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TREE GROWTH DECREASE BETWEEN AD 1800 AND 1840 IN SUBARCTIC AND HIGHLAND REGIONS OF RUSSIA

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ABSTRACT. I analyzed the variability of ring-width indices from AD 1800 to 1840 in 110 temperature-sensitive tree-ring chronologies developed for subarctic and mountain regions of Russia in order to discover any possible effect of the catastrophic Tambora eruption in 1815 on tree growth and climatic conditions. In most regions studied there was intensive cooling from 1810 to 1840. Extremely low ring-width indices (60–95% below average) during the first three years after the eruption occurred in the northern regions of the Russian Plain, the Polar, Subpolar and Northern Ural Mountains and the northwestern part of the West-Siberian Plain. It is possible that the Tambora eruption, which occurred during a period of short-term cooling, caused an even greater decrease in summer temperatures in those regions in 1816–1818.

INTRODUCTION

Large volcanic eruptions may affect solar radiation, thermal regime, precipitation pattern, atmospheric circulation and other climatic characteristics (Lamb 1970; Pokrovskaya 1971; Spirina 1971; Borisenkova 1974; Budyko 1980). Because few large eruptions have occurred during the period of instrumental meteorological observations, it is difficult to determine the effects of volcanic eruptions on climatic variability. Therefore it is important to use proxy climatic data for longer time intervals, particularly dendroclimatic data, when undertaking studies involving climatic reconstruction, the exact dating of volcanic eruptions and the effects of volcanic eruptions on climatic and other natural phenomena (Smiley 1958; LaMarche and Hirschboeck 1984; Lough and Fritts 1987). One of the largest volcanic eruptions in recorded history, the Tambora (Indonesia) eruption of 1815 is of special interest for the unusual climatic conditions observed afterwards in many regions of the world. In particular, a very cold summer occurred in northeastern North America and Western Europe in 1816. To evaluate climatic patterns following the Tambora eruption, the International "Workshop on World Climate in 1816" was held in 1988 in Canada (Harington 1992). Unfortunately, scientists from Russia did not take part in this meeting, and vast territories of Eastern Europe and North Asia have remained "silent regions" concerning 1816 (Wilson 1992).

DESCRIPTIVE BACKGROUND

My aim here is to help fill the gap of information on climatic conditions in the early nineteenth century in the territory of Russia using temperature-sensitive tree-ring chronologies. For this purpose, 110 mean (or site) and generalized (or regional) ring-width chronologies developed for the polar and upper timberlines were analyzed. Generalized chronologies were developed by averaging indices of several mean chronologies if they were similar. Growth index calculations were made using the corridor method (Shiyatov 1986; Cook *et al.* 1990) and the TREND program developed by T. Rimer (1992). Brief characteristics of the most typical chronologies plotted from 1800 to 1840 are given in Table 1 with sites shown in Figure 1. The following tree species were used to develop these chronologies: *Larix sibirica* Ldb., *L. Gmelini* Pilger, *L. Cajanderi* Mayr, *L. kurilensis* Mayr, *Picea obovata* Ldb., *Pinus sylvestris* L., *P. sibirica* (Rupr.) Mayr. Most of the chronologies contain a strong climatic signal, mainly of June and July temperatures of the current growth year (Graybill and Shiyatov 1992; Shiyatov, Mazepa and Fritts 1992). Tree-ring chronologies developed for high-latitude regions are the most interesting, as air-temperature variability in these regions is higher than that of middle and low latitudes (Budyko 1980).

TABLE 1. Brief Characteristics of Tree-Ring Chronologies Shown in Figures 2–6

Series no.	Site	Lat. N	Long. E	Elevation (m)	Species*	Time interval	Mean sensitivity	Authors
Kola Peninsula								
1	Murmashi Village	68°49′	32°49′	150	P. s	1698–1971	--	Bitvinskas and Kairaitis (1978)
2	Kandalaksha City	67°11′	32°28′	50	P. s.	1614–1971	--	Bitvinskas and Kairaitis (1978)
3	Khibiny Massif	67°38′	33°42′	350	P. o.	1691–1978	--	Shiyatov, unpublished
Northern Part of Russian Plain								
4	Pinega River	64°55′	42°30′	250	P. o.	1711–1990	0.15	Schweingruber, unpub.
5	Lower Pechora	67°13′	52°21′	30	P. o.†	1707–1968	0.27	Shiyatov (1981)
6	Upper Usa	67°05′	63°50′	90	P. o.	1723–1968	0.35	Shiyatov (1981)
Polar and Subpolar Ural Mountains								
7	Rai-Iz Massif	66°50′	65°35′	220	L. s.†	1541–1969	0.37	Shiyatov (1986)
8	Neroika Mountain	64°50′	59°58′	620	L. s.†	1673–1970	0.38	Shiyatov (1986)
9	Rai-Iz Massif	66°50′	65°35′	200	P. o.	1637–1969	0.29	Shiyatov (1986)
10	Neroika Mountain	64°32′	59°58′	600	P. o.†	1681–1969	0.33	Shiyatov (1986)
Northern Part of West-Siberian Plain								
11	Khadyta-Yakha River	67°12′	69°50′	40	L. s.	1628–1990	0.37	Shiyatov, unpublished
12	Lower Ob	66°35′	66°25′	40	L. s.†	1609–1973	0.32	Shiyatov (1984a)
13	Lower Ob	66°35′	66°25′	40	P. o.	1650–1967	0.22	Shiyatov (1984a)
14	Upper Poluy	65°18′	69°41′	35	P. s.	1595–1992	0.22	Shiyatov, unpublished
15	Lower Taz	66°36′	82°20′	25	L. s.	1103–1969†	0.25	Shiyatov (1977, 1984b)
16	Lower Taz	66°36′	82°20′	25	P. o.†	1245–1969	0.24	Shiyatov (1972, 1984b)
17	Lower Taz	66°36′	82°20′	25	P. c.	1642–1969	0.23	Shiyatov (1973)
Putorana Plateau and Western Part of North-Siberian Lowland								
18	Talnakh Village	69°27′	88°36′	120	P. o.	1618–1977	--	Shiyatov, unpublished
19	Miktchanda River	69°51′	90°48′	175	L. s.	1702–1988	0.43	Ivshin, unpublished
20	Lower Khatanga	72°05′	103°07′	25	L. g.	1514–1977	0.48	Shiyatov, unpublished
21	Ayakly River	69°32′	97°32′	400	L. g.	1517–1990	0.43	Shiyatov and Vaganov, unpub.
Anabar Plateau and Eastern Part of North-Siberian Lowland								
22	Ary-Ongorbut River	71°42′	118°33′	80	L. g.	1600–1990	0.41	Shiyatov and Vaganov, unpub.
23	Lower Lena	71°13′	127°26′	40	L. g.	1380–1991	0.43	Shiyatov and Vaganov, unpub.
24	Olenek River	69°47′	119°07′	210	L. g.	1398–1990	0.33	Shiyatov and Vaganov, unpub.
Kolyma Lowland and Anuy-Chukot Highland								
25	Alazeya River	69°17′	154°46′	50	L. c.	1412–1991	0.43	Shiyatov, unpublished
26	Vyrney Stream	68°48′	163°03′	300	L. c.	1468–1991	0.35	Shiyatov, unpublished
27	Maly Anuy River	67°28′	167°40′	450	L. c.	1420–1991	0.36	Shiyatov, unpublished
Northern Ural Mountains								
28	Kytlym Massif	59°35′	59°10′	890	L. s.	1598–1969	0.29	Shiyatov (1986)
29	Kytlym Massif	59°35′	59°10′	800	P. o.	1676–1969	0.21	Shiyatov (1986)
30	Kytlym Massif	59°35′	59°10′	690	P. s.	1557–1969	0.24	Shiyatov (1986)
Southern Ural Mountains								
31	Taganay Ridge	55°13′	59°40′	820	P. s.	1731–1970	0.20	Shiyatov (1986)
32	Taganay Ridge	55°18′	59°50′	1050	P. o.	1764–1970	0.29	Shiyatov (1986)
33	Iremel Massif	54°32′	58°48′	1000	L. s.	1770–1972	0.31	Shiyatov (1986)
Kamchatka								
34	Esso Village	55°54′	158°48′	900	L. k.	1689–1984	0.35	Shiyatov, unpublished
35	Tolbachek Volcano	55°49′	160°10′	750	L. k.	1707–1983	0.24	Shiyatov, unpublished
Highlands around Lake Baikal								
36	Baikal Ridge	53°58′	108°06′	1630	L. s.	1700–1989	0.37	Glyzin (1994)
37	Barguzin Ridge	53°40′	109°36′	1370	L. s.	1550–1989	0.31	Glyzin (1994)
38	Barguzin Ridge	55°20′	109°56′	1050	L. g.	1690–1984	0.38	Glyzin (1994)

*P.s. = *Pinus sylvestris;* P.c. = *Pinus sibirica;* P.o. = *Picea obovata;* L.s. = *Larix sibirica;* L.g. = *Larix Gmelini;* L.c. = *Larix Cajanderi;* L.k. = *Larix kurulensis*

†The generalized chronology

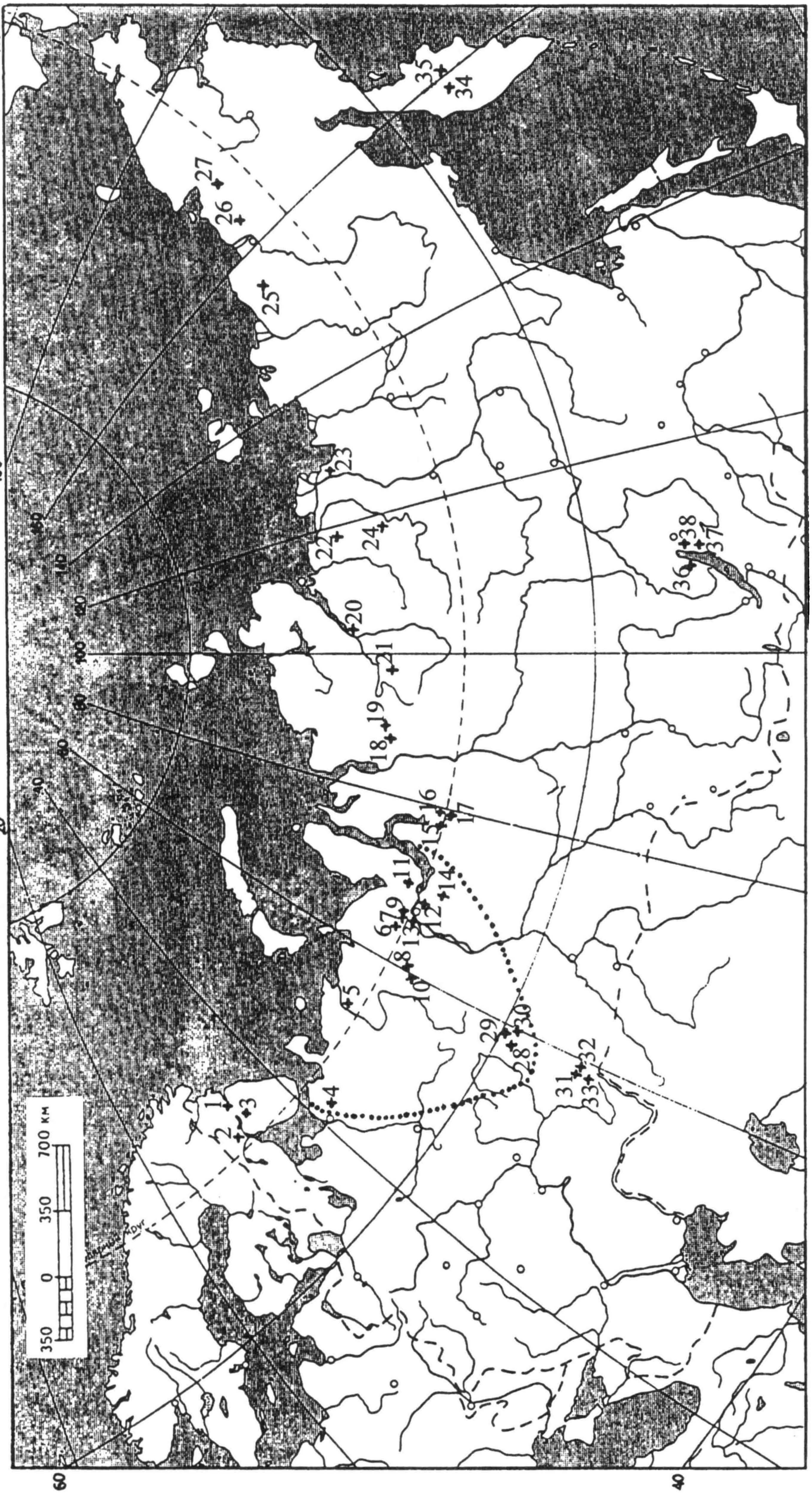

Fig. 1. Locations and numerical codes (Table 1) of tree-ring chronologies, segments of which are shown in Figures 2–6. • • • • • delimits the area of possible influence of the Tambora eruption on summer cooling and tree growth decrease.

To evaluate the summer temperature variability in various regions, I visually inspected plots of ring-width indices from 1800 to 1840, paying special attention to the presence of extreme index values in the years immediately after the Tambora eruption, when its effect on climate was most probable (Budyko 1980; Lough and Fritts 1987).

Lowland and Mountain Subarctic Regions

Kola Peninsula

Pinus sylvestris growing at a site located near the northern tree line (series 1) and in the southern part of the peninsula (series 2) had low growth from 1810 (20–25% below average). Northern pines had low growth until 1817, southern pines until 1825 (Fig. 2). *Picea obovata* trees growing at the upper timberline in the Khibin Mountain Massif (series 3) had very low growth in 1814–1815 and 1817 (60–75% below average), but the index value for 1816 was rather high (80%) in comparison with the previous and the following year.

Northern Part of the Russian Plain

For this territory (from the lower reaches of the Severnaya Dvina River in the west to the Polar Ural Mountains in the east), six mean and two generalized *Picea obovata* chronologies were analyzed. In the western part of this territory (Pinega River) the growth began decreasing in 1810, and the lowest growth was in 1817. Beginning in 1818 tree growth gradually increased. In the middle part of this area (Pechora River) very low values of indices at various sites (from dry to swampy ones) occurred for the years from 1814 to 1825 (series 5). In the eastern part of the Russian Plain (Usa River, series 6) very low growth occurred from 1814 to 1828. Thus, over the northern part of the Russian Plain the lowest growth of trees (30–75% below average) occurred in 1816–1817 (Fig. 2).

Polar and Subpolar Ural Mountains

I analyzed ten chronologies for *Larix sibirica* and four for *Picea obovata* growing at the upper timberline. Larch chronologies (Fig. 2, series 7 and 8) show that during 1815–1820, radial growth was extremely low (60–90% below average). In spruce chronologies (series 9 and 10), a similar growth decline was observed for a longer period (from 1814 to 1828). The lowest values for larch indices occurred after 1815, especially in 1816 and 1818, and for spruce in 1816, 1822 and 1828 (Fig. 2).

Northern Part of the West-Siberian Plain

A large number of tree-ring chronologies for various coniferous species and habitats have been analyzed for this territory (from the Polar Urals in the west to the lower reaches of Enisei River in the east). I examined 40 mean and generalized chronologies: 23 for *Larix sibirica*, 15 for *Picea obovata*, 1 for *Pinus sylvestris* and 1 for *Pinus sibirica*. Chronologies developed for the northwestern part of the plain (lower reaches of the Ob and Nadym Rivers) are very similar to the chronologies developed for the Polar Ural Mountains and, to a lesser degree, to the chronologies developed for the Subpolar Ural Mountains (Fig. 2 and 3). Extremely low values of indices are evident for larch chronologies (series 11 and 12) in 1816–1820, especially in 1816, 1818 and 1820; for spruce chronologies (series 13) in 1816–1818; and for Scotch pine chronology (series 14) in 1816 and especially in 1818 (40–90% below average). In the northeastern part of the plain (lower reaches of the Pur and Taz Rivers) the lowest growth occurs later, from the late 1820s to the early 1830s) (Fig. 3). 1819 was the most unfavorable year for larch growth (series 15), 1819–1822 for spruce (series 16) and 1819–1821 for *Pinus sibirica* (series 17). However, rather low values were recorded for larch indices in 1815–1816 (40–60% below average).

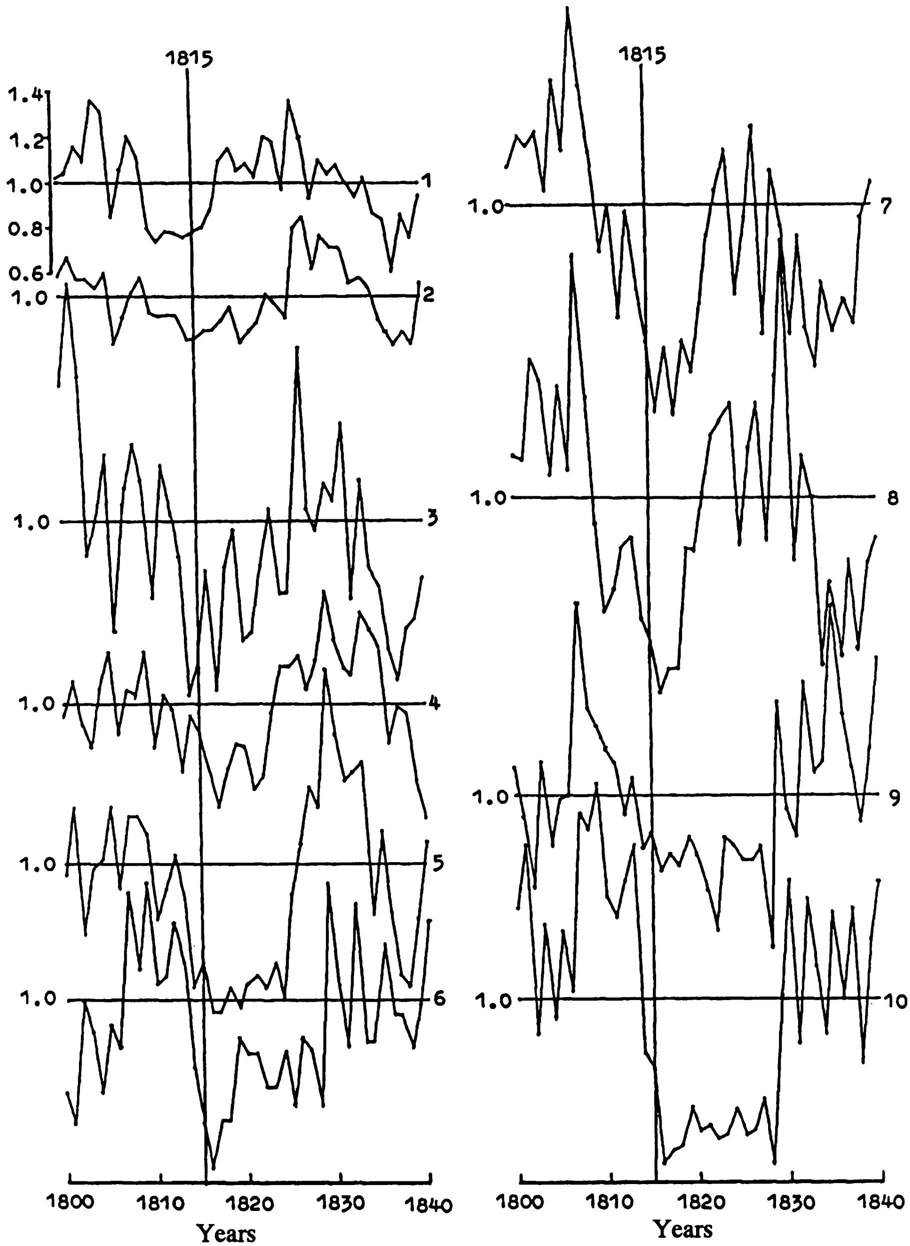

Fig. 2. Indexed ring-width chronologies for the period 1800–1840 developed for the Kola Peninsula (series 1–3), the northern part of the Russian Plain (series 4–6) and the Polar and Subpolar Ural Mountains (series 7–10)

Putorana Plateau and the Western Part of the North-Siberian Lowland

Twelve chronologies of *Larix sibirica* and *Larix Gmelini* and three chronologies of *Picea obovata* were analyzed for this area (from the lower reaches of the Enisei River to the lower reaches of the Khatanga River). There were no extreme values in growth for several years after the Tambora erup-

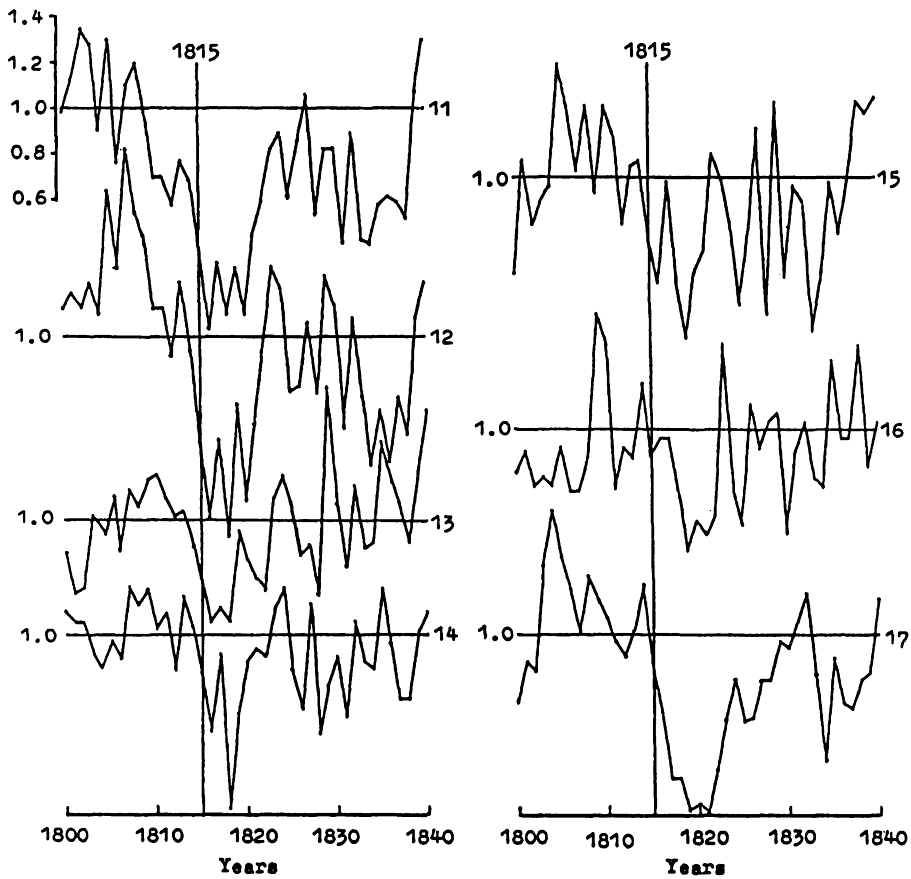

Fig. 3. Indexed ring-width chronologies for the period 1800–1840 developed for the northern part of West-Siberian Plain (series 11–17)

tion, but index values were rather low in 1815–1816 (Fig. 4). The lowest growth of spruce trees was in 1812, 1819 and especially 1824–1825 (series 18); of larch trees, in 1812, 1819–1820 and 1825 (series 19–21). In the western part of the Putorana Plateau, fairly low growth of larch trees was observed in 1816 (as much as 60% below average). All larch chronologies show an increase of index values in 1817.

Anabar Plateau and the Eastern Part of the North-Siberian Lowland

Six *Larix Gmelini* chronologies were analyzed for this area (from the lower reaches of the Khatanga River in the west to the lower reaches of the Lena River in the east). Trees growing at the polar timberline had the lowest growth in 1813 and 1817 (Fig. 4, series 22 and 23). In regions situated 250–300 km to the south of the polar timberline the lowest growth was in 1813, 1817 and especially 1819 (series 24). On the whole, summer temperature conditions in the 1820s and 1830s were unfavorable for the growth of larch trees.

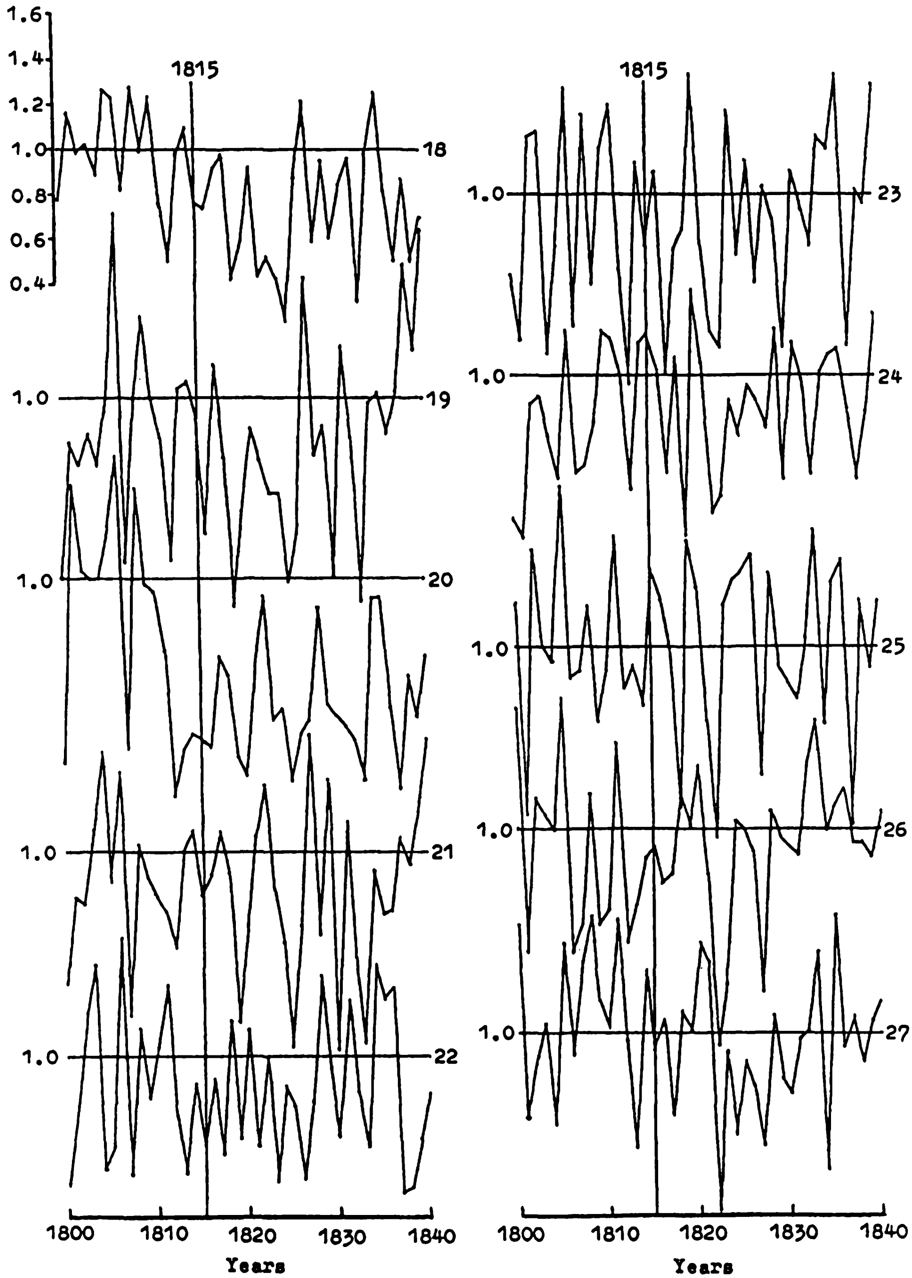

Fig. 4. Indexed ring-width chronologies for the period 1800–1840 developed for the Putorana Plateau and the western part of the North-Siberian Lowland (series 18–21), the Anabar Plateau and the eastern part of the North-Siberian Lowland (series 22–24) and the Kolyma Lowland and the Anuy-Chukot Highland (series 25–27).

Kolyma Lowland and the Anuy-Chukot Highland

For this area three *Larix Cajanderi* chronologies were analyzed (Fig. 4, series 25–27). They are all similar, with a few differences. Reduced growth began in 1812. Extremely low index values occurred in 1822. In addition, very unfavorable climatic conditions for tree growth occurred in 1818 in the Kolyma Lowland (series 25) and in 1813 and 1817 in the eastern part of the Chukot Peninsula (series 27).

Highland Regions of the Boreal Zone

Northern Ural Mountains

For this area (Kytlym Massif), there are 9 mean and generalized tree-ring chronologies from the upper timberline: 4 for *Larix sibirica* trees, 4 for *Picea obovata* trees and 1 for *Pinus sylvestris* trees. The lowest growth indices (30–80% below average) in larch chronologies occurred between 1810 and 1819, especially in 1810 and 1815 (Fig. 5, series 28). The reduction in the growth of spruce was not so extreme (20–40% below average) or long (between 1815 and 1818), and the lowest index values were in 1816–1818 (series 29). The growth of pine trees (series 30) was approximately the same as in spruce.

Southern Ural Mountains

Quite a number of tree-ring chronologies were developed for the upper timberline in this area (Taganay Ridge and Iremel Massif): 10 chronologies for *Picea obovata,* 3 for *Pinus sylvestris* and 1 for *Larix sibirica*. A marked decrease of growth in pine trees occurred from 1810 to 1820, and the lowest values were in 1816–1818 (Fig. 5, series 31). Spruce and larch trees had low growth before the Tambora eruption, but for several years after this event climatic conditions were favorable for growth of these species (series 32 and 33).

Kamchatka

I have analyzed five chronologies of *Larix kurilensis* growing at the upper timberline in an area of recent volcanic activity (Tolbachek and Kronozky volcanoes) and in an area of past volcanic activity (Sredinny Ridge). Figure 5 shows that in the central part of Kamchatka growth variability was very similar during 1800–1840 (series 34–35). The lowest index values were in 1811–1813 and 1817 (30–70% below average). Climatic conditions for larch growth in 1816 were favorable; index values were *ca*. 125%.

Highlands around Lake Baikal

For this area, situated in the south part of the boreal zone and under the influence of the huge cold-water mass of Lake Baikal, there are nine larch chronologies from the upper timberline. All chronologies show that the lowest growth was in 1815–1820 (Fig. 5, series 36–38). This decrease of tree growth is well defined in the highlands situated along the eastern shore of the lake. Larch trees growing along the western shore had low growth from 1806, *i.e.*, low growth began much earlier than along the eastern shore (series 36). Extremely low index values were most common in 1816, 1818 and 1820 in this area.

Discussion

The variability of ring-width indices between 1800 and 1840 in various subarctic and highland regions of Russia is evidence of abrupt summer cooling for *ca*. 10–15 yr. during the 1820s and 1830s. The intensity of this cooling was not the same in all of the regions studied. The most intensive cooling occurred in the northern regions of the Russian Plain, the Ural Mountains (Polar, Subpolar

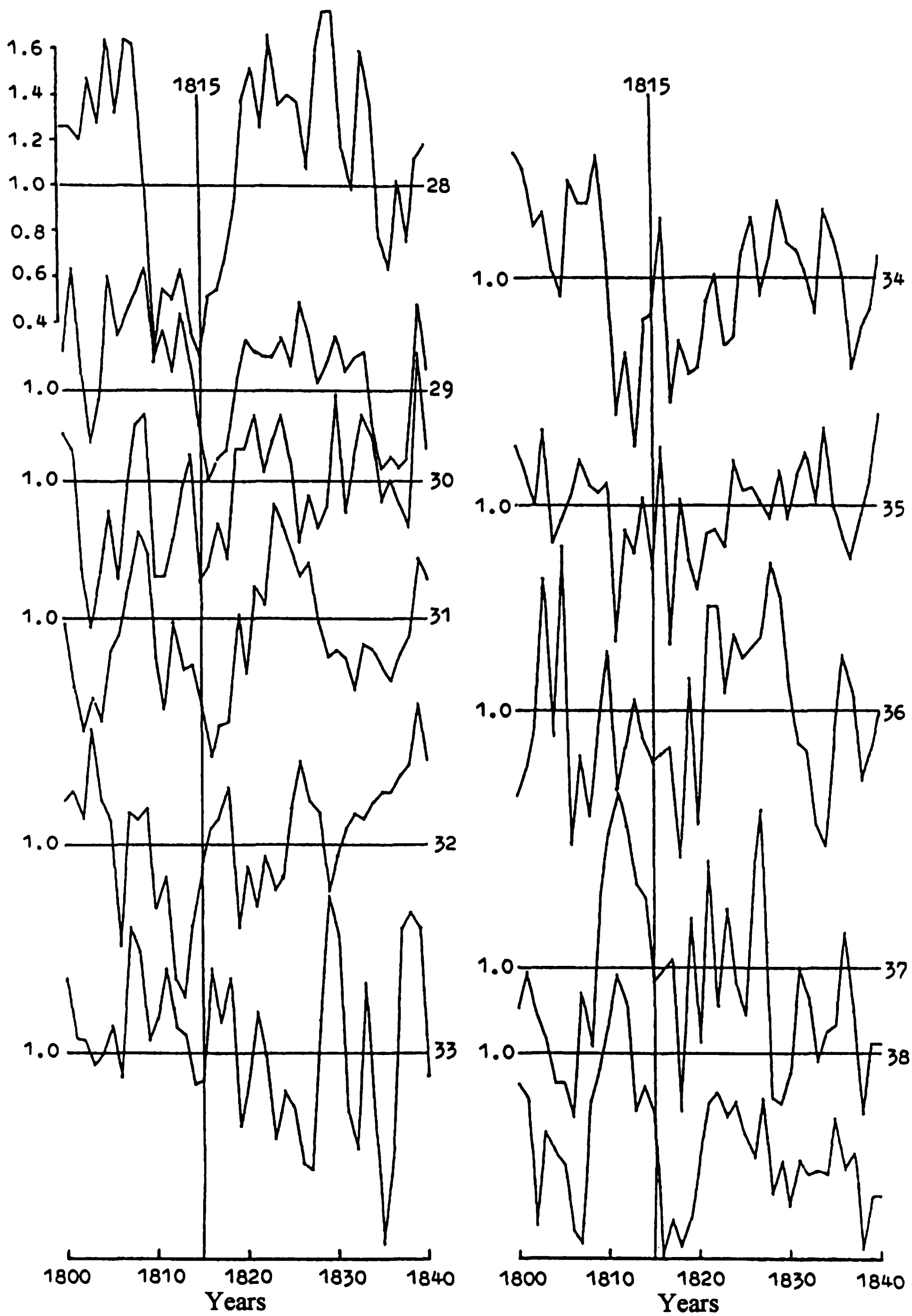

Fig. 5. Indexed ring-width chronologies for the period 1800–1840 developed for the Northern Ural Mountains (series 28–30), the Southern Ural Mountains (series 31–33), the Kamchatka Peninsula (series 34–35) and the highlands around Lake Baikal (series 36–38)

and Northern Urals) and the northwestern part of the West-Siberian Plain (lower reaches of the Ob and Nadym Rivers) (Fig. 1). For example, this was the most intensive cooling recorded during the last 960 yr in the Polar Ural Mountains: from 1810 to 1820, June and July temperatures were 1.7°C below average, and 2.3–2.8°C below average during the coldest summers of 1816, 1818 and 1820 (Graybill and Shiyatov 1992). During this period there was intensive degradation of forest-tundra ecosystems at the upper timberline in the Polar Ural Mountains (Shiyatov 1993), abrupt southward displacement of northern border of agriculture in the northern regions of the Russian Plain (Schrenk 1855) and severe summer sea ice in the Kara Sea (Nazarov 1947).

Maximum cooling occurred at different times in various regions. The coldest summers in the Kola Peninsula were in the mid-1820s (Fig. 1, series 1–3); in the Polar Urals, Subpolar Urals and lower reaches of the Ob River they were at the end of the 1820s (Fig. 1, series 7–8; Fig. 2, series 11–14); and in the Putorana Plateau in the mid-1830s (Fig. 3, series 18–19). In most subarctic and highland regions, cooling began before the Tambora eruption. In the Kola Peninsula, the northern part of the Russian Plain, all northern provinces of the Ural Mountains, the northwestern part of West-Siberian Plain, the northern part of the Central Siberia, the Kamchatka Peninsula and the highlands around the Lake Baikal, tree growth decrease began at the end of the 1810s or the beginning of the 1820s. Thus, the eruption took place during a regular cooling trend.

The analysis of growth-index variability in 110 chronologies has shown that there are no extremely high values for several years following 1815, but extremely low values did occur in many regions. Tree growth in 1816–1818 was unusually low throughout a vast territory: the northern part of the Russian Plain (series 4–6), the Polar, Subpolar and Northern Ural Mountains (series 7–10 and 28–30) and the northwestern part of the West-Siberian Plain (series 11–14), *i.e.*, regions situated between 45° and 75°E and to the north of 56°N along the Ural meridian (Fig. 1). Extremely low index values (as much as 60–95% below average) were recorded in the first three years after the Tambora eruption, especially in 1816 and 1818 (Fig. 2 and 3). Most trees that survived this cooling have very narrow or missing rings in the period 1816–1820. Growth response to this cooling among conifers differed according to species. Larch and pine trees recovered their growth rapidly (series 7–8, 11–12, 14, 30 and 31). Growth recovery of spruce trees took place 5–7 yr later (series 5–6 and 13) than in larch and pine trees. This difference may be related to needle longevity. Needles of *Picea obovata* are held for 10–12 yr and a much longer time is therefore required before photosynthetic capacity recovers.

In other regions studied there was no such well defined anomalous growth of trees during the years immediately after the Tambora eruption. However, in the Lake Baikal area several chronologies (series 36–38) show rather low index values in 1816–1818. This growth reduction can be related to decreasing precipitation as this area is situated in the southern part of the boreal zone and in many sites a limiting growth factor is available moisture.

Based only on visual inspection of ring-width chronologies, it is difficult to conclude that the Tambora eruption did affect climate and tree growth. More detailed and complex investigations are needed. In particular, it is necessary to develop a dense dendroclimatic network over the boreal zone and to produce a quantitative spatiotemporal reconstruction of climatic conditions for various seasons of the year. I think that tree growth-climate models can also be useful in evaluating the effects of volcanic eruptions on the climate and other natural phenomena. For example, Figure 6 shows segments of the larch chronology (series 11) developed for the southern part of the Jamal Peninsula. The series 11A was obtained using the ARMA(2,0) model, which eliminates the effects of tree growth of previous years on tree growth of current year, and the series 11B was obtained from the polycyclic model of the same chronology (Mazepa 1986) using 18 cyclic components from 2.1 to 72 yr long. The mean chronology (Fig. 6, series 11) has much lower index values in 1815–1820 (20% on average) than chronologies 11A and 11B (55% on average). This suggests that the Tambora eruption may have affected tree growth and summer-month cooling in this area.

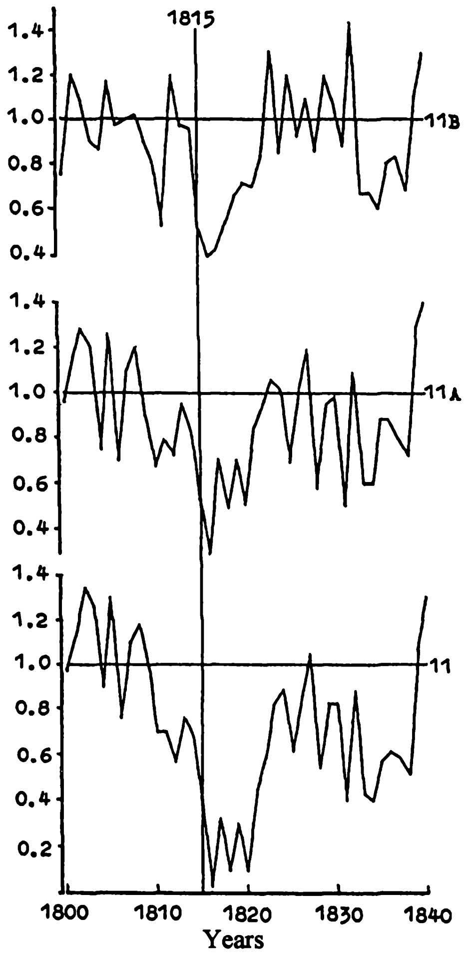

Fig. 6. The segments of the mean chronology (series 11), the prewhitened chronology using the ARMA (2,0) model (series 11A) and the chronology developed using the polycyclic model (series 11B) for the period 1800–1840

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