLIMATE

The standardized Kolymskaya larch curve (Fig. 5) shows recurring periods of increased growth. The most prominent of these was during the time spans 1720-1737 and 1782-1800. The growth curve remained stably low during 1840-1920, after which there was a marked increase in the late-1920s, culminating in 1941-1944. In the same region, at the upper Kolyma site Jack London Lake (62° 10'N, 149° 30'E), a Dahurian larch chronology shows a similar growth increase during 1942-1965 (Earle et al. 1994). The regional nature of this latest period of favourable growth conditions is reflected also in tree-ring chronologies at other Siberian sampling sites, e.g. '*Larix gmelinii*' on the Ary Mas forest island in the Khatanga Basin (72°30'N) about 2000 km west of the River Kolyma (Chernavskaya 1985) and *Larix dahurica* near the city of Yakutsk (63°N, 129°E) (Osawa 1993).

Episodes of depressed growth are especially notable at Kolymskaya during the periods 1671-1685, 1764-1781 and in several years during 1788-1823. The first of these periods coincides with lowered temperatures reconstructed from a Dahurian larch chronology at the upper Kolyma site at Jack London Lake (Earle et al. 1994: 65). However, there are too few samples from Kolymskaya in this period to draw any conclusions about the correspondence. The results confirm the general tendency for a regional depression in tree growth across the whole of Eurasia during 1810-1820 (Graybill & Shiyatov 1992). It is notable that this growth minimum set in later at Kolymskaya than the other Siberian locations investigated, e.g. Chernavskaya (1985), Earle et al. (1994). Since 1978 there is a period of reduced tree growth at Kolymskaya and this is also observed at Jack London Lake (Earle et al. op. cit.).

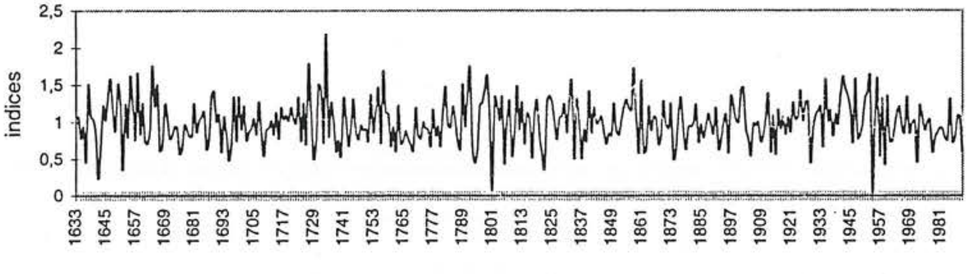

Fig. 5. Standardized tree-ring chronology from Kolymskaya 1633-1991.

2.3 THE MISSING 1822 YEAR RING

The 1822 year ring is the one which is most frequently absent. Six cores lack this ring, and the 1820 and 1821 rings are missing from one and two samples, respectively; the 1823 ring is missing from one sample. A zero value was therefore introduced after the samples had been verified against the five cores which had a complete record in the time span of 1820-1823. Earle et al. (1994) assume that the 1816 ring is missing in all the cores investigated at Jack London Lake Upper Kolyma and introduce a zero value based on the fact that Graybill & Shiyatov (1992) found extremely narrow rings in Ural chronologies during 1816-1818. The narrowest rings at the Upper Kolyma site were for the years 1817 and 1818.

The assumption that the missing rings in the Kolymskaya larch cores during the period 1820-1822 is caused by the harsh climate of these summers, is supported by accounts of the local weather and growing conditions. Admiral von Wrangell's expedition surveyed the lower Kolyma River and its extensive surroundings from their headquarters at Nizhnekolymsk during 1820-1823. This settlement is situated about 90 km east of Kolymskaya. Wrangell (1844) attributed the severity of the climate to the high latitude and the open, unsheltered landscape with an extensive barren tundra to the west and the sea to the north. Cold northwesterlies consequently meet no impediment and bring violent snowstorms, even frequently in summer. According to Wrangell, berries do not survive to maturity every year and in "the years 1821, 22, and 23 the berries failed so completely that none of these forest fruits were to be met with" (cit. Wrangell 1844: 66). A more detailed description of temperatures and other weather parameters during the summer of 1821 shows that this probably was the coldest summer in the three-year period covered. Only short spells of summery weather occurred interrupted by several days with cold northwesterlies and frequent snow in July. Observations made by Kosmin, a member of the Wrangell expedition, support the descriptions of the severe weather in July 1821, describing periods of northwest winds, fogs, snow and temperatures ranging from -2 to 3°C for several days while travelling from Kolyma to the mouth of Indigirka (Wrangell 1844). The summer of 1822 seems to have been a little milder than the preceding year. However, mid-July 1822 saw a period of several days with northwesterly winds, thick fog, snow and daytime temperatures around 1-2°C.

Whereas Earle et al. (1994) attribute the growth minima in the larch curve during 1816-1818 at the upper Kolyma sampling site directly to the Tambora volcanic eruption of 1815, there are no obvious links with this event in the Kolymskaya data as the tree-ring events are more delayed in time. Although the Kolymskaya growth indices show a narrow year ring for 1817, the greatest number of missing rings on individual cores is found in 1822. Tambora was the greatest ash eruption since the end of the last ice-age, but 5-7 years after the event the direct effects on global climate are assumed to be minimal (cf. Vupputuri 1992). If there is a connection between the Kolymskaya tree-ring records and the Tambora eruption it is indirect and complex. Volcanic dust veils would affect solar radiation greatest in the Arctic and long after the dust veil has gone (Lamb 1970). The unsheltered position of Kolymskaya at the northern forest border close to the Arctic Ocean makes this site more likely to be influenced by even small changes in the pressure system boundaries in this region (cf. Lydolph 1977: 127). The tree-ring chronology as well as the historical records demonstrate that an increased frequency of northerly to northwesterly winds will seriously affect the limited growing conditions.

Temperature data. - The response function analysis shows a positive relationship between tree growth and summer temperatures, with a significant coefficient in June (Fig. 6). Results obtained from *Larix sibirica* in the Polar

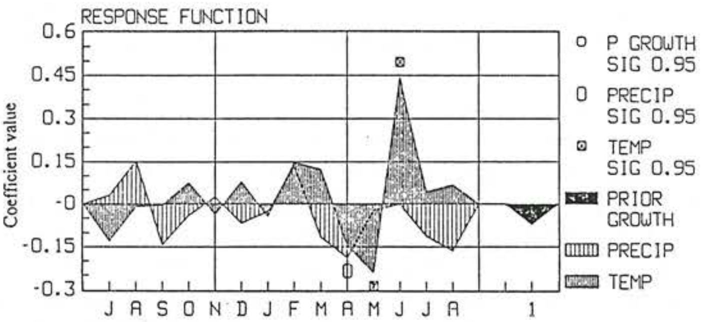

Fig. 6. Bootstrap response function for the *Larix gmelinii* chronology from Kolymskaya. Variables are mean monthly temperatures and monthly precipitation at Chersky 1945-1990. The fractional variance reduced was 0.616 with the climate data and 0.137 with prior growth.

Urals (Shiyatov et al. 1992) also show a direct response of the trees to June as well as to July temperatures. A somewhat similar response pattern was found at Jack London Lake on the upper Kolyma where the influence of the average maximum temperatures for June, July and August were positive and significant (Earle et al. 1994).

A plot of the mean temperatures for June-August 1941-1991, which had a complete record at Chersky, with the growth indices from Kolymskaya on similar scaled ordinates (Fig. 7) displays the positive correlation. The influence on tree-ring growth by current June temperatures is especially strong at Kolymskaya. Usually the larch needles appear by June 5-7 in the sampling area (A.V. Andreev pers. comm. 1995). It is not known when the formation of xylem cells starts at Kolymskaya. However, a positive response to June temperatures in *L. sibirica* in the Polar Urals is thought to be indirectly an effect of rapid shoot growth and needle development increasing the production of growth regulators (Shiyatov et al. 1992).

A significant negative relationship is observed between the Kolymskaya tree growth and the May temperature of the same year. This may be explained by increasing temperatures starting the growth processes too early, making the larch trees susceptible to frosts.

Precipitation data. - The response function analysis shows that the influence of precipitation on ring growth during the summer season is insignificant or negative. The sampling site is probably excessively moist during the growing season, mainly due to thawing of the permafrost. The monthly climate data indicate that a wet July or August is frequently associated with reduced temperatures. Similar results are recorded by Earle et al. (1994) who observed a nearly consistent negative relationship between ring width growth and

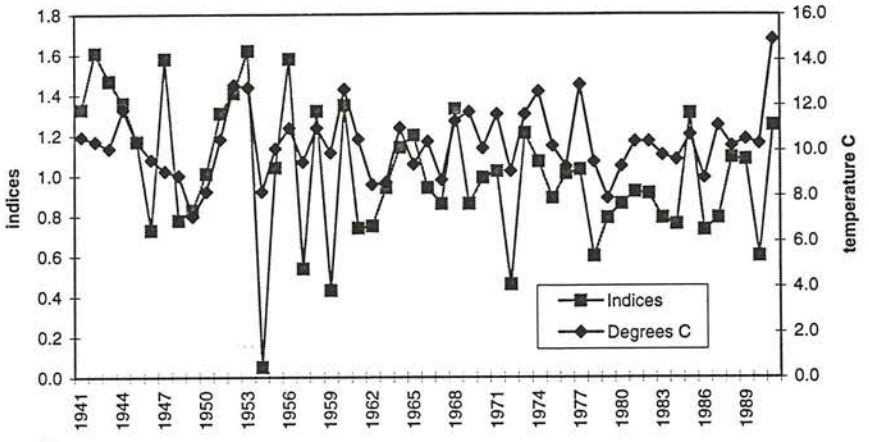

Fig. 7. Standardized tree-ring chronology and mean summer temperatures for June-August at Chersky 1941-1991.

summer precipitation in the upper Kolyma region. The significant and negative influence of precipitation on ring growth in current April might be due to snowfall causing a delay in the start of the growing season.

3 CONCLUSIONS

The study has demonstrated that the construction of tree-ring chronologies based on Dahurian larch near the northern forest limit is somewhat restricted by the very narrow year rings, caused by the severe climate. In addition, a number of other factors affect the ring patterns, for instance cryogenic influences which can cause abnormal growth of tree-rings.

The response function analysis shows that current June temperatures are especially important for the growth. Increased precipitation and temperatures during April-May have a negative effect on the growth of the larch trees that year. *Larix gmelinii* is the most suitable tree species for dendroclimatological studies in the area and is also long-lived. These latitudes offer favourable conditions for preserving dead material, implying a potential for long-term reconstruction of regional climates. The results reveal that Dahurian larches, growing here at the border between two vegetation regions, are sensitive recorders of changes in early summer temperature conditions. The larch trees provide valuable dendroclimatological information for studying variations in the influence of the Arctic Ocean low pressure system. The chronology derived from Kolymskaya may contribute to establish a spatial grid of tree-ring sites across the Siberian boreal forest limit to support time-series studies of global climatic change. Further work can presumably give a more detailed picture of the relationship between the tree-ring records of *Larix gmelinii* and the local or regional climates at these locations.

4 ACKNOWLEDGEMENTS

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