Approaches for the Identification of Long-term Trends in Growth of Siberian Spruce and Scots Pine in North West of Russia

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Abstract

Komi is situated at the eastern boundary of the European part of Russia, in the boreal region where large areas of natural forest still exist. Using radial and apical growth it was possible to detect positive long-term trends of the growth in Scots pine (*Pinus sylvestris L.*) and Siberian spruce (*Picea obovata Ledeb.*) in the forest-tundra transition zone, the northern taiga zone, the middle taiga zone, and the southern taiga zone of boreal forests in the Komi Republic. Three different approaches were used for identifying long-term trends in the growth of Siberian spruce and Scots pine: the construction of the chronology, comparison of the radial increment at similar cambial age, and comparison of the height increment at similar cambial age. The combination of methods for estimating long-term growth trends emphasizing the height increment has proven to be an adequate approach.

Key words: *Pinus sylvestris* L., *Picea obovata* Ledeb., radial increment, height increment changes, dendrochronology, growth variation, stem analysis

Introduction

According to the World Meteorological Organization (2003) the global surface air temperature has increased since measurements were first recorded in 1861. During the 20th century the increase was more than 0.6°C. The rate of change for the period 1976 to present was roughly three times that of the last 100 years as a whole. Analyses of proxy data for the Northern Hemisphere indicate that this increase in air temperature during the latter part of the 20th century is unprecedented when compared to the last millennium (World Meteorological Organization (2003)). In the Northern Hemisphere, the 1990s were the warmest decade and 1998 was the warmest year during the last 1000 years. Borehole temperature measurements in the Komi Republic also indicate strong subsurface warming, reflecting changes in the trends of both surface air temperature and solid precipitation (Oberman and Mazhitova 2004).

In many boreal regions warming is associated with increased precipitation, increased river discharge, a longer growing season, a change in the distribution of plant species, and higher net primary productivity. Recent findings clearly show that nitrogen deposition and climate change are major driving force behind growth variation and differences in tree mortality (Spiecker 1995, Spiecker 1996, Spiecker 2000, Raitio 2000, Mäkinen *et al.* 2001). The understanding of growth trends in the Komi Republic's forests as a response to global change for both the past and the future is very important for the development of the European forest sector.

Case studies in the Komi Republic including Drobushev (Drobushev 2004) showed that latewood width of Scots pine (*Pinus sylvestris* L.) was positively correlated with air temperature in April-May and July-August of the current growing season and with the July-August precipitation of the previous year. Earlywood width was positively affected by the precipitation in

May and November of the previous year (Drobushev 2004). This is in accordance with the observation which shows that the growth of conifers in the boreal zone positively correlates with air temperatures of the growing season (Briffa *et al.* 1988). Physiologically, this is due to the fact that in the boreal zone, the carbon gain of the trees is typically limited by the air temperature during growing season. As long as water is not a limiting factor for the radial growth, increased carbon gain in the tree ring should positively correlate with the increment. One possible hypothesis could be that increased air temperature results in more carbon being assimilated by the tree and as a result trees will grow faster. In this case there are two scenarios of possible development:

- trees will be larger as there will be changes in height, shape and thickness of stems as a result of carbon accumulation and higher biomass production;
- trees will grow faster but the increased growth could be counterbalanced by a higher rate of mortality resulting in an identical volume of growing stock or carbon accumulation.

On an European scale, an attempt to identify forest growth trends was made in 1993-1996 (Spiecker 1996, Spiecker 1999b). The main purpose of the project was to analyze whether site productivity had changed in European forests during the last decades. It was possible to observe an increasing growth trend in most cases in Europe. However, in some studies (Mielikäinen and Sennov 1996, Nöjd 1996, Mäkinen *et al.* 2001) a decreasing trend was reported at specific sites. Information about forest growth in the Kola Peninsula and Russian Karelia was represented by Russian studies in this project. In Northern Europe, both negative and positive trends have been found. A negative trend was found in the Kola Peninsula which can be attributed to the non-ferrous smelter in the area (Nöjd 1996, Mäkinen *et al.* 2001) while a positive trend was found in the Saint-Petersburg region (Mielikäinen and Sennov 1996). Studies in Karelia showed that no definite conclusions can be drawn regarding site productivity changes in the area (Sinkevich and Lindholm 1996). Those study areas represent only 17% of the forest area of North-West Russia. Previous studies on growth trends were conducted mostly in secondary even-aged forests in Europe (Spiecker 1996). Studies of growth trends in untouched pristine uneven-aged forests may provide a better understanding of the reaction of forest ecosystems to global climate change. It is especially important for modelling of forest growth in the future. Usually the effects of forest management are well understood.

The main aim of this paper is to compare different tree-ring based methods for identification of long-term trends in the growth of Siberian spruce and Scots pine in the Komi Republic (North-West Russia).

Materials and methods

Study area

Komi is one of the eastern most boreal regions of European Russia where large areas of natural forest still exist. The land area of Komi Republic, 415,900 km^2, is situated within two major land shields – the Russian shield in the southwest and the Pechora shield to the northeast (Dedeev 1997) with moraine and surface loams being the most typical soil types (Zaboeva 1997). The forested area totals around 300,000 km^2, which constitutes 4.1% of all forested areas in Russia (Obuhov and Larin 1999).

Climatically, the Komi Republic lies within the Arctic, Atlantic-Arctic and Atlantic-Continental zones. The annual average air temperature varies between +1^{0}C in the southern part of the Komi Republic and -6^{0}C in the northern part, with the growing season (days with daily average air temperature above +10^{0}C) being between 45 and 10 days, respectively. Annual rainfall decreases from 700 mm in the south to 450 mm in the north. The accumulation of thick snow cover (70-80 cm) is characteristic of the winter period which lasts for 130 – 200 days (Stolpovski 1997).

Selection of sites and trees

The material was collected along transect from the south of Komi (south taiga sub-zone of taiga) to the Arctic spruce timberline. The study stands were grouped into 'sub-zones' according to their geographical position in the taiga sub-zones of the boreal forests (Table 1).

The sites were selected using GIS datasets of forest management units, old forest inventory maps and satellite images TERRA ASTER (scene size 60x60 km) with a spatial resolution of 15 m. In the procedure for site selection, the main aim was to find representative site types and at the same time exclude possible forest management or any other human impact from the past. Sites with a low productivity index (class 5, according to the classification system for Russian forest productivity) comprises 70% of the forest area of the Komi Republic (Kozubov and Taskaev 1999). Therefore the analytical approaches used in this study helped to generalize the results from different geographical areas. Differences in site characteristics, such as exposure, soil properties, topography or vegetation development, are assumed to have been minimized accordingly. To obtain information about changes in site productivity trees of different ages on comparable sites were selected. The trees were randomly sampled on sites of medium fertility.

Table 1. Samples collected in the Komi Republic in 2003

Site number	Forest subzone	Location	Spruce n sampled trees	Spruce n model trees**	Spruce Time span	Pine n sampled trees	Pine N model trees**	Pine Time span
1. *	Middle taiga zone	61°39'576" N 50°46'467" E	9	0	1855-2003 (148)	15	0	1847-2003 (156)
2. *	Middle taiga zone	61°43'491" N 50°38'736" E	2	0	1853-2003 (150)	12	0	1844-2003 (159)
3.	Northern limit of the northern taiga zone	65°59'697" N 57°48'820" E	14	3	1877-2003 (126)	14	3	1924-2003 (79)
4.	Northern forest - tundra transition zone	66°41'260" N 56°49'142" E	12	1	1811-2003 (192)	-	-	-
5.	South taiga zone	60°33'615" N 49°26'945" E	4	2	1916-2003 (87)	10	5	1877-2003 (126)
6.	Middle taiga zone	61°44'834" N 50°34'910" E	12	13	1774-2003 (229)	14	14	1824-2003 (179)
	Total:		53	19	1774-2003 (229)	65	22	1824-2003 (179)

* Only crossectional cores were collected for these sites.
** Model trees means trees selected for stem analysis.

The stands were selected according to the following criteria for site conditions:

- spruce or pine dominating species;
- low site index (class 5, according to the Russian forest productivity classification system (Hytteborn *et al.* 2005);
- multistoried mature stands represented by trees of 3-5 different age classes.

In most of the regions in Komi the forest stands are represented by the trees of different age classes. Therefore the sample trees were chosen from among trees not dominated by older trees but rather located in openings within the stand. The sample trees chosen from within an opening were expected to reveal homogeneity in their tree-ring pattern as they showed no obvious signs of near-neighbour competition or forest management. From within an opening, healthy looking trees with straight, unbroken stems and regularly shaped crowns were chosen from different diameter classes. Only mature dominant trees without visible signs of damage were selected as sample trees. Thus, the selected trees were assumed to represent similar site conditions but different tree ages. The sample trees in the stands were expected to have a common growth trend, which was influenced by a large portion of the climatic effects and other factors, which differ among individuals and from site to site. On each site an averaging process, during building chronology, helped to minimize the influence of other factors.

Prior to felling, for visual assessment of the tree ring pattern, the core of the tree was extracted with an increment borer. This allowed exclusion of those trees affected by competition in the past. Siberian spruces and Scots pines were sampled at breast height (about 1.3 m above the ground, or a few centimeters higher or lower if a branch or something else made ring measurement difficult). In most cases, disks were cut using a chain saw. If it was difficult to cut disks, cores were extracted from two radii per tree (the first one oriented to the north, the others at 90^0-120^0 to the first). A disk was sawn every 2 m from breast height to top of the stem. On all disks, the north direction was marked. Geographical coordinates of sample trees were measured using GPS.

Sample preparation and measurement

The disks and cores were dried in normal room conditions and then sanded. The prepared surfaces were measured with system WinDENDRO (Guay *et al.* 1992), and using a traditional microscope based system in case of extremely narrow rings.

The measurements of the tree rings were carried out on a minimum of two radii per disk, though usually on four radii. Where the samples were cored, the two cores per tree were measured to reduce the amount of intra-tree variability, and enabling the discounting of non climate factors that are peculiar to one core. Having numerous sample trees from one site and several sites in the region ensures that the influence of other external factors is minimized. The data collected from the measurement of the tree rings was cross-dated using a visual control by comparing the series graphically. Data quality was assessed with the aid of the computer program COFECHA (Grissino-Mayer *et al.* 1997, Holms 1999).

The identification of long-term forest growth trends

In the Komi Republic there are no available data because of the lack of permanent research plots within the observation period. Because forest growth cannot be analyzed in a direct way, reconstructed radial and height increment of dominant trees is used in this study as an indirect measure of the past changes in development of site productivity (Spiecker 1999a).

The definition of growth trend in this study is similar to previous research projects (Spiecker 1996). Growth trend can be defined as a persistent change in the average rate of the growth. Growth trends within this project are indicated by long-term (more than 30 years) site-induced deviations of observed versus expected growth without taking into account site changes. Long-term trends in the growth can be defined as a component of annual growth variation dominated by low-frequency variation (period = 30 years).

There are 3 methodological approaches chosen for the identification of long-term growth trends using the measurement of tree rings from the sampled trees:

- chronology building,
- comparison of the radial increment at similar cambial age at 1.3m height, and
- comparison of the height increment in similar cambial age reconstructed from stem analysis

Building of the chronologies and evaluating long-term changes in forest growth using these chronologies is one of the most widely used methods of identifying forest growth trends (Spiecker 1996, Mielikäinen and Sennov 1996, Sinkevich and Lindholm 1996, Spiecker 1999b, Grudd *et al.* 2002).

The ARSTAN program was used to detrend the raw chronologies of individual trees (Holms *et al.* 1986, Grissino-Mayer *et al.* 1997, Holms 1999). To remove the non-climatic trends in the radial annual increments, single series were double detrended. For each detrending a negative exponential curve was used if possible, or if not, a linear regression line of negative slope or a horizontal line through the mean is fit and then through the mean value. Then the individual series were averaged in chronologies and the autocorrelation was removed using autoregressive modelling, the deviation from the mean value over the whole period of observation was calculated and then smoothed by employing a 10-year running average. The removal of growth trends from an individual sample requires the removal of the age trend, thereby enhancing the signal of the changing environment, such as global climate change. The disadvantage of this method is that it can also lead to the discounting of long-term growth trends as a result of changes in site productivity.

In this study we also used raw radial increment series, trying to avoid any bias introduced by indexation. Radial growth was analyzed within age classes to check whether there were any size differences between the radial increment of trees of the same cambial age in different periods (Briffa *et al.* 1992, Becker *et al.* 1994, Lebourgeois and Becker 1996, Lebourgeois *et al.* 2000). In this approach the radial increment series are divided into age classes so that only data derived from rings within a specific age range are averaged in succession. This gives tree-growth estimates within which the age of trees is held roughly constant through time (Briffa *et al.* 1992). Data are averaged year by year, separately, for the two species. Four age classes were considered: 1-50, 51-100, 101-150 and 151-200. Only the series derived from disks and cores where the innermost rings allowed the estimation of pith location and cambial age were included in the analysis.

The aim of the height growth assessment was to generate information about the height development rate of trees starting to grow in different time periods by comparison of growth rates at similar cambial age. The approach applied here is the reconstruction of diameter and height growth by means of a stem analysis technique. It is possible to reconstruct the height of trees with a similar cambial age though having germinated in different calendar years.

Results

The south taiga zone

Due to the lower number of sampled trees it was not possible to identify long-term trends in the growth of Siberian spruce at this stage of analysis. The standardized tree-ring chronologies of Scots pine and cambial age approach show a decrease in the growth in the last 50 years compared with the similar period in the first decades of the 20th century (Figure 4).

The middle taiga zone

The standardized tree-ring chronologies of Siberian spruce show an increase in the growth since 1950 that is confirmed by the cambial age approach and height increment (Figures 1,2,3). Siberian spruces in the middle taiga sub zone are growing faster now than they grew 50 years ago. It means that site productivity has changed (Figure 3, comparison with yield tables of Zagreev (1992), Table 2). The mean radial increment of Siberian spruce during the last 30 years has increased by 115% as compared with long-term mean

Figure 1. Standardized tree-ring chronologies of Siberian spruces smoothed with a 10-year moving average, shown as a deviations from the mean (n=number of trees)

A. Middle taiga zone

B. Northern limit of northern taiga zone

C. Northern forest-tundra transition zone

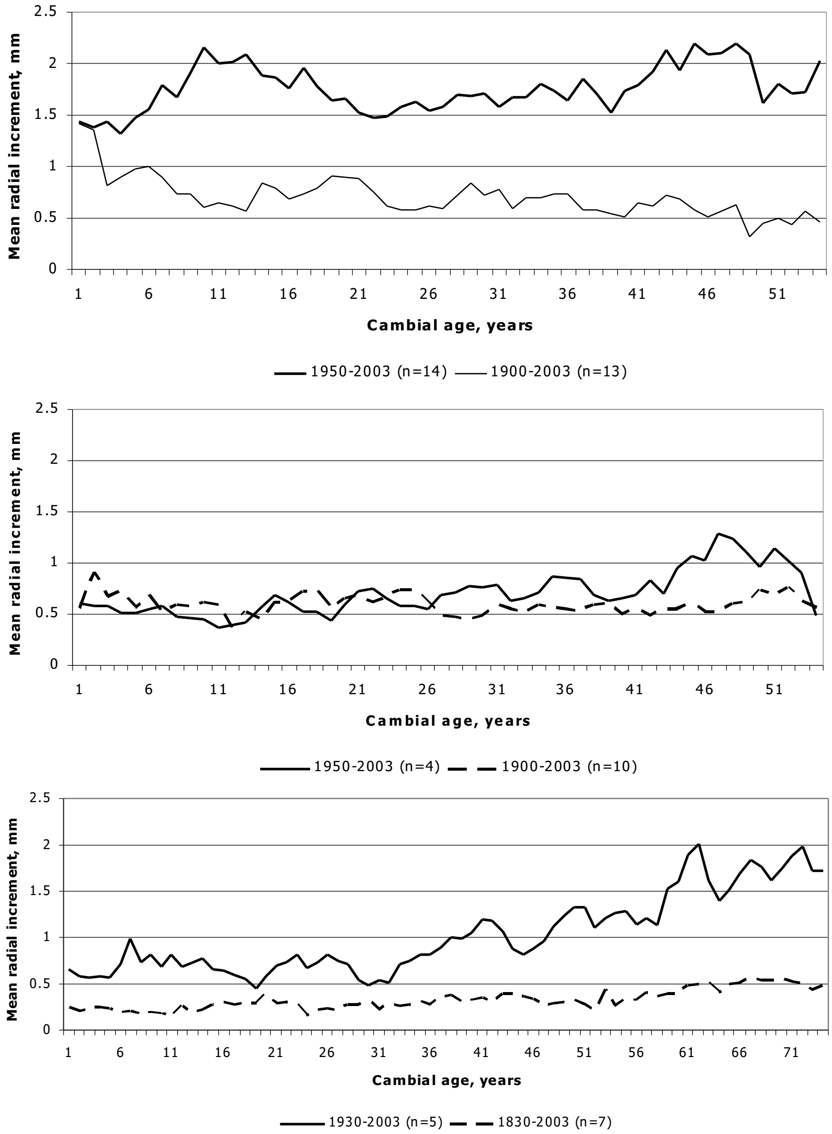

Figure 2. Mean radial increment of Siberian spruces of different age versus similar cambial age (n=number of trees)

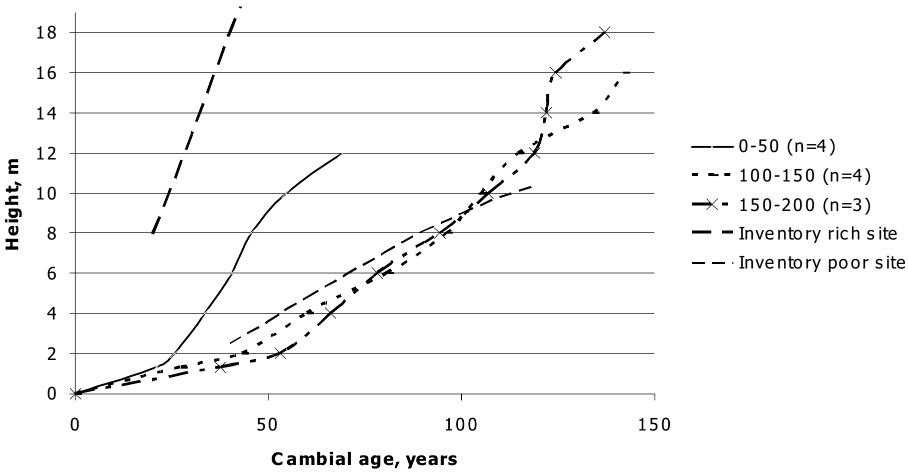

Figure 3. Height increment of Siberian spruces in Middle taiga zone of different age versus similar cambial age (n=number of trees), comparison with yield tables of Zagreev (1992)

Table 2. Long-term growth trends of Siberian spruce and Scots pine in the Komi Republic using the method of calculating the sums of the radial increment for the equal intervals

Sub zone of taiga boreal forest	Siberian spruce			Scots pine		
	Increment sum,mm 1940-1970	Increment sum, mm 1970-2000	% of increase	Increment sum, mm 1940-1970	Increment sum,mm 1970-2000	% of increase
Northern forest – tundra transition zone	22.71	42.45	86.91	-	-	-
Northern taiga	16.91	25.09	48.34	16.72	36.11	116.00
Middle taiga	50.47	54.70	8.39	51.88	58.41	12.57
Southern taiga	-	-	-	44.48	59.78	34.38

growth for the previous 50 years (Figure 1). Trees are growing 58% faster in height (Figure 3).

The radial increment of Scots pine has varied during the last 80 years with periods of high and low growth; however since 1980 there has been a significant increase in the radial growth that was not observed during the last 47 years (Figure 4). This tendency is also confirmed by the cambial age approach and height increment (Figure 6). During the last 30 years Scots pine trees are growing faster, which is supported by the radial increment (Figure 5) and height increment (Figure 6). The mean radial increment of Scots pine during the last 30 years increased by 67% as compared with the long-term mean growth for the previous 50 years. Trees are growing 42% faster in height. In the middle taiga zone site productivity has changed, the response of Siberian spruce to changing conditions is more pronounced than the response of Scots pine.

Northern limit of the northern taiga zone

Standardized tree-ring chronologies of Siberian spruce in the forest-tundra transition zone (Figure 1) show an increase in the growth since 1943 that is confirmed by the height increment (Figure 3). However the cambial age approach (Figure 2) shows a significant increase after 1975 (Figure 2). Siberian spruces in the northern limit of the northern taiga zone are growing faster now than they grew 30 years ago. The mean radial increment of Siberian spruce during the last 30 years increased by 48% as compared with the long-term mean growth for the period 1940 - 1970. In spite of the fact that few trees sampled for stem analysis show a decrease in the growth, the youngest sampled tree (1933) is twice as tall as the older trees at the cambial age of 40 years (1905, 1913). The result suggests a strongly accelerated height increment on this site.

The radial increment of Scots pine has varied periodically during the last 80 years (Figure 4). We found an increasing trend since 1969 that is confirmed by the cambial age approach and a few sampled trees show an accelerated height increment. During the last 30 years Scots pine has been growing faster, as shown by the mean radial increment during the last 30 years increased by 116% as compared with the long-term mean growth for the previous 30 years (1940-1970).

Figure 4. Standardized tree-ring chronologies of Scots pine smoothed with a 10-year moving average, shown as deviations from the mean

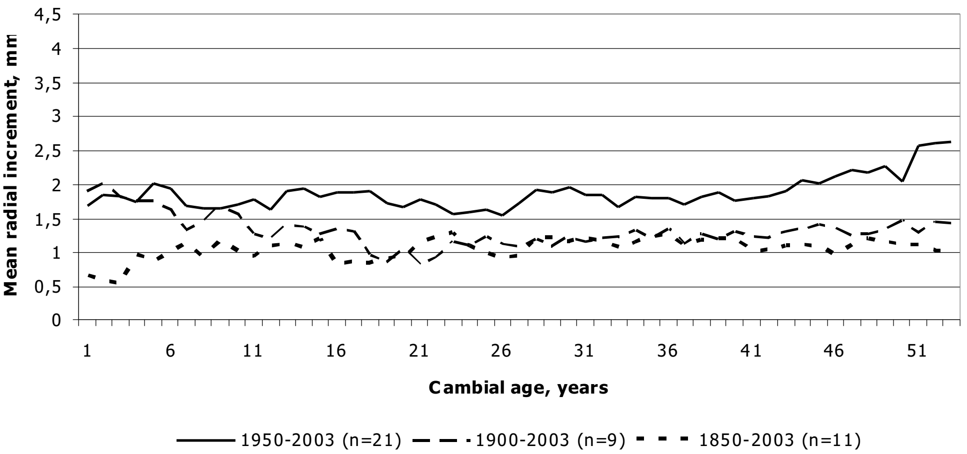

Figure 5. Mean radial increment of Scots pine of different age versus similar cambial age in Middle taiga zone (n=number of trees)

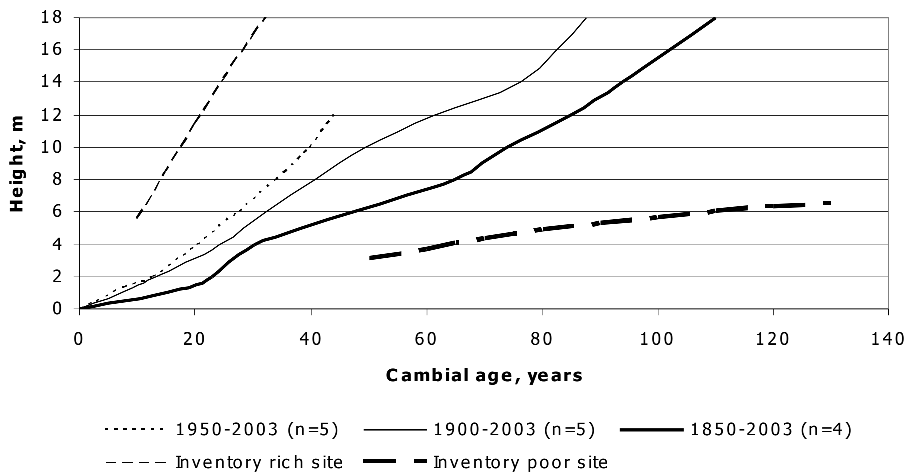

Figure 6. Height increment of Scots pine in Middle taiga zone of different ages versus similar cambial age, comparison with yield tables of Zagreev (1992)

In the northern limit of the northern taiga boreal zone there is a positive long-term trend in the growth of conifers, though the response of Scots pine to changing conditions is more marked than the response of Siberian spruce.

Northern forest - tundra transition zone

There were no pines found in the northern forest-tundra transition zone. The trees were grouped in cambial age classes of 70 years on this site, as the youngest tree was 70 years old.

The standardized tree-ring chronologies of Siberian spruce (Figure 1) show a strong trend of almost linear increasing radial increment starting in 1940 (R^2=0.91). In the long term the mean radial increment has never been as high as in the last 70 years. This increase is confirmed by the cambial age approach using the data of raw tree ring measurements (Figure 2). Siberian spruce in the forest-tundra transition zone is growing faster now than they grew 70 years ago. The mean radial increment of Siberian spruce during the last 30 years increased by 87% compared with the long-term mean growth for the preceding 30 years. The absence of Scots pine on this site also highlights its inability to grow in extreme conditions and underlines the expected difference in reactions of the two species to site changes.

In the forest-tundra transition zone there is a strong positive long-term growth trend in the growth of Siberian spruce.

Comparison of growth trends in different forest zones

The long-term growth trends of Siberian spruce and Scots pine were studied in four subzones of the taiga boreal forests in the Komi Republic. The approach implemented in our study estimates the sum of the mean annual increment for two periods of equal length. Table 2 summarizes the findings and showing the increments for the two periods: 1940-1970 and 1970-2000. The ages of the trees were comparable in all cases. The evaluation of all subzones showed a positive trend.

Discussion

As there were no comparable forest inventory data (based on constant forest area and species composition) available with annual resolution for the last 100 years, the dendrochronological approach was chosen to identify long-term forest growth trends in the Komi Republic.

From the methodological point of view, for identifying changes in site productivity, the comparison of the height increment is a better approach, because the height growth of dominant trees is relatively independent of stand density (Lanner 1985, Magnussen and Penner 1996). However, at the same time the height increment of the current year is more strongly correlated with the radial increment of the preceding year (Mäkinen 1998) *i.e.* height growth probably contains a 1 year bias partly due to the fact that the height growth generally stops much earlier in the growing season than the radial growth. The disadvantage of this method is the high financial costs for collecting and measuring sufficient samples, and it is a destructive method.

The interpretation of trends in tree-ring series is neither easy nor unequivocal. The main problem with the interpretation of tree-ring series trends is the method of indexation (Innes 1991). The method for identifying long-term growth trends through building chronology with standardisation of raw tree ring measurements for the whole sub zone of taiga contains some limiting factors. At present it is impossible to find an ideal curve that removes variation in the radial increment caused by age trend, competition, stand dynamics and other factors reflected in tree rings at the same time preserving the long-term growth trend. Furthermore it is even more difficult to find an individual curve for each separate factor. However the method could be used in case the number of sampled trees is high and those limits could be minimized due to the process of averaging. In this study an attempt to remove low frequency variation caused by the above mentioned factors was achieved, but with the understanding that standardisation partly removes the long-trend growth trends which belong to low- and medium-frequency growth variation *i.e*. periods of more than 30 years.

The method of calculating the sums of the radial increment for the equal intervals (Table 2) for the following comparison those sums showed an increase in the growth of Scots pine from 12% to 116% and of Siberian spruce from 8% to 87%. It contains a potential bias, which is dependent on the size of estimation period (*i.e.* in case of global warming selection of different time intervals will influence the result), age structure of sampled trees, and the bioecological properties of tree species. Calculating the sum of the annual radial increments for the same periods (Table 2) is far from an ideal indication of the total biomass production, not taking into account the possible changes in total wood density which could compensate the volume changes.

The rational for combining the methods for estimating long-term growth trends (Table 3) should be used in the future with emphasis on estimating the height increment and evaluating ring density.

Standardized tree-ring chronologies of Siberian spruce in the middle taiga zone describe an increase in the growth since 1950, in the northern taiga zone since 1943 and in the northern forest-tundra transition zone since 1926. Furthermore there has also been an increase in the southern taiga zone since 1966. This response gradient shows a faster response in high latitudes to climate change and lower response in more temperate zones confirming findings that the response of trees growing under average conditions are less affected by climate variation (Mäkinen *et al.* 2003).

For Scots pine we observed different results. The increasing trend started in the middle taiga zone later than in the south taiga zone and the percentage of increase is less. This shift could be explained by the lower quality of the data in the southern taiga zone, and possibly by the different response of Scots pine compared to Siberian spruce. If we take into account the temporal shift of the beginning of the productivity increase, one could conclude that the response to the changing environment of the Siberian spruce is higher than that of Scots pine.

The highest increase in the growth of Siberian spruce was observed in the northern taiga zone and the northern forest-tundra transition zone. This finding provides at least circumstantial evidence for the conclusion that environmental conditions for conifers may have improved at the limits of their distribution.

The absence of Scots pine in the forest-tundra transition zone shows a reduced ability of Scots pine to grow in more extreme conditions in comparison to Siberian spruce, and different reaction of these two species to climate change could be expected. In the middle taiga zone of boreal forests the response of Siberian spruce to changing conditions is more obvious than that of Scots pine. A decrease in the growth of Scots pine on this site from the period 1933 till 1969 is different from the growth pattern observed for the Siberian spruce on the same site. It could be also explained as the two species react differently to the changing conditions.

The results for the sums of the radial increment for two equal periods in the middle taiga zone (Table 2) show the opposite effect, namely an increase in sums of the radial increment for equal periods of Siberian spruce is lower than Scots pine. This could confirm also that the response of these two species to the changing environment differs with time. In the future, the influence of climate parameters on the growth (not only air temperature and precipitation, but also radiation, relative humidity, wind direction and speed), and their temporal variability should be studied.

There could be various causes for the general increase in the growth of both Scots pine and Siberian spruce in the Komi Republic but the driving factor seems to be air temperature. It was shown by Drobushev (2004) that the growth rate of conifers in the Komi Republic is more related to air temperature than precipitation. Similar results were found in Finland at the same latitude (Mäkinen *et al*. 2001) as our sites in the middle and southern zones of taiga. An additional possible cause of the increased forest growth could be an increase in the amount of nitrogen available for plants (Spiecker 1999b). But the factors driving the site productivity increase in the Komi Republic are still uncertain. The trends of increasing air temperature and amount of precipitation are different in the Komi Republic. In Komi, the annual evaporation is less than the annual precipitation. Consequently, air temperature in the strongly continental climate of Komi appears a limiting growth factor.

This assumption could also explain the absence of a clear gradient from south to north in growth increase from the southern taiga to the northern taiga. It could be a spatial and temporal shift as the trees respond to global climate change. The impact of stand density could be clarified by increasing the number of samples taken in the south. No clear conclusion can be drawn regarding growth trend in the southern taiga zone at this stage of analysis.

Conclusions

It is not possible in the current system of forest inventory in Russia to use official forest statistics data to identify long-term forest growth trends on a regional scale. The disadvantage of height increment comparison in similar cambial age is the high financial costs for collecting and measuring sufficient samples, and it is a destructive method. The method for identifying long-term growth trends through building chronology with standardisation of raw tree ring measurements for the whole sub zone of taiga contains some limiting factors. However the method could be used in case the number of sampled trees is high and those limits could be minimized due to the process of averaging. The method of calculating the sums of the radial increment for the equal intervals contains a potential bias, which is dependent on the size of estimation period (*i.e.* in case of global warming selection of different time intervals will influence the result), age structure of sampled trees, and the bioecological properties of tree species. The rational combination of methods for estimating long-term growth trends should be used in the future with emphasis placed on estimating height increment.

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ПОДХОД К ИДЕНТИФИКАЦИИ ДОЛГОВРЕМЕННЫХ ТРЕНДОВ РОСТА СИБИРСКОЙ ЕЛИ И СОСНЫ ОБЫКНОВЕННОЙ НА СЕВЕРО-ЗАПАДЕ РОССИИ

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Резюме

Республика Коми, расположенная на восточной границе Европейской части России, является регионом, где большие площади девственных лесов до сих пор сохранились. Используя, данные прироста по диаметру и высоте было показано наличие долговременных трендов в изменении прироста сосны (*Pinus sylvestris L.*) и ели (*Picea obovata Ledeb.*) в лесотундре, в подзонах северной, средней и южной тайги Республики Коми. Использовано три различных подхода к идентификации долговременных трендов: построение древесно-кольцевых хронологий, сравнение радиального прироста в одинаковом камбиальном возрасте, и сравнение прироста по высоте в одинаковом камбиальном возрасте. Показано, что комбинация этих трех методов является наиболее оптимальным подходом в оценке долговременных трендов в росте деревьев. При этом особое внимание должно быть уделено методу сравнения прироста по высоте в одинаковом камбиальном возрасте.

Ключевые слова: *Pinus sylvestris* L., *Picea obovata* Ledeb., радиальный прирост, прирост по высоте, дендрохронология, вариации роста, анализ роста стволов