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Determination of forest growth trends in Komi Republic (northwestern Russia): combination of tree-ring analysis and remote sensing data

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It is very important to detect changes in forest productivity due to the global change on a large scale. In this work, the evolution of the vegetation in the Komi Republic (northwestern Russia) from 1982 to 2001 was analyzed using NOAA AVHRR PAL time series. A statistically significant correlation (adjusted r^2 = 0.44–0.59) between Normalized Difference Vegetation Index (NDVI) data and tree ring width (261 living trees) was identified for the territory of the Komi Republic. The increased site productivity reflected an increase of integrated NDVI values from June to August. This allows NDVI to be used as a proxy for estimation of forest growth trends for the recent decades. A positive and significant trend in NDVI data was identified from 1982 to 2001, coinciding with an increase in site productivity in the study area. The decrease in precipitations coincided with an increase in site productivity (highest r^2 was 0.71). The increase in productivity reflected in NDVI data is maximal on the sites with increased temperature and decreased precipitations. In the Komi Republic the distribution of the trends in NDVI data changes on the south-west to north-east gradient. NDVI data could be used to increase spatial resolution of tree ring width series. Taking into account the relatively small role of human activity in the Komi Republic compared with Europe, the site productivity during recent decades also increased in relatively untouched forests.

Introduction

Climate change with lengthening growing season (Menzel and Fabian 1999), increasing CO_2 and nitrogen deposition and changes in management practices are assumed to cause the increased forest growth (Spiecker 1999, 2000, Mäkinen *et al*. 2002, 2003). Climate change has been defined on both global and local scales (Miller 2003, Knowlton *et al*. 2004, Da Motta 2004,

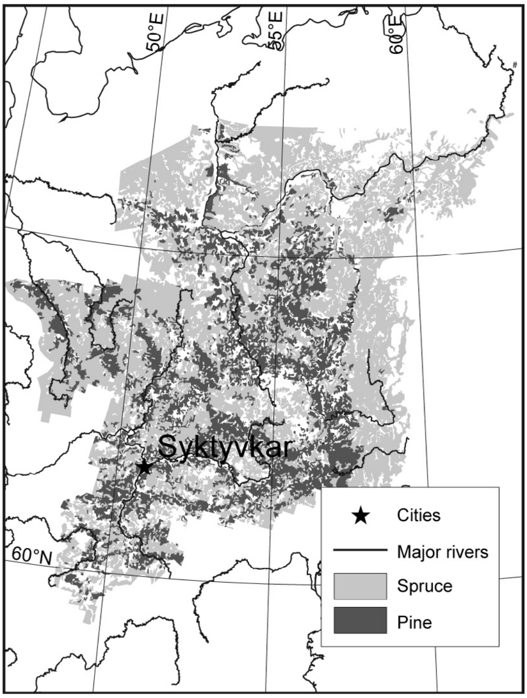

Fig. 1. Dominant species distribution in the Komi Republic.

Mauro 2004, Meyneeke 2004). According to the IPCC, warming trends have already started and will increase in the future (IPCC 2001). Therefore, it is very important to detect changes on large-scale not only in vegetation distribution but also in productivity of plants.

In Europe, most forests are managed, except for those in northwestern Russia, where old-growth natural forests are dominant (Aksenov *et al.* 2002). It is important to understand the long-term response of unmanaged natural forests to changing climate. Since it is possible to adapt forest management practices to changing environment, currently it seems impossible to change the global climate back to its previous state. Therefore, with knowledge of tree-growth response to changing climate on different temporal and spatial scales, forest management practices can be adapted to achieve a defined output from the forests.

We identified major climatic factors influencing radial growth of Siberian spruce and Scots pine using dendroclimatic analysis and a clear long-term trend in climate change. During the last 20 years at meteorological stations, the temperature has increased; and 40 years ago, the precipitation began to increase. This is reflected in the radial increment of Siberian spruce and Scots pine. Thus, climate change could partly explain the increased site productivity. The total variance explained by temperature varied from 22% to 41% and precipitation from 19% to 38%. The significant climatic parameters for radial increment in the Komi Republic have been identified, but the response to climate parameters alters over time (E. Lopatin *et al.* unpubl. data).

We came to the conclusion that the response of the radial increment to climate parameters changed over the last 20 years, during the same period productivity increased considerably (E. Lopatin *et al.* unpubl. data). Even with a special procedure for tree and site selection, those studies are limited to representative sites in different sub-zones of taiga. It is important to understand changes in forest productivity not only on the temporal scale, but also on the spatial scale. Currently, due to the low accessibility and huge size of the territory, it is impossible to create systematic sample plots in the Komi Republic (Fig. 1). Therefore, to draw conclusions regarding forest growth trends, other methodological approaches should be used, i.e. to up-scale from individual stands to the whole region and sub-zones of taiga. Spatial information on changes in site productivity could provide access to evaluation of other factors, such as nitrogen deposition and changes in management practices that influence growth on the regional scale.

Several studies (Riebsame *et al.* 1994, Myneni *et al.* 1998, Vicente-Serrano *et al.* 2004) have shown a recent increase in vegetation cover in different world ecosystems adducing that the principal cause is the rise in temperature and precipitation. Since the first satellites were launched, remote sensing with a high temporal frequency which allows analysis of large areas, has been widely used for monitoring vegetation dynamics. The high temporal frequency and the availability of relatively long-time series of NOAA-AVHRR images taken on different spectral channels, make such data very useful for monitoring changes in vegetation. The use of these data for the monitoring of vegetation is based on the response of vegetation cover to radiation in the visible and near-infrared regions of the electromagnetic spectrum. High vegetation development is characterized by low reflectivity of solar visible radiation and high reflectivity in the near infrared region of the spectrum. Therefore, various vegetation indices have been developed for monitoring and measuring the status of the vegetation using spectral data. The most frequently used is the Normalized Difference Vegetation Index (NDVI), which is calculated as:

$$\mathrm{NDVI} = (\mathrm{NIR} - R)/(\mathrm{NIR} + R) \qquad (1)$$

where NIR is reflectance measured from Channel 1 (visible: 0.58–0.68 microns) and R is reflectance measured from Channel 2 (near infrared: 0.725–1.0 microns).

The changes in the physiology and structure of plant canopies, i.e. development of pigment systems and leaf area, are viewed directly by NDVI (Wang *et al.* 2004b), as well as direct indicators of forest productivity (i.e. tree-ring widths, height increment, diameter increase, seed production, foliage production (Wang *et al.* 2004a) and maximum latewood density (D'Arrigo *et al.* 2000). It has been shown in many studies that NDVI were found to be strongly correlated with the leaf area index (LAI) and biomass (Tucker *et al.* 1986, Häme *et al.* 1997, Rees *et al.* 2002).

Consequently, the data on NDVI changes for a relatively long period of time (around 20 years of operation of NOAA-AVHRR) could be used as a reliable proxy for identification of changes in site productivity on a large regional scale.

The main objective of this study was to investigate the impact of climate change on development of forest productivity in the Komi Republic (northwestern Russia) during the period from 1981 to 2001. The specific aims were (1) to determine the relationships between NDVI and tree-ring width of Siberian spruce (*Picea obovata*) and Scots pine (*Pinus sylvestris*), (2) to study the relationships between NDVI development and trends in climate data, and (3) to analyse the spatial distribution of the temporal development of vegetation.

Material and methods

Study area

The study area is located in the northeast European part of Russia (Fig. 1), from 59°12´ to 68°25´N and 45°25´ to 66°10´E. The total area of the Komi Republic is 416 800 km^2. The annual mean temperature varies between +1 °C in the southern part of the republic and –6 °C in the northern part. The annual rainfall decreases from 700 mm in the south to 450 mm in the north. A characteristic for the winter period, which lasts 130–200 days, is the accumulation of a thick snow cover (70–80 cm). The territory of Komi is characterized by surplus moisture. Mean annual evapotranspiration is significantly lower than annual rainfall (Galenko 1983).

Forest structure of the Komi Republic

With the exception of mountainous parts of the Republic where forest-tundra and tundra ecosystems have developed, the vegetation cover of Komi is dominated by middle and northern taiga forests (Larin 1997). Boreal vegetation is dominated by two pine species (primarily by *Pinus sylvestris* and rarely by *Pinus sibirica*), Siberian spruce (*Picea obovata*) and Siberian fir (*Abies sibirica*) (Fig. 1 and Table 1). Pubescent birch (*Betula pubescens*) forests are the first stages of post-fire succession, frequently with abundant Aspen (*Populus tremula*).

The forested area covers about 300 000 km^2 making up 4.1% of the forested areas in Russia. The total stock of wood in the forests of Komi

Table 1. Area of different dominant tree species in Komi (10^6 ha) (Kozubov and Degteva 1999)

Species	1961	1988	1993	1997
Scotch pine	6.70	7.30	7.10	7.10
Siberian spruce	14.80	16.00	16.10	16.20
Siberian larch	0.30	0.30	0.20	0.20
Siberian pine	0.01	0.03	0.02	0.02
Birch	4.80	4.50	4.30	4.60
Aspen	0.30	0.50	0.70	0.60
Other (alder, willow)	0.03	0.03	0.05	0.10

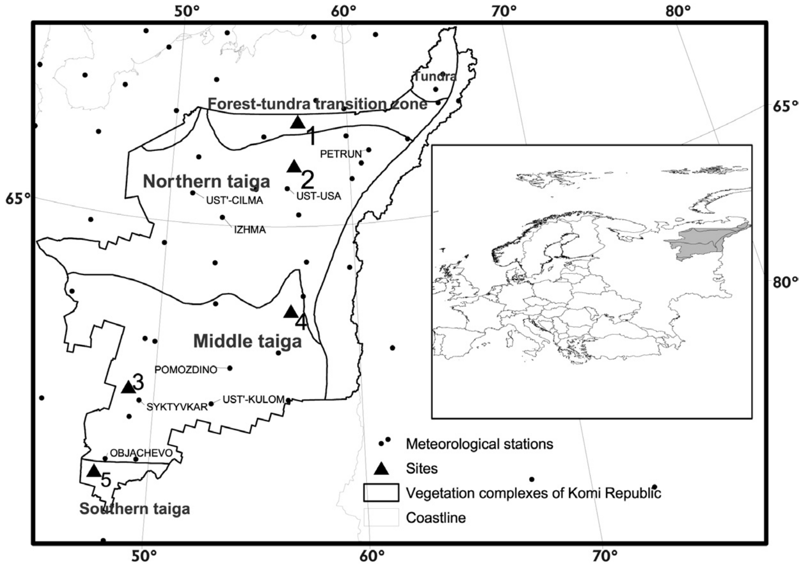

Fig. 2. Location of sampled stands and sub-zones of taiga boreal forests. Borders of vegetation complexes according to Kozubov and Degteva (1999). Numbers refer to the zones (*see* Table 3).

is calculated at 2855.8 × 10^6 m^3 (Obukhov and Larin 1999). The stand mean volume of wood is about 80–100 m^3 ha^{-1}. In southern regions, the mean standing volume is 300 m^3 ha^{-1}. Total annual allowable cut in Komi is 26.4 × 10^6 m^3, but only 25.5% of this is actually cut (Obukhov and Larin 1999).

Forests in Komi with Siberian spruce reach 16 × 10^6 ha, i.e. 60% of the whole forest area. In optimal conditions, Siberian spruce can reach a height of 35–40 meters and 90–110 cm diameter at breast height. Scots pine is distributed over 24% of the forest area and represents 23% of the total growing stock. The mean height is 22–24 m and the mean diameter is 28–30 cm with a growing stock of 160–190 m^3 ha^{-1} (Kozubov and Taskaev 1999). The forest stands with high productivity are concentrated in the middle and southern sub-zones of Komi. The proportions of main tree species in different sub-zones in Komi and area covered by the different tree species are shown in Tables 1 and 2.

Table 2. Proportion (%) of main tree species in different sub-zones in Komi (Kovalev 1990).

Sub-zone of taiga boreal forest	Scots pine	Siberian spruce	Birch	Aspen
Northern forest–tundra transition zone	10.0	70.2	17.6	–
Northern taiga	25.7	60.2	11.0	0.2
Middle taiga	31.1	49.9	16.1	1.8
South taiga	26.8	37.5	23.8	11.9

Data collection and processing

Material used for identification of the relationship between site productivity and NDVI was collected along a transect from the south of Komi (south taiga sub-zone of boreal forests) to the Arctic spruce timberline. The trees were sampled in 5 sub-zones of taiga forests in Komi (Fig. 2). Discs and cores were collected from living trees in 5 stands. A total of 151 Siberian spruce and 110 Scots pine were sampled.

The sites were selected using GIS datasets of forest management units, old forest inventory maps and satellite images TERRA ASTER (scene size 60 × 60 km) with a spatial resolution of 15 m. In the procedure for site selection, the main aim was to find representative relatively large (more than 64 km^2, i.e. single PAL NDVI pixel) site types and at the same time exclude possible forest management or any other human impact from the past by masking. Then the sites (Fig. 2) were randomly selected using a 64 km^2 grid. Sites with a low productivity index represent 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 averaged out accordingly. To obtain information about changes in site productivity, trees of different ages at comparable sites of similar forest density were selected. The trees were randomly sampled on sites of medium fertility.

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

- spruce or pine dominating species,
- low site index,
- 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 (Hytteborn *et al*. 2005). 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 were expected to reveal homogeneity in their tree-ring pattern; they showed no obvious signs of near-neighbour competition or forest management. Trees were chosen from different diameter classes, healthy looking with straight, unbroken stems and regularly shaped crowns. Mature dominant trees without visible signs of damage were selected as sample trees. The selected trees represented similar site conditions but different tree age. 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. At 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, discs were cut using a chain saw. If it was difficult to cut discs, cores were extracted from two radii per tree (the first one oriented to the north, the others at 90°–120° to the first).

Radial increments were measured to an accuracy of 0.01 mm. Boundaries between early- and late-wood were determined according to differences in colour, cell size, and relative thickness of the cell wall (Cook and Kairiukstis 1990). During the process of measurement, the raw measurements of tree-rings were cross-dated using visual control by comparing the series graphically. Cross-dating and data quality were assessed using the computer program COFECHA (Grissino-Mayer *et al*. 1997).

Individual ring-width series were double detrended through the use of a negative exponential curve, if it was a fit or if it failed, a linear regression line of negative slope or a horizontal line is fitted through the mean (i.e., individual type of curve for each single tree, chosen using statistics). The common interval adjusted for order of the pooled autoregressive model was used for analysis of climate-growth relationships. Indices were further pre-whitened using Box and Jenkins' methods of autoregressive and moving average time series modeling (ARMA), (Box and Jenkins 1976, Monserud 1986). The order of the autoregressive-moving mean process was determined by Akaike's Information Criteria (Akaike 1974, Cook 1985). Chronologies were produced by averaging the annual values of indices. The program ARSTAN (Holmes 1999) was used to calculate chronologies from tree-ring measurement series by de-trending and indexing (standardizing) the series, then applying a robust estimation of the mean value function to remove the effects of endogenous stand disturbances (for detailed descriptions of the standardization process, *see* Cook and Kairiukstis 1990). Residual ARSTAN chronologies (Figs. 3 and 4) containing high-frequency variation were used to examine relationships between NDVI values and radial increment on a year-by-year basis.

Correlation analysis between NDVI and tree production

The NDVI extracted from remote sensing is an excellent tool for monitoring vegetation status and its temporal dynamics. However, the creation of NDVI temporal series is problematic due to difficulties related to the non-uniform-

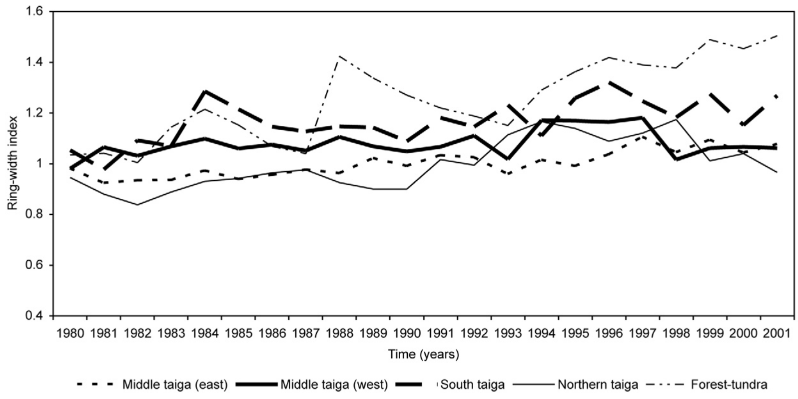

Fig. 3. Standardized tree-ring chronologies of Siberian spruces.

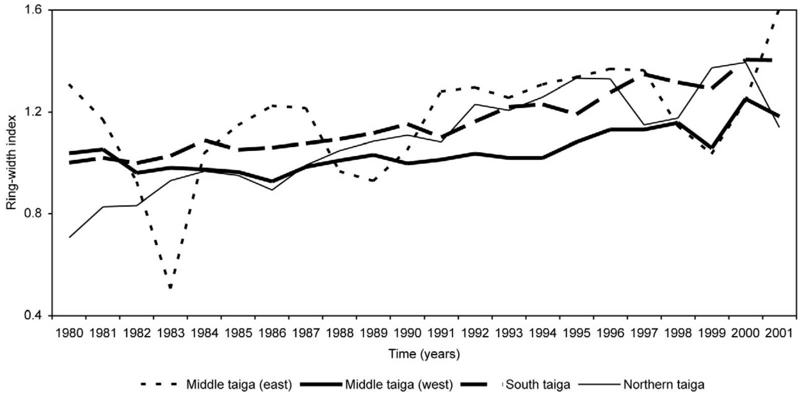

Fig. 4. Standardized tree-ring chronologies of Scots pines.

ity of satellite time-series that can restrict satellite use for temporal analysis of vegetation cover. Nowadays different NDVI global data series of contrasted calibration reliability are available from AVHRR data (PAL and GIMMS NDVI) that have been widely used in ecosystem monitoring (Mikkola 1996, Gaston *et al.* 1997, Young and Anyamba 1999, Pelkey *et al.* 2000, Lovell and Graetz 2001, Young and Wang 2001, Lafont *et al.* 2002, Dong *et al.* 2003, Al Bakri and Taylor 2003, Vicente-Serrano *et al.* 2004, Tateishi and Ebata 2004, de Beurs and Henebry 2004). The PAL-NDVI database (available at http://daac.gsfc.nasa.gov) has monthly NDVI data from 1981 to 2001 and could be useful for determining trends in vegetation cover with satellite observations. The calibration of this series has been meticulous, and much effort has been expended to develop post-launch calibration coefficients, which were tested in areas without vegetation cover where high NDVI temporal stability is assumed. Moreover, the homogenization of the series has been checked with good results (Kaufmann *et al.* 2000).

The spatial resolution of the PAL-NDVI database (8 km grid cell size) is generally enough for estimation of changes in site productivity in conditions where the logging activities could be carried out. The maximum allowed area of clearcut in Russia is nowadays 50 ha, which is less than 1% of the PAL-NDVI pixel. Forests dominate Komi covering more than 80% of the land, therefore the NDVI values of individual pixels reflect the value of the forest cover with a very high probability.

During the sampling of trees, coordinates of the sampling sites were measured with GPS (accuracy of 30 m). Pixel values from the PAL-NDVI (mean 8-day values in the geographic projection) database were extracted for the sites. It was shown that during the main growth period (Julian days 90–270) satellite-derived NDVIs were highly correlated with tree productivity but, when the entire year was considered, they were poorly correlated, i.e. large differences occurred during winter (Wang *et al.* 2004a). Therefore, mean monthly NDVI sums from June to August were used for calculation of correlation coefficients between NDVI and standardized tree-ring series (Table 3) for the period 1982 to 2001.

Trend estimation in NDVI data

Trends in PAL-NDVI pixels were identified by means of nonparametric Spearman correlation coefficient (r_S) using annual sums of NDVI values from June to August and one series of time in years (i.e., in the PAL-NDVI series, 1982 was considered as year 1 and 2001 as year 20). A nonparametric coefficient was selected because it is more robust than parametric coefficients and does not make it necessary to assume the normality of the data series (Lanzante 1996, Vicente-Serrano *et al*. 2004). The values of r_S indicate whether there are significant trends in development of vegetation. Positive and significant values indicate an increase in the vegetation biomass, and negative values indicate a regressive trend (Goetz *et al*. 2005). Trends were considered significant when $r_S < 0.1$. The trends were assessed in PAL NDVI database for the territory of the Komi Republic (subset of 17 995 pixels).

Results

Relations between NDVI and tree rings

Standardized residuals for tree-ring width were significantly correlated with NDVI sums for June–August (Table 3). For NDVI integrated from June to August, the highest significant correlation was found in the western part of the middle taiga zone. No significant correlations were found in the eastern part of the middle taiga zone. Furthermore, there were no significant correlations between tree-ring width of pine and NDVI time series in the southern sub-zone of taiga.

Significant correlation coefficients between tree-rings and cumulated NDVI values from June to August indicate that integrated NDVI values could be used in the Komi Republic as a proxy for estimation of forest growth trends on the scale of the whole region.

Spatial distribution of temporal vegetation evolution

The positive trends in NDVI were identified primarily for the southern taiga sub-zone and middle taiga sub-zone (Fig. 5). The absence of a trend in NDVI data in the eastern part of the middle taiga zone was confirmed by the absence of a correlation in this part of the study region (Table 3).

Significant NDVI trends showed a clear gradient from south-west to north-east in the Komi Republic.

Relations between NDVI evolution and climate data (temperature and precipitations)

Climate data from 14 meteorological stations showed increase and decrease in annual tem-

Table 3. Correlation coefficients between standardized residuals for tree-ring width and NDVI sums for June–August.

Site	Forest zone	Siberian spruce		Scots pine	
		n	Pearson correlation	*n*	Pearson correlation
1	Forest–tundra transition zone	14	0.565**		
2	Northern taiga zone	16	0.522*	20	0.445*
3	Middle taiga zone (west)	40	0.453*	45	0.593*
4	Middle taiga zone (east)	51	0.272	17	0.056
5	South taiga zone	30	0.565*	28	0.085

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

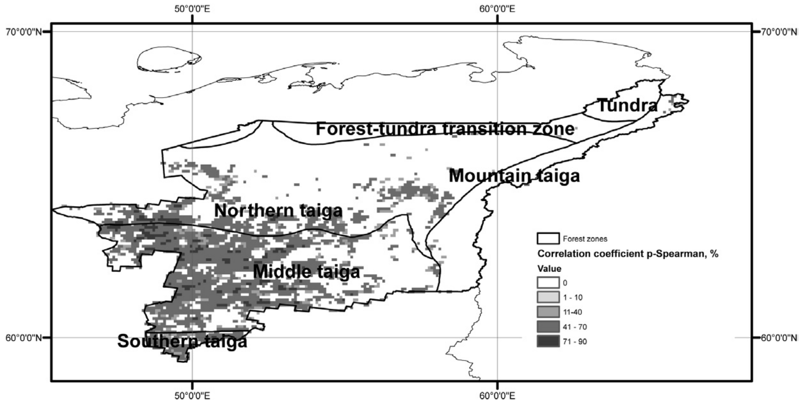

Fig. 5. Spatial distribution of significant trends in NDVI data.

perature and precipitations for two sub-periods (Table 4). Based on location of meteorological stations small subsets from map of spatial distribution of NDVI trends (Fig. 3) were created. Each subset included 9 pixels (around 576 km^2). Changes in maximum summer NDVI values were negatively correlated with precipitations (–0.713). There was no significant direct relationship between NDVI and temperature on selected meteorological stations. The decrease in precipitations reflected an increase in NDVI. Increase in productivity reflected in NDVI data was maximal on the sites with increased temperature and decreased precipitations (Fig. 6).

Medium-term changes in NDVI index in forest sub-zones

At high latitudes the highly dynamic phenology of the vegetation is one of the possible sources of ambiguity (Rees *et al*. 2002), but acquiring a time series of maximum NDVI values will reduce this source of error. Analysis of NDVI data for the Komi Republic showed that NDVI reached maximum values in July. In all sub-zones of taiga, the maximum annual peaks showed important differences between years. For up-scaling from individual stands to the regional level, analysis of maximum values could be used as a measure

Table 4. Absolute changes in temperature and precipitations during the period from 1982 to 2001 on meteorological stations of the Komi Republic.

Station	Changes between 1982–1991 and 1992–2001		Long. E	Lat. N
	in temperature (K)	in precipitations (mm)		
Vendinga	0.32	–55.20	63.34	47.25
Izhma	–0.08	23.52	65.01	53.58
Lun	0.16	–44.00	63.23	53.27
Mytniy Materik	0.11	26.86	65.56	55.10
Objachevo	0.37	1.08	60.22	49.39
Okunev Nos	0.09	26.72	66.15	52.35
Petrun	–0.19	16.35	66.26	60.46
Pomozdino	–0.51	–18.81	62.11	54.12
Syktyvkar	0.14	–41.92	61.40	50.51
Troitsko-Pechersk	0.08	–61.96	62.42	56.12
Ust-Vym	–0.19	–63.90	62.55	50.96
Ust-Kylom	0.16	–83.19	61.41	53.41
Ust-Usa	–0.10	46.13	65.58	56.55
Ust-Cilma	0.00	–28.50	65.45	52.17

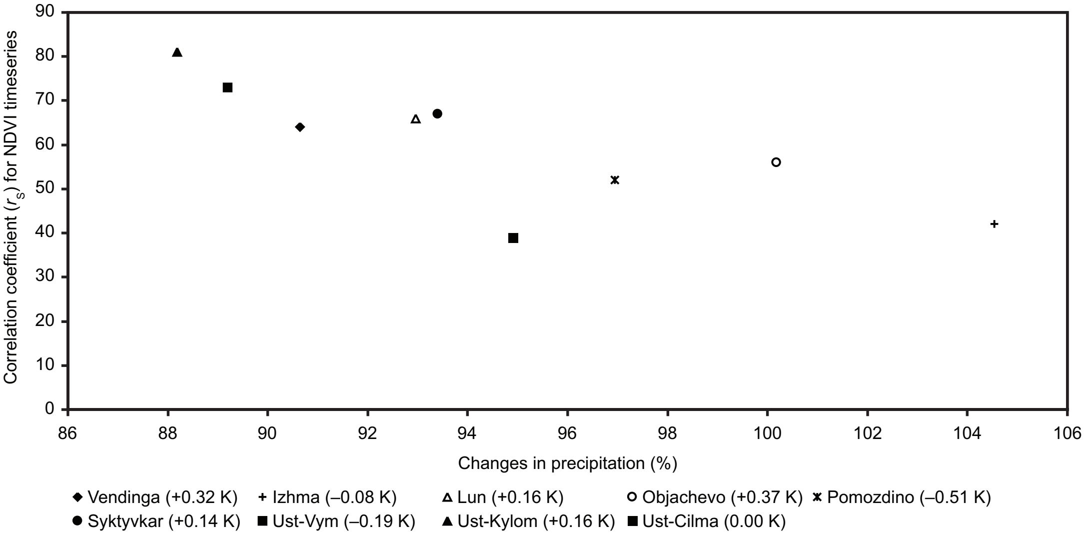

Fig. 6. Relations between NDVI trends, precipitation (mm) and temperature (K).

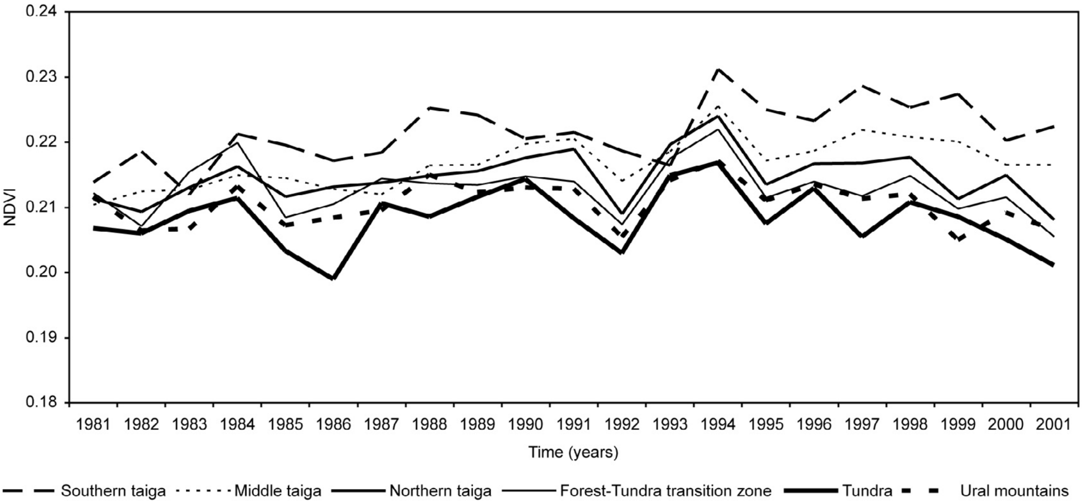

Fig. 7. Maximum value of the mean monthly cumulated NDVI index in different vegetation complexes of the Komi Republic.

for comparison of productivity trends in different sub-zones of taiga. Maximum values were calculated for the vegetation complexes of the Komi Republic using a vector map (Fig. 2 and Table 5). The mean value of the pixels completely contained within the boundaries of the vegetation zones was calculated.

The mean maximum NDVI values in vegetation zones of the Komi Republic were clearly different (Fig. 7). In all vegetation zones of the Komi Republic the trends were positive but were statistically significant only in the middle and southern sub-zones of taiga.

Discussion

There are several limitations in our study. Current models of vegetation dynamics using the NDVI time series perform poorly for high-latitude environments. This is due partly to specific attributes of these environments, such as short growing season, long periods of darkness in winter, persistence of snow cover and dominance of evergreen species, but also to the design of the models (Beck *et al.* 2006). It was shown in previous studies (Rees *et al.* 2002) that NDVI is a poor indicator of taiga forests where dark coniferous trees dominate and where spaceborne imagery acquired from sparse forests of predominantly narrow-crowned columnar trees tend to be dominated radiometrically by the understorey. Therefore, the changes in site productivity in the northern taiga zone and the Ural mountains are not statistically significant, however, our previous studies showed the significant increase in site productivity in the northern taiga sub-zone (E. Lopatin *et al.* unpubl. data). Apparently, the distribution of Scots pine is also increased due to movement North. This was also identified by other authors for the Ural mountains (Shiyatov *et al.* 2005). Therefore, we conclude that NDVI data could be used on a large scale for identification of growth trends in southern and middle taiga sub-zones.

Recently, however, a new method for monitoring vegetation activity at high latitudes using Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI was presented (Beck *et al.* 2006). This method estimates the NDVI of the vegetation during winter and applies a double logistic function, which is uniquely defined by six parameters that describe the yearly NDVI time series. Therefore we think that it is possible to use NDVI as a proxy for estimation of changes in site productivity, applying different models for NDVI calculation for the northern taiga and forest tundra transition zone than for the southern and middle taiga.

Another limitation of NDVI as a proxy for the whole region is the relatively low correlation coefficients between tree-rings and NDVI as compared with those given by Wang *et al.* (2004a). This could be due to the fact that growth measured at an individual site may not represent the growth patterns of an entire region. In the Komi Republic it is a mixture of spruce and pine. The cross effects among them, therefore, will make the NDVI data lose the ability as a proxy for estimation of forest growth according to the species.

Utilities of the summer NDVI sums could be problematic, because the NDVI will be saturation during the summer season in some dense forest regions, which will make the NDVI lose the ability to identify the changes of biomass. The forest canopy density in Komi is relatively low, compared with broadleaved and tropical forests. The temporal NDVI data (Fig. 5) show the fluctuations at an inter-annual scale, which never reach the maximum of NDVI value. Consequently in the boreal forest zone, changes in NDVI reflect changes in forest growth.

The reasons for increased NDVI could vary; not only reasons attributed to the increased site productivity, such as change due to a lengthening of the growing season (Menzel and Fabian 1999), increasing CO_2 and nitrogen deposition and changes in management practices (Spiecker 1999, 2000, Mäkinen *et al.* 2002, 2003), but also changes in distribution of vegetation, such as in shifts of tree-line and changes in species composition (Tables 1 and 2). We assume that the causes are specific for each sub-zone of taiga. This could be analyzed in future using the

Table 5. Changes in mean maximum NDVI values in the Komi Republic.

Vegetation complex	Area (10^6 ha)	Percentage of territory	Mean maximum NDVI value 1982–1991	Mean maximum NDVI value 1992–2001	Percentage of of increase	Trend (r_S)
Ural mountains	4.059	9.73	0.210	0.211	0.40	0.028
Tundra	0.982	2.35	0.208	0.209	0.59	0.024
Forest–tundra transition zone	2.936	7.04	0.212	0.213	0.20	–0.112
Northern taiga zone	17.792	42.63	0.213	0.216	1.22	0.185
Middle taiga zone	15.036	36.03	0.214	0.219	2.39	0.672**
South taiga zone	0.927	2.22	0.219	0.223	2.14	0.615**

** Correlation is significant at the 0.01 level.

data from medium resolution satellites such as Landsat.

Several studies (Riebsame *et al*. 1994, Myneni *et al*. 1998, Vicente-Serrano *et al*. 2004) have shown a recent increase in vegetation cover in different world ecosystems adducing that the principal cause is the rise in temperature and precipitation. In the Komi Republic we found that increase in productivity reflected in NDVI data is maximal on the sites with increased temperature and decreased precipitations (adjusted $r^2 = -0.71$). The absence of statistically significant correlation between NDVI and temperature in the Komi Republic could be explained by a surplus of precipitation in the boreal forest zone. The territory of Komi is characterized by surplus moisture, mean annual evapotranspiration is significantly lower than annual rainfall (Galenko 1983).

This study demonstrates both the limitations and the potential value of using NDVI to estimate trends in forest growth of taiga forests during recent decades. A statistically significant correlation between NDVI data and tree-ring width has been identified for the territory of the Komi Republic (northwestern Russia). The increased site productivity caused the increase in integrated NDVI values from June to August. This indicates that NDVI can be used as a proxy for estimation of the forest growth trends of recent decades for generalization on a large scale. The increased site productivity in the southern and middle sub-zones of taiga in the Komi Republic has been shown using NDVI data for 20 years. In the region under discussion, the distribution of the trends in NDVI data changes on a south-west to north-east gradient. NDVI data could be used to increase the spatial resolution of tree-ring width series. The decrease in precipitations reflected an increase in NDVI. Increase in productivity reflected in NDVI data is maximal on the sites with increased temperature and decreased precipitations. Taking into account the relatively small influence of humans in the Komi Republic (Aksenov *et al*. 2002) compared to Europe, the site productivity during recent decades has also increased in relatively untouched forests. In Komi, which is also a relatively untouched region (Aksenov *et al*. 2002), there are several possible reasons for the changes in site productivity, i.e. changes in species composition and distribution. A study of the changes in vegetation using high resolution satellite images could provide the information on the reasons for increased site productivity.

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