DECLINE IN LENGTH OF THE SUMMER SEASON ON THE KOLA PENINSULA, RUSSIA

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Abstract. By analysing records made in the northern taiga forests of the Lapland Reserve (Kola Peninsula, Russia) during 1930–1998, we unexpectedly discovered a decline in the length of the snow-free and ice-free periods by 15–20 days due to both delayed spring and advanced autumn/winter. Respective seasonal temperatures best explained the dates of all phenological phases: 1 °C shift in temperature was approximately equal to 2–5 day shift in phenology. However the phenological shifts during the observation period are much larger than could be expected from the slight (0.56 °C) drop in temperatures during August–September, suggesting that the biotic effects of a very slight cooling have been enhanced by one or more unknown factors. Although emissions of sulphur dioxide from the nickel-copper smelter at Monchegorsk may have contributed to the observed trend (via changes in regional radiative budget), we found no evidence of direct pollution impact on dates of birch autumnal coloration or birch leaf fall, which exhibited the largest (22 days) shift between 1930 and 1998. The detected phenological trends agree with an increase in winter (snow) precipitation in the study area by 44%; however, effects of precipitation on any of the investigated phenological phases were far from significant. Our results highlight the importance of phenological records for the assessment of past regional environmental changes, and demonstrates that the prediction of even the simplest biotic responses to the Global Changes requires a profound understanding of the interactive impact of abiotic factors on the ecosystem.

1. Introduction

The global mean temperature has increased over the past 100 years by 0.3–0.6 °C, and a further increase by 0.9 to 3.5 °C is predicted by the year 2100 (Houghton et al., 1996). Although warming is expected to be greater at high latitudes (Chapman and Walsh, 1993), it is still unclear how temperatures may change in the Barents Sea region (Räisänen, 1994; Lange et al., 1999). Predictions for precipitation patterns are also variable, although several models agree on a possible increase in precipitation, expected to occur mainly in wintertime (Houghton et al., 1996; Räisänen, 1994).

Climatic changes are expected to affect the seasonal patterns, distribution ranges and population dynamics of all groups of organisms (Heal et al., 1998; Lange et al., 1999), and there are already numerous records which can be interpreted as biological consequences of global warming (Hughes, 2000). However, there still exist major uncertainties in predicting the biotic effects of climate change (Heal et

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al., 1998; Press et al., 1998; Kramer et al., 2000). The accuracy of predictions can be increased by the coordinated investigation of past changes in both biotic and abiotic environments (Houghton et al., 1996), which has given special importance to old phenological records (Heikinheimo and Lappalainen, 1997; Sparks and Yates, 1997; Minin, 1998; Sparks et al., 1999). In this study we searched for a pattern in the length of the warm (summer) season in the European northern taiga forests during the past 70 years, and compared trends in the timing of seasonal events with those in temperature and precipitation.

2. Materials and Methods

We used a small fraction of the records of more than 200 seasonal events (Semenov-Tian-Schanskij, 1947; Semenov-Tian-Schanskij and Ablaeva, 1983) made at the Tshuna settlement (67°39′ N, 32°37′ E) of the Lapland Biosphere Reserve, 40 km S of Monchegorsk (Kola Peninsula, NW Russia). Records have been made since 1930 along a 1000 m route in sparse old-grown Norway spruce (*Picea abies* (L.) Karst.) forest with Scots Pine (*Pinus sylvestris* L.) and mountain birch (*Betula pubescens* subsp. *czerepanovii* (Orlova) Hämet-Ahti). Forest structure and composition along the route have remained unchanged during the observation period. O. I. Semenov-Tian-Schanskij, who worked in the Reserve from 1931 to 1990, collected most of the data used in the present study; since 1982 records were made by N. Berlina. Some records are missing from 1941–1945 (World War II) and 1952–1957 (when the Reserve was closed down), which affected the number of data values in the analysis.

The following phenological indicators were used: (1) beginning of spring: the day when complete circles of open ground appeared around at least two of the seven old (aged more than 200 years) trees of Scots pine at the settlement; (2) snow-free period: from the day when snow disappeared at 26 of 50 fixed points along the route to the day of the appearance of stable snow cover, e.g. snow cover which never melted completely before the spring; (3) ice-free period: from the day when a continuous band of open water (1–1.5 m wide) appeared along the 200 m shore of the Tshuna lake to the day of freezing; (4) mountain birch being in leaf: from the beginning of leaf unrolling (leaf length about 10 mm) in at least 2–3 of 25 birches to the day when the first yellow leaves fell from the first 2–3 trees along the route; (5) length of reproductive period of cloudberry, *Rubus chamaemorus* L.: from onset of flowering in at least 2–3 of 25 plants to appearance of ripe fruits (as indicated by colour and taste) in at least 2–3 of 25 plants along the route; (6) length of reproductive period of cowberry, *Vaccinium vitis-idaea* (L.) Avz.: from onset of flowering in at least 2–3 of 25 plants to appearance of ripe fruits in at least 2–3 of 25 plants along the route; (7) end of autumn: appearance of the first snow on the forest floor.

Meteorological data were recorded at the site of phenological observations only from 1977 to 1994. However, these data were strongly (monthly mean temperatures: $r = 0.89$, $n = 216$ months, $P < 0.0001$; monthly precipitation: $r = 0.71$, $n = 215$, $P < 0.0001$; values standardised by month to eliminate seasonal trend) correlated with the corresponding records at the town of Monchegorsk, thus justifying the use of Monchegorsk meteorological data (available since 1936; received directly from the station) in the analysis of our phenological records. Neither annual ($r = -0.03$, $n = 63$ years, $P = 0.82$) nor seasonal nor monthly mean temperatures in Monchegorsk showed any directional changes between 1936 and 1998 (table-wide $P > 0.05$). Temperature and precipitation records from the two nearest stations, Murmansk (150 km N) and Kandalaksha (60 km S of our observation point) were obtained at http://ingrid.ldgo.columbia.edu/SOURCES/.NOAA/.NCDC/.GCPS/.MONTHLY/.

The hypothesis on possible effect of environmental pollution, which increased in the study region during 1946–1990 (Rigina and Kozlov, 1999), on autumnal coloration and loss of foliage in mountain birch was tested by using two independent data sets. First, on 12–13 September 1999 we visually (to the nearest 20%) estimated loss of foliage in five mountain birches in each of 20 plots located 1 to 65 km from the nickel-copper smelter at Monchegorsk (for more details on trees and plots see Valkama and Kozlov, 2001); coloration of the remaining foliage was classified as bright green, pale green, yellowish green or bright yellow. Plot-specific means of these two characteristics were correlated with respective mean concentrations of nickel in birch foliage during 1991–1999 (data after Kozlov et al., 1995; and unpublished); note that two most distant plots represented regional background level of foliar nickel (4–6 mg kg^{-1}). Second, we correlated dates of birch leaf yellowing during 1940–1998 with respective annual amounts of sulphur dioxide emissions by the smelter (emission data after Alexeyev, 1993; Kozlov and Barcan, 2000; Dubrovskij, 2000).

3. Results

In the 1990s, snow around tree-trunks melted on average 16 days later than in the 1930s (Figure 1a), and the permanent snow cover in forests appeared 13 days earlier (Figure 1b); however the date when snow was first detected on the forest floor was not affected (Figure 1b). The duration of the snow-free period in forests decreased by 20 days (Figure 1c); similarly, the ice-free period on lakes decreased by 15 days (Figure 1f), although the trends in both appearance of open water (Figure 1d) or freezing of Tshuna lake (Figure 1e) were not significant.

Observations on three plant species revealed no phenological response to the delayed snow melt (Figures 2a,c,e), whereas an advancement of autumn was detected in one of three investigated species (Figures 2b,d,f). Birch leaf fall in the 1990s started 22 days earlier than in the 1930s (Figure 2b), indicating a shortening

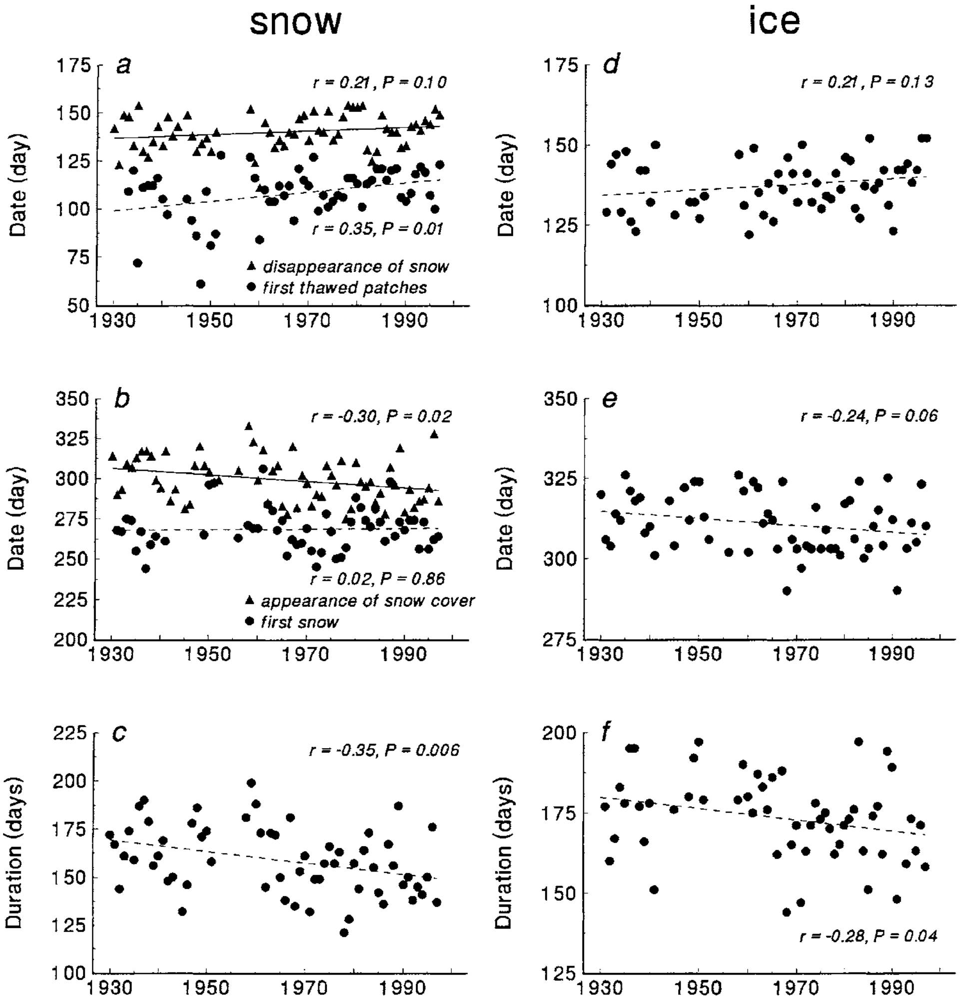

Figure 1. Trends in phenological phases associated with snow-free period in forests and ice-free periods on lakes: annual values and regression lines. (a) Snow melt; (b) appearance of snow; (c) duration of snow-free period; (d) appearance of open water on Tshuna lake; (e) freezing of Tschuna lake; (f) duration of ice-free period. Days are counted starting from January 1.

of the growing season. Cowberry fruits ripened 10 days later than in the 1930s (Figure 1d), whereas those of the cloudberry ripened on about the same date as in the 1930s (Figure 1f).

Although some phenological phases correlated with seasonal precipitation values (Table I), there were only five significant correlation coefficients out of 48, which is pretty close to the number expected just by chance (at the probability level $P = 0.05$). Furthermore, none of the significant correlations matched the season when the event occurs (Table I). In contrast, correlations with seasonal temperatures were significant in 13 out of 48 cases (Table I), and ten of them

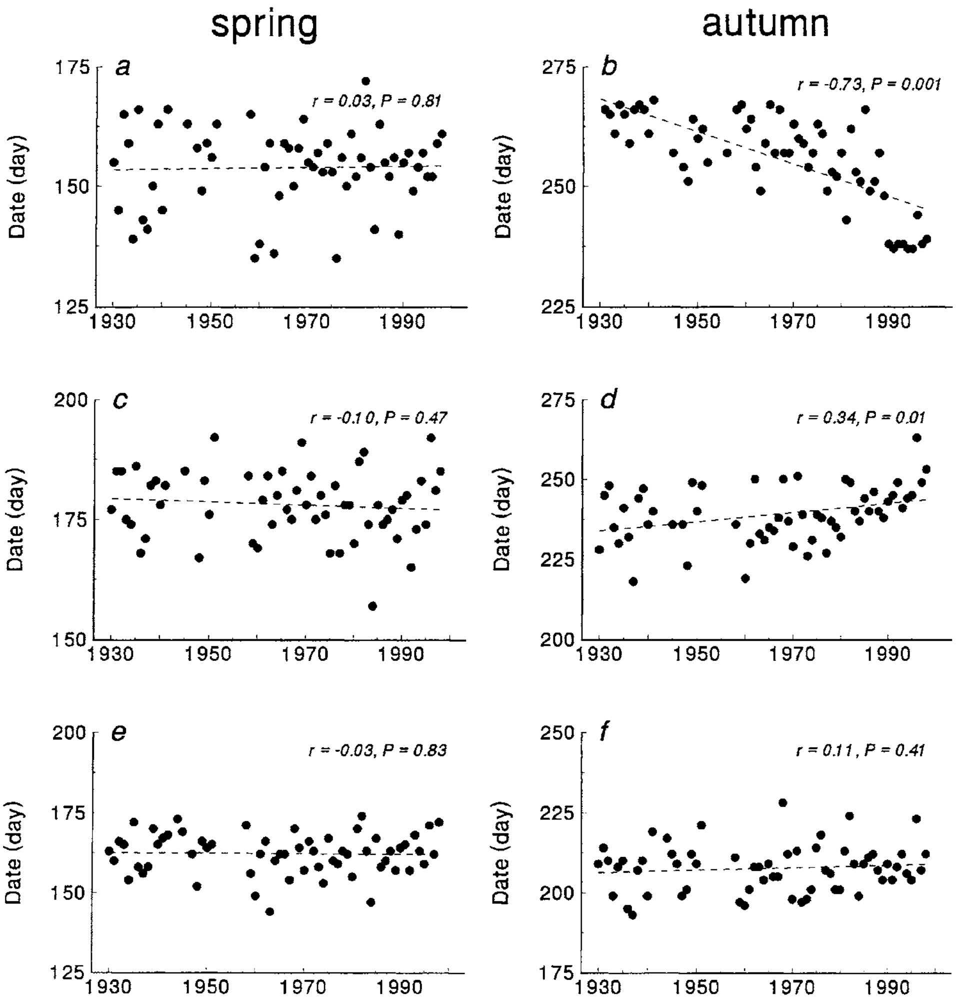

Figure 2. Trends in plant phenological phases: annual values and regression lines. (a) Leaf unrolling in mountain birch; (b) beginning of leaf fall in mountain birch; (c) onset of flowering in cowberry; (d) ripening of cowberry fruits; (e) onset of flowering in cloudberry; (f) ripening of cloudberry fruits. Days are counted starting from January 1.

matched the season when the event occurs (Table I). Regression analysis with the stepwise selection of variables in all cases ended with the model where temperature explained the largest part of variation in dates of phenological phases (Table II). There was no difference in regression coefficients for abiotic and biotic processes (Kruskal-Wallis test, $\chi^2 = 2.56$, $df = 1$, $P = 0.11$); however, seasonal variation was significant ($\chi^2 = 9.46$, $df = 3$, $P = 0.02$): 1 °C shift in temperature was approximately equal to 2.5 day shift in spring phenology and to 5 day shift in autumnal phenology (Table II).

Table I

Correlations between the dates of phenological phases and seasonal meteorological conditions during the preceding 12-month period (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$). Boldface indicates coefficients corresponding to the periods when the phenological phase occurs

Phenological phase	Precipitation				Temperature			
	XII–II	III–V	VI–VIII	IX–XI	XII–II	III–V	VI–VIII	IX–XI
First thawed patches	0.19	**0.05**	–0.06	–0.15	–0.08	**–0.24**	–0.12	–0.23
Destruction of snow cover	0.09	**–0.01**	–0.20	0.13	–0.23	**–0.50*****	–0.22	–0.01
First snow on forest floor	–0.03	0.09	0.30*	**–0.11**	–0.05	0.03	–0.17	**0.41****
Appearance of snow cover	0.06	0.18	0.12	**0.14**	0.05	0.14	0.02	**0.44*****
Open water on Tshuna lake	–0.03	**–0.06**	–0.28*	0.09	–0.21	**–0.52*****	–0.09	–0.04
Freezing of Tshuna lake	–0.01	0.16	0.25	**–0.03**	0.17	0.24	0.07	**0.61*****
Birch leaf unrolling	–0.26	**0.18**	–0.12	0.09	–0.21	**–0.52*****	–0.25	0.08
Birch leaf fall	–0.31*	–0.02	–0.03	**–0.07**	–0.26	–0.16	0.16	**0.15**
Flowering of cowberry	–0.41**	–0.10	**–0.14**	–0.07	–0.21	–0.49***	**–0.31***	0.14
Ripening of cowberry	–0.03	0.06	**0.05**	0.04	0.08	–0.17	**–0.52*****	0.09
Flowering of cloudberry	–0.30*	0.16	**–0.05**	–0.19	–0.14	–0.48***	**–0.39****	0.11
Ripening of cloudberry	–0.22	0.06	**–0.05**	–0.13	–0.10	–0.28*	**–0.69*****	0.06

Table II

Regression of the dates of phenological phases to seasonal meteorological conditions which best explain the annual variation (selected by the stepwise regression analysis from four seasonal precipitation values and four seasonal temperature values during the preceding 12-month period)

Phenological phase	Variable	Estimate	SE	F	Pr > F
First thawed patches	Intercept	105.54	2.34	2038	<0.0001
	T (III–V)	–1.96	0.87	5.07	0.0295
Destruction of snow cover	Intercept	133.80	1.82	5422	<0.0001
	T (III–V)	–3.14	0.68	21.49	<0.0001
First snow on forest floor	Intercept	266.92	1.93	19050	<0.0001
	T (IX–XI)	4.57	1.41	10.50	0.0023
Appearance of snow cover	Intercept	296.91	2.00	22142	<0.0001
	T (IX–XI)	5.35	1.46	13.49	0.0006
Open water on Tshuna lake	Intercept	131.23	1.58	6906	<0.0001
	T (III–V)	–2.93	0.59	24.80	<0.0001
Freezing of Tshuna lake	Intercept	308.73	1.20	66671	<0.0001
	T (IX–XI)	4.31	0.87	24.36	<0.0001
Birch leaf unrolling	Intercept	89.91	1.63	3048	<0.0001
	T (III–V)	–2.38	0.60	15.69	0.0003
Birch leaf fall	Intercept	181.43	5.73	1001	<0.0001
	T (XII–II)	–1.22	0.47	6.63	0.0133
Flowering of cowberry	Intercept	114.14	1.47	6056	<0.0001
	T (III–V)	–2.16	0.54	15.90	0.0002
Ripening of cowberry	Intercept	219.70	9.59	525	<0.0001
	T (VI–VIII)	–3.36	0.81	17.40	0.0001
Flowering of cloudberry	Intercept	99.14	1.34	5498	<0.0001
	T (III–V)	–1.70	0.49	11.86	0.0012
Ripening of cloudberry	Intercept	193.75	7.07	750	<0.0001
	T (VI–VIII)	–3.82	0.59	41.24	<0.0001

Among the observed phenological phases, the largest shift (22 days) was recorded in birch leaf fall (Figure 2b), the event that was worst explained by temperature and precipitation data (Table I). The trend remains significant ($r = -0.52$, $n = 53$ years, $P < 0.0001$) even when the records for the past decade, which markedly differ from the remaining data set (Figure 2b), were excluded. Since the observation area during the past decades was affected by the emissions of the copper-nickel smelter located at Monchegorsk (in 40 km distance), the trend may have arisen due to increase in pollution. However, autumnal coloration and loss of foliage by mountain birches, experiencing high pollution loads, were the same as

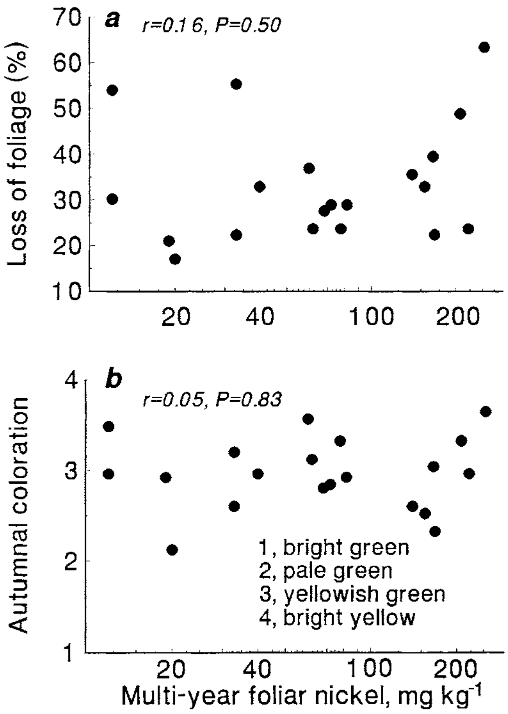

Figure 3. Relationships between birch leaf fall and environmental contamination. (a) Loss of foliage; (b) Autumnal coloration.

in the background area (Figure 3). Furthermore, dates of leaf fall since the time of establishment of the smelter at Monchegorsk did not correlate with respective annual emissions of sulphur dioxide ($r = 0.05$, $n = 43$ years, $P = 0.75$).

4. Discussion

Recent analyses of long-term data sets indicate that some species are already responding to the anomalous climate of the 20th century, confirming the global warming concept (Hughes, 2000; Minin, 2000). However, the data which demonstrate opposite trends also exist, although they are less likely to be submitted and published; moreover, if they happen to be published (Kozhevnikov, 1996; Kullman, 1996; Minin, 2000; Høgda et al., 2001), they are only rarely referred to in the discussions on climate change (Kozlov, 2000).

Our data on phenological shifts in Northern Europe clearly contradict the expected regional warming, forcing us to suggest that something is wrong with the data itself. However, close scrutiny of the original records, protocols, and other relevant information did not reveal any possible source of the error. Therefore we concluded that the length of the summer season on the Kola Peninsula (as reflected by the length of snow-free and ice-free periods) really declined during the past 60 years due to both delayed spring and advanced autumn/winter. This conclusion is indirectly supported by the recently published results of the satellite-based study of the length of the growing season during 1982–1989 in Fennoscandia (Høgda et al., 2001), which demonstrated one-week delay in spring at high latitudes (including the Kola Peninsula) clearly contrasting to the advancement of spring occurring in Southern Fennoscandia. However, our data showed no changes in spring phenology, while an advancement of autumn is reflected for instance by early leaf fall in mountain birch.

Since a 5-day shift in autumnal phenology approximately corresponds to 1 °C shift in tempereture (Table II), the insignificant ($r = -0.14$, $n = 62$ years, $P = 0.28$) decrease in the mean temperatures of August and September by 0.56 °C recorded at Monchegorsk is unlikely to explain either the advancement of birch leaf fall by 22 days or the postponement of cowberry ripening by 10 days. The late summer cooling was observed also in Murmansk (140 km N of Monchegorsk; by 0.90 °C; $r = -0.28$, $n = 65$ years, $P = 0.02$), but this trend did not reach the significance level in Kandalaksha (100 km S; by 0.40 °C; $r = -0.15$, $n = 64$ years, $P = 0.21$), suggesting the existence of a regional trend rather than a local fluctuation.

The observed phenological trends agree with an increase in winter (snow) precipitation in the study area by 44% ($r = 0.38$, $n = 63$ years, $P = 0.0025$); Høgda et al. (2001) also explained delayed spring in northernmost Fennoscandia by an increase in winter precipitation. However, winter precipitation did not enter the stepwise regression analysis for any of the phenological phases (Table II), and the weak correlation between winter precipitation and date of birch leaf fall (Table I) may well be spurious. Early leaf fall in birch may result from drought, but summer precipitation did not influence the date of birch leaf fall (Tables I, II). Finally, we failed to detect the direct effect of pollution on leaf fall in mountain birch; therefore the immediate reasons of the observed shortening of summer remain unknown.

Our data support the conclusion by Myneni et al. (1997) that small changes in temperature may lead to disproportionally large biotic responses, in particular due to possible positive feedbacks in the ecosystems. In our case, the minor climatic signal was ‘amplified’ by the ecosystem to a detectable level. This finding highlights the urgent need for the investigation of the interactive effects of abiotic factors, which are expected to change in relation to the increasing concentration of greenhouse gases; the present level of knowledge, in combination with individualistic plant responses to changes in abiotic environment (Chapin and Shaver, 1985; Heal et al., 1998; Press et al., 1998), makes speculation on the mechanisms underlying the observed shifts premature.

Past phenological changes demonstrate pronounced spatial variation: even the direction of trend may change within ca. 1000 km distance (Minin, 2000; Høgda et al., 2001). Furthermore, all climatic models agree that the effects of global warming will be differently expressed in different parts of the Globe (Chapman and Walsh, 1993; Räisänen, 1994; Houghton et al., 1996; Mann et al., 1998). A recent discussion on the climate of the Barents Sea region (Lange et al., 1999) demonstrated a wide variety of opinions: while some scientists suggested a warming, others predicted either a stable temperature regime or a slight increase in temperatures for the next 20 to 50 years, followed by a decrease. Some observations in Northern regions were already said to contradict the general predictions on global warming (Normile, 1995); thus our conclusion as to the recent decline of the growing season on the Kola Peninsula (possibly indicating regional cooling) is not exceptional. Furthermore, in the Kola Peninsula we found the same seasonal trend as detected at the larger geographical scale: the warming is smallest in autumn (Chapman and Walsh, 1993). This may suggest that some regional processes may have interfered with the global trend.

The postponment of spring and advancement of autumn on the Kola Peninsula contrasts with the trends detected both south and north of our observation area: advancement of spring was reported in both Southern Karelia (Minin, 1998) and Southern Finland (Sparks et al., 1999), and shortening of the ice season was observed in the Barents Sea (Parkinson, 1992) as well as on several lakes and rivers in Finland (Magnuson et al., 2000). The Kola Peninsula differs from these regions by its severe environmental contamination due to emissions of sulphur dioxide from two powerful nickel-copper smelters (Rigina and Kozlov, 1999). Since emissions may negatively affect the regional temperatures due to radiative forcing (Berntsen et al., 1996), a model (Mitchell et al., 1995) accounting for both greenhouse gases and sulphate aerosols may appear more suitable for the Barents Sea region than models (Räisänen, 1994; Lange et al., 1999) accounting for greenhouse gases only. Alternatively, decrease in regional temperatures may have resulted from changes in heat transfer by the Gulfstream, triggered by global warming (Bonyard, 1999). However, both these hypotheses are debatable, because the largest decline in the length of the growing season during 1982–1998 was recorded in the area between Kiruna (Northern Sweden) and Enontekiö (Northern Finland) (Høgda et al., 2001), which is located far from big polluters and separated from the seashore by a mountain range.

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