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Article

Trends in the Start of the Growing Season in Fennoscandia 1982–2011

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Abstract: Global temperature is increasing, and this is affecting the vegetation phenology in many parts of the world. In Fennoscandia, as well as Northern Europe, the advances of phenological events in spring have been recorded in recent decades. In this study, we analyzed the start of the growing season within five different vegetation regions in Fennoscandia using the 30-year Global Inventory Modeling and Mapping Studies (GIMMS) NDVI3g dataset. We applied a previously developed pixel-specific Normalized Difference Vegetation Index (NDVI) threshold method, adjusted it to the NDVI3g data and analyzed trends within the different regions. Results show a warming trend with an earlier start of the growing season of 11.8 ± 2.0 days ($p < 0.01$) for the whole area. However, there are large regional differences, and the warming/trend towards an earlier start of the growing season is most significant in the southern regions (19.3 ± 4.7 days, $p < 0.01$ in the southern oceanic region), while the start was stable or modest earlier (two to four days; not significant) in the northern regions. To look for temporal variations in the trends, we divided the 30-year period into three separate decadal time periods. Results show significantly more change/trend towards an earlier start of the growing season in the first period compared to the two last. In the second and third period, the trend towards an earlier start of the growing season slowed down, and in two of the regions, the trend towards an earlier start of the growing season was even reversed during the last decade.

Keywords: phenology; start of the growing season; NDVI time series; NDVI3g; Fennoscandia; vegetation regions; temporal trends

1. Introduction

Global temperature is increasing, especially in the polar and boreal zones, due to positive feedbacks (e.g., albedo-temperature feedback) of increased greenness and shrubification [1]. Fennoscandia is a geographic and geological term for the region made up by the Scandinavian Peninsula, Finland, Karelia and the Kola Peninsula. Fennoscandia stretches more than 1,800 km from south to north. Hence, it encompasses several vegetation zones with different climate conditions from the nemoral zone to the arctic and alpine tundra [2]. In May–June, the nemoral broadleaf forests in southern Fennoscandia may stand lush and green, whilst the alpine and arctic tundra experiences the last stages of snow-melt [3,4]. Fennoscandia is one of the regions of the world where the distance between the arctic and the nemoral zones is shortest [2], and this gives a unique opportunity to both observe and assess climatic change. In Fennoscandia, as well as Northern Europe, advancements of phenological events in spring and, to a lesser degree, in autumn have been recorded in recent decades (e.g., [5–9]). Karlsen *et al*. [10], Xu *et al*. [1] and Bi *et al*. [11] have also observed the same pattern in Northern Europe as elsewhere in the northern lands (>50°N), but found a lesser increase of the length of the growing season (photosynthetic active period) in the northern parts of Fennoscandia compared with the southern parts of the same area. It is well known [9,12–17] that the spring temperature is the dominating factor for explaining the onset of the growing season in Fennoscandia. Xu *et al*. [1] also showed that the onset of the growing season was significantly correlated with the spring temperatures in the circumpolar and circumboreal areas. So far, there are three types of approaches for detecting the start of the growing season for vegetation [18]: (a) the conventional phenology approach observing the phenology of individual plants or tree stands [12,13,17,19]; (b) the land surface phenology approach using satellite-derived growing season metrics retrieved from various vegetation index data, such as the Normalized Difference Vegetation Index (NDVI) data from, e.g., the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) [9,20–22]; (c) temperature, solar radiation and water availability are assumed to be the key factors that control plant phenology. Statistical, mechanistic and theoretical approaches have often been used for the parameterization of plant phenology models describing the response to these key factors [18]. The phenological spatial modeling approach in northern regions is often based on growing degree days.

Experiences from, e.g., Karlsen *et al*. [9] and Luo *et al*. [23] showed that the land surface phenology approach using satellite-derived growing season metrics is a promising and reliable measure. In Karlsen *et al*. [9], the standard deviation between surface phenology data and NDVI-based data for the start of the growing season was shown to be 8.2 days. Karlsen *et al*. [10], analyzing the same area as we do in this paper, showed that the onset of the growing season was well mapped by satellite-derived phenological metrics using the AVHRR Global Inventory Modeling and Mapping Studies (GIMMS) NDVIg dataset. Most sites of a total of 28 phenological observations sites in Fennoscandia showed a moderately strong positive correlation between *in situ* phenological observation and NDVI data. However, mapping of the end of the growing season showed less correlation with field phenology data and presented some uncertainty. On average, for 1982–2006, there was a linear trend for all of Fennoscandia of a 0.27 days/yr earlier onset of the growing season, a 0.37 days/yr later end of the growing season and a 0.64 days/yr longer growing season [10]. Within Fennoscandia, the trends showed similarities with vegetation zones and sections, which reflect the climatic gradients from north to south and from west to east in the study area. The southern and oceanic regions showed a trend of about a one day/yr longer growing season, in contrast to the alpine and northern continental regions, which showed either no trend or a slightly shorter growing season.

The objectives of the present study were to apply the AVHRR GIMMS NDVI3g data set for the 1982–2011 period in order to map trends in the onset of the growing season, correlate these trends with temperature data and, finally, analyze the spatial pattern of these trends according to vegetation regions within Fennoscandia.

2. Data and Methods

2.1. GIMMS NDVI3g Data

The NDVI is a radiometric measure of the amount of photosynthetically active radiation (~400 to 700 nm) absorbed by chlorophyll in the green leaves of vegetation and has proven to be a good surrogate of vegetation photosynthetic activity during the growing season [21,24]. It is defined as the ratio of the difference of the near-infrared (NIR) and red reflectance (ρ) values, ($\rho_{NIR} - \rho_{red}$), divided by the sum of the red and NIR reflectance values ($\rho_{NIR} + \rho_{red}$).

Two NDVI datasets generated from the AVHRR sensor by the GIMMS group [25] were used in this study. The first is the GIMMS NDVIg dataset covering the time period from July 1981 to December 2006 with the spatial resolution of 8 km × 8 km and a temporal interval of 15 days. The maximum NDVI value over a 15-day period is used to represent each 15-day interval to minimize corruption of the vegetation signal from atmospheric effects, scan angle effects, cloud contamination and effects of varying solar zenith angle at the time of measurement [26]. This dataset is a widely used data source for monitoring global vegetation dynamics during the past two decades (e.g., [9,21,27]). The latest version (third generation) GIMMS NDVI3g dataset is generated from AVHRR data from July 1981 to December 2011 and is the main dataset applied in this study. This dataset was produced with the goal of improving data quality in the northern parts of the world, where the growing seasons are short, using improved calibration procedures, unlike its previous counterpart, NDVIg [28,29]. For instance, the NDVI3g data were calibrated using Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data from May–September in comparison with NDVIg, which were calibrated using Satellite Pour l'Observation de la Terre Vegetation (SPOT Vegetation) data from the whole year [29]. The NDVI3g data set is produced in a geographical latitude/longitude projection with a spatial resolution of 1/12 of a degree per pixel. The NDVI3g data record from January 1982, to December 2011, was used in this study.

2.2. E-OBS Temperature Data

It is well known [9,12–17] that spring temperature is the dominating factor for explaining the onset of the growing season in Fennoscandia. However, very few high resolution gridded temperature datasets covering the whole area exist, and the meteorological stations are relatively sparse and unevenly distributed within Fennoscandia. In this study, we use the ENSEMBLES Observations gridded dataset (E-OBS) dataset [30,31] for comparing the onset of the growing season variability with spring temperature variability within each vegetation region.

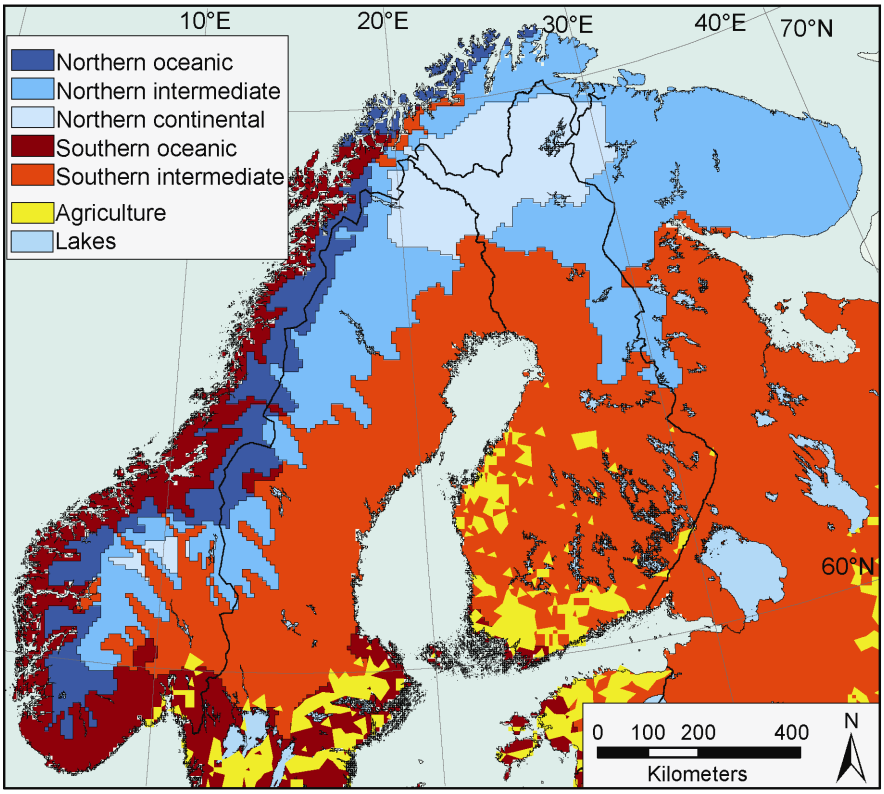
The E-OBS dataset is a European land-only daily high-resolution gridded data set for precipitation, minimum, maximum and mean surface temperature for the period 1950–2012. The dataset is produced by a three-step process of interpolation, by first interpolating the monthly precipitation totals and monthly mean temperature using three-dimensional thin-plate splines, then interpolating the daily anomalies using indicator and universal kriging for precipitation and kriging with an external drift for temperature, then combining the monthly and daily estimates [30].

The data files contain gridded data for the five elements (daily mean temperature, daily minimum temperature, daily maximum temperature, daily precipitation sum and daily averaged sea level pressure). The dataset covers the area 25°N–75°N, 40°W–75°E. The dataset is delivered in four versions, with two different map projections and two spatial resolutions. Data applied in this study has 0.25 degree spatial resolution on a regular latitude-longitude grid. In order to fit the daily E-OBS data to the GIMMS NDVI3g temporal resolution, we computed average temperatures for each bi-monthly 15-day period from January 1982, to December 2011, and resampled the E-OBS data to GIMMS spatial resolution.

2.3. Vegetation Regions

The regional variation in vegetation and related climate in Fennoscandia can be expressed in terms of vegetation zones and sections [2]. Vegetation zones are considered to mostly reflect summer temperatures, whereas vegetation sections indicate oceanic gradients. In this study, "vegetation regions" are defined as the combination of overlapping vegetation zones and sections. The six vegetation zones and five vegetation sections in the study areas presented by Moen [2] creates 30 vegetation regions. Due to the spatial resolution of the GIMMS NDVI3g dataset, many of these regions have too few pixels to be analyzed. To simplify it, we combined the six zones into two zones: a northern zone (which constitutes the arctic-alpine and the northern boreal zones) and a southern zone (which constitutes the middle boreal, the southern boreal, the boreonemoral and the nemoral zones). The five vegetation sections were combined into three sections: an oceanic section (which constitute the highly oceanic, markedly oceanic and the slightly oceanic sections), while the intermediate section and the slightly continental section covers large areas and were kept as they are. Then, these two zones and three sections where combined to five vegetation regions and, in this study, named: a northern oceanic, a northern intermediate and a northern continental region, a southern oceanic and a southern intermediate region (Figure 1), where each vegetation region has similarities in climate and vegetation. As we are interested in natural vegetation phenology only, agricultural areas (pixels with more than 20% farmland) are kept out of the analysis.

Figure 1. Vegetation regions in the study area. The five regions are reclassified, combined, simplified and redrawn from the Vegetation Zone Map and Vegetation Section Map consisting of 30 regions published by Moen [2].



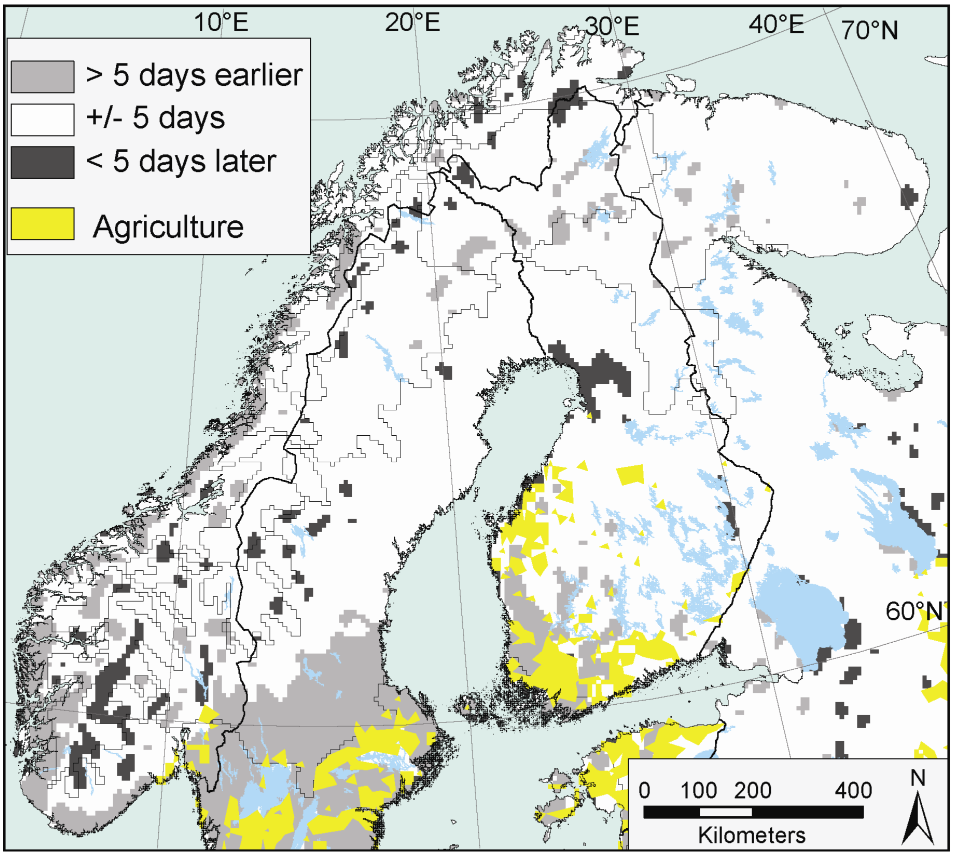
2.4. Satellite Data Processing

For Fennoscandia, it is necessary to apply a pixel-specific method for determining the start of the growing season, as the vegetation is very heterogeneous and sparse for large parts of the area. To estimate the onset of the growing season, we applied a pixel-specific threshold method first used by Høgda *et al.* [32], later described and discussed by Karlsen *et al.* [3,14] and applied in Karlsen *et al.* [4,10]. With this method, for each pixel, a 30-year mean NDVI value for the period from 15 June to 1 September was computed. The start of the growing season was defined as the time period each year when 0.70 of this mean NDVI value was surpassed. For removing outliers in the NDVI time series, a median filter of a length of three was also applied at each pixel.

This method was developed comparing the onset of spring as obtained from the NDVI threshold with date for budburst of birch (*Betula pubescens*) measured at sites around Fennoscandia. It has proven to be a robust method with the previous versions of the GIMMS dataset, and to investigate if the method also can be applied to the GIMMS NDVI3g data, we computed a mean spring date for the period 1982–2006 and compared it with the results in Karlsen *et al.* [10]. To obtain the best possible fit between the NDVIg start of the growing season (previously calibrated to *in situ* data) and the NDVI3g start of the growing season, the pixel-based threshold was adjusted from 0.70 to 0.72.

The result is illustrated in Figure 2, and the map here shows the day number for the onset of the growing season based on NDVI3g compared to the NDVIg version presented in Karlsen *et al.* [10]. As we can observe, most of the area has a very similar start of the growing season computed from the two datasets, and the differences we observe are located in the northern/southern oceanic and the southern intermediate regions, where the average onset is more than five days earlier with the NDVI3g than the NDVIg. The areas with a later onset of the growing season based on NDVI3g are located in narrow coastal areas (e.g., Lofoten) and mountainous areas dominated by rocks and barrens. These differences might be partly due to improved georeferencing of the NDVI3g dataset compared to the NDVIg dataset, as well as the new procedures of calibration [29] of NDVI3g that make the newest version more sensitive in the detection of the start of the growing season than the previous version [23].

Figure 2. Comparing mean onset of the growing season for the 1982–2006 period based on the NDVI3g and the NDVIg shown in Karlsen *et al*. [10]. Map shows the day number based on NDVI3g minus the day number based on NDVIg. Yellow areas are agricultural land, while lakes are presented in blue. Black line, national borders; grey line, vegetation region borders (see Figure 1).



For all of the area, the average day number for the start of the growing season based on NDVI3g is 140.2, and the average day number based on the NDVIg is 141.5, showing an overall earlier onset of 1.3 days in the period 1982–2006 with the NDVI3g. In Karlsen *et al*. [10], the overall deviation between field observations and onset data based on NDVIg was +4.5 days (later), while using NDVI3g, we now observe about +3.3 days (later) compared to the NDVIg dataset. This indicates that the differences are very small between the NDVIg and NDVI3g applying the pixel-based threshold method, and we can conclude that the *in situ* phenology station assessment (28 locations) previously published in Karlsen *et al*. [10] fit well with this dataset also.

For computing trends in the start of the growing season within each of the five vegetation regions and the whole study area, for each pixel, the start of the growing season time series was first smoothed with a three element central moving average filter, and then, an average 30-year time series was computed for the region. Next, a linear model, $y = aX + B$, was fitted for the region by minimizing the chi-square error statistic for the computed time series. This was done for three periods (1982–1991, 1991–2001, 2001–2011) and the whole 1982–2011 timespan. In order to avoid time gaps, the two last periods are started on the last year of the previous period and spans 11 years.

3. Results

3.1. Trends in Start of the Growing Season

Trends for the onset of the growing season for the period 1982–2011 based on NDVI3g data and expressed as the number of days earlier in 2011 compared to 1982 are presented in Figure 3.

Figure 3. Number of days of the earlier start of growing season in Fennoscandia in 2011 compared to 1982 assuming a linear trend. Black line, national borders; grey line, vegetation region borders (see Figure 1).

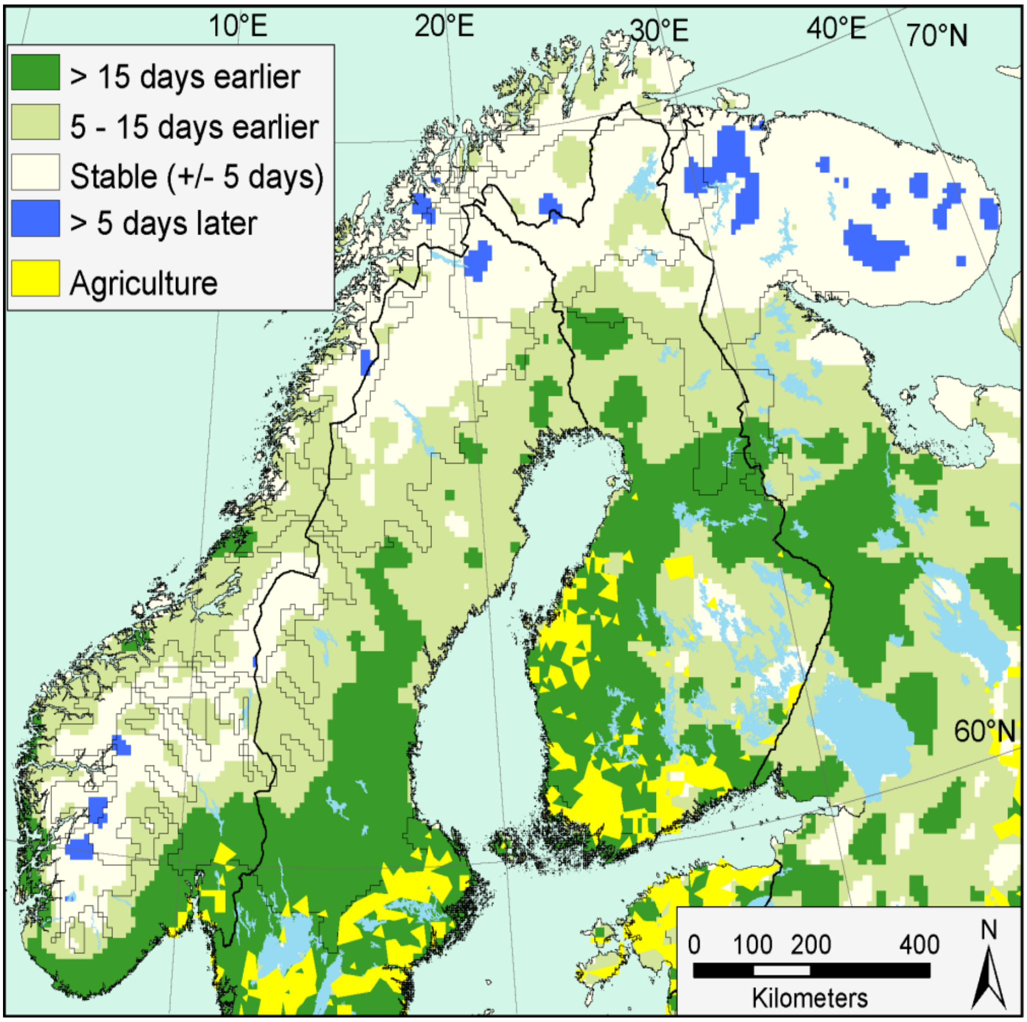
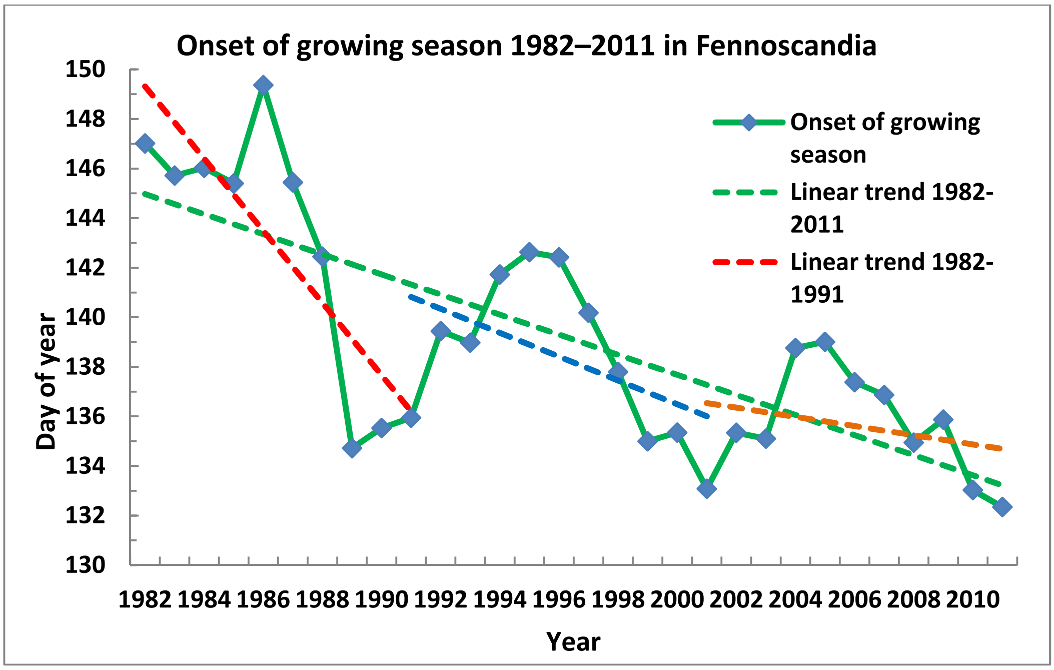


Table 1 list the trends in the three investigated decadal periods (1982–1991, 1991–2001, 2001–2011) and the total number of days shifted in the start of the growing season for the whole (30-year) 1982–2011 period. In Figure 4, we present a graph showing the start of the growing season and linear trends of the start of the growing season for the whole area for the three decadal sub-periods and the 1982–2011 period.

Table 1. Linear trends (days/year) for the NDVI-based start of the growing season for the three decadal time periods (1982–1991, 1991–2001, 2001–2011) and the total number of days shifted in the start of the growing season for the whole 1982–2011 time period for the various regions. * = $p < 0.05$; ** = $p < 0.01$.

Region	**Trend 1982–1991 days/yr**	**Trend 1991–2001 days/yr**	**Trend 2001–2011 days/yr**	**Shift 1982–2011 days**
N-oceanic	−0.77 ± 0.22 **	−0.19 ± 0.36	0.49 ± 0.17 *	−2.22 ± 2.02
N-intermediate	−0.84 ± 0.24 **	−0.20 ± 0.27	−0.15 ± 0.33	−3.60 ± 1.86
N-continental	−1.13 ± 0.30 **	−0.01 ± 0.30	−0.24 ± 0.36	−2.22 ± 2.33
S-oceanic	−3.18 ± 0.76 **	−0.52 ± 0.63	0.56 ± 0.33	−19.32 ± 4.70 **
S-intermediate	−1.47 ± 0.43 **	−0.69 ± 0.26 *	−0.43 ± 0.22	−15.90 ± 2.05 **
All	−1.46 ± 0.36 **	−0.48 ± 0.28	−0.19 ± 0.22	−11.75 ± 1.97 **

Figure 4. Trends in the start of the growing season for the whole study area for the whole period (1982–2011) and the 1982–1991, 1991–2001 and 2001–2011 periods. For the details of the trends, see the last row in Table 1.



Generally speaking, the trend for the whole area (all regions) and the whole study period (1982–2011) show that the average start of the growing season was 11.8 ± 2.0 days ($p < 0.01$) earlier in 2011 with respect to 1982. This is 0.39 days/yr and, accordingly, 0.12 days/yr higher than the 0.27 days/yr observed in Karlsen *et al.* [10]. If we divide the 30 year-long period in three sub-periods (1982–1991, 1991–2001, 2001–2001), we observe a much more significant trend towards an earlier start of the growing season for the first period (−1.46 ± 0.36 days/yr, $p > 0.01$) than in the following two periods (−0.48 ± 0.28 days/yr and −0.19 ± 0.22 days/yr, respectively). This indicates that the trend towards an earlier start of the growing season was reduced in the last two periods compared to the first, as we can observe in Figure 4. If we analyze the different regions and time periods, we observe a similar pattern that the trend to an earlier start was more strong and significant for the first period (1982–1991) than the latest two periods.

The trend towards an earlier start was also stronger and more significant in the southern regions compared to the northern regions (Table 1). On the other hand, the trend towards an earlier start was reduced in both the second (1991–2001) and the third period (2001–2011), and for the southern and the northern oceanic regions, the trend was even reversed towards a later start of the growing season (0.49 ± 0.17 days/yr, $p < 0.05$ and 0.56 ± 0.33 days/yr (ns)) in the third period. The overall shift of the start of the growing season for the 1982–2011 period was estimated to be 19.3 ± 4.7 days earlier ($p < 0.01$) in the southern oceanic region compared with 2.2 ± 2.0 days (ns) in the northern oceanic and 2.2 ± 2.3 days (ns) in northern continental regions (Table 1).

3.2. Temperature vs. *Start of the Growing Season*

The relationship between the start of the growing season and the mean temperatures for March, April, May and June is presented in Figure 5. The highest negative correlation (high temperature = early start of the growing season, *i.e.*, low day number) for a time period for a region implies that the temperature in this period is the most important for the timing of the start of the growing season. We observe that mean March and April temperatures were most (negatively) correlated with the start of the growing season in the southern regions. On the other hand, the mean May and June temperatures were most (negatively) correlated with the start of the growing season in the northern regions.

In Table 2, we have listed the four-week period with the highest (negative) correlation between temperature and the start of the growing season for each of the vegetation regions and the whole study area. The highest (negative) correlation is for the northern areas, varying between −0.76 (in June) for the northern oceanic, −0.77 (16 May–15 June) for the northern continental and −0.79 (16 May–15 June) for the northern intermediate region. The temperature trends in the same period are 0.9 ± 0.8 °C, 0.9 ± 1.2 °C and 0.7 ± 1.1 °C, respectively, meaning that there was a trend towards an earlier start of the growing season with increasing mean temperatures for these four-week periods. For the southern regions, the correlation was less, with □0.61 (in April) for the southern oceanic region and −0.56 (16 April–15 May) for the southern intermediate region. Looking at the whole study area, the best correlation was −0.56 for April. However, temperature trends were larger for these regions/periods compared with the Northern regions, varying from 1.5 ± 0.9 °C for the southern oceanic, 1.8 ± 0.9 °C for the southern intermediate and 2.0 ± 0.9 °C for the whole study area.

Accordingly, we can observe a trend towards increased temperature for the time around the start of the growing season for all regions and the whole study area, which is in accordance with Bi *et al.* [11] and Xu *et al.* [1]. However, the year-to-year variability in temperature was too large in order to be statistically significant for the different regions. When averaging the whole study area, we find a trend of 2.0 ± 0.9 °C ($p < 0.05$) over the 1982–2011 period for April.

Figure 5. Correlation between the start of the growing season and temperature in (**a**) March, (**b**) April, (**c**) May and (**d**) June. Red is large (negative) correlation between temperature and the start of the growing season.

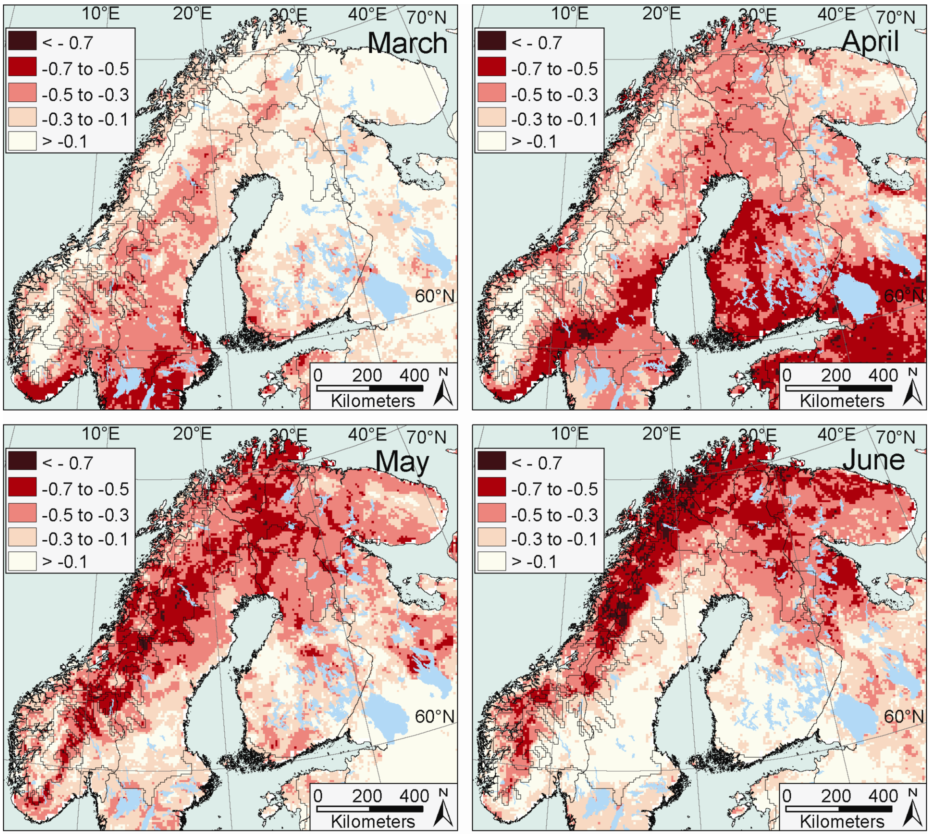


Table 2. Four-week period with the highest correlation to the start of the growing season, correlation and temperature trend. * $p < 0.05$; ** $p < 0.01$.

Region	Period	Correlation (negative)	Temperature Trend (°C) 1982–2011
N-oceanic	1 June–30 June	0.76 **	0.9 ± 0.8
N-intermediate	16 May–15 June	0.79 **	0.7± 1.1
N-continental	16 May–15 June	0.77 **	0.9 ± 1.2
S-oceanic	16 March–15 April	0.56 **	1.5 ± 0.9
S-intermediate	1 April–30 April	0.61 **	1.8 ± 0.9
All the area	1 April–30 April	0.56 **	2.0 * ± 0.9

4. Discussion

The trend towards an earlier start of the growing season was strong and significant in the southern regions compared to the northern regions. Unexpectedly, there was a weaker trend towards an earlier and, in last decade, even, a trend towards a later start of the growing season in the northern and southern oceanic regions compared to the intermediate and continental parts of Fennoscandia. This is in contrast to other parts of the Arctic and boreal zones of the world, where the start of the growing season has become earlier [33] or the length of the growing season has been extended the last decade [1,11]. The length of the snow cover season, the extension of snow cover and the depth of the snow cover have decreased in much of Norway during recent decades, as well as other parts of Fennoscandia [34], hence, also, a trend towards an earlier start of the growing season.

On the other hand, the trend towards an earlier start was reduced in both the second (1991–2001) and, especially, the third period (2001–2011) for all regions. However, the measured trends for these two last periods are mostly not statistically significant, and accordingly, no certain conclusions can be drawn. However, this is in agreement with Barichivich *et al*. [35], who reported that the spring advance halted in North America in the early 1990s, hence resulting in contrasting continental trends during the GIMMS NDVI3g period between 1982 and 2011. For the southern and the northern oceanic regions, the trend was pushed to a later start of the growing season in the third period. The latter may be consistent with a global warming slowdown the last decade despite a sustained top-of atmosphere excess energy input associated with greenhouses gases reported by Guemas *et al*. [36] and other references therein. Why this is more pronounced in the oceanic regions of the Fennoscandia is due to the region’s dominance of high altitude mountains trapping the increased winter precipitation as snow during the last decade [34,37–39], hence leading to a stable or even a later start of the growing season the last decade in these high mountainous areas. However, in the low altitude parts of the oceanic region, trends toward decreased snow depths/cover are observed in the period 1981–2010 [34,37].

Bi *et al*. [11] found that temperature trends showed more extensive cooling in the boreal parts of North America compared to boreal Eurasia, about seven times higher, which could plausibly account for the browning trends found in the boreal parts of North America. Our results encompassing the nemoral to low Arctic areas of Fennoscandia show that the trends to an even later onset of the start of the growing season in the last period is more pronounced in the northern regions than in the southern regions, consistent with the reported global slowdown the last decade. This is more comparable with the North American boreal than the Eurasian boreal, which showed a more rapid greening and extension of the growing season, including an earlier start of the growing season. Bi *et al*. [11] found that precipitation is also a key driving factor in vegetation growth, besides temperature, especially in North America, but they stated: “It is important for precipitation to keep the same pace as the temperature change in order to support the northward migration of structurally different vegetation, such as shrubs and trees, which need more water supplies. Concordant velocities of temperature and precipitation, such as in Eurasia and in the boreal part of North America, support continued vegetation migration (greening)” and, hence, an earlier start of the growing season [11].

In Fennoscandia and, especially, in the northern parts, there have been both increased precipitation and temperatures during the whole period of 1982–2011 [34,39,40], indicating that there might be driving factors other than temperature around. However, the warming in the four-week period before the start of the growing season varied from 0.7 ± 1.1 °C in the northern intermediate region to 1.8 ± 0.9 °C in the southern intermediate region, which partly explains the variation in the start of the growing seasons in Fennoscandia. Accordingly, this study extends the results identified by previous studies in Fennoscandia (e.g., [10]) and sparks interest for a deeper analysis for the dynamics of the entire growing season, as well as identification of key driving factors concerning phenology in the Fennoscandian environment.

5. Conclusions

This study assessed the 30-year AVHRR NDVI3g dataset to detect the dynamics of the start of the growing season across vegetation regions encompassing nemoral to low arctic zones within Fennoscandia. The main conclusions are as follows:

We observed a trend towards the earlier start of the growing season all over Fennoscandia, but most significant in the southern regions. Unexpectedly, there was a weaker trend towards an earlier start of the growing season in the northern rather than the southern regions of Fennoscandia, which is in contrast to other parts of the Arctic and boreal zones of the world, but consistent with reports from North America, where the spring advance halted in the early 1990s.

The trend to an earlier start of the growing season varied from 2.2 ± 2.0 days in northern oceanic and 2.2 ± 2.3 days in northern continental regions to 19.3 ± 4.7 days in the southern oceanic region. For the whole area, the trend was an 11.8 ± 2.0 days earlier start of the growing season within the investigated time period.

Looking at the trends at a decadal scale, results showed significantly more change/trend towards an earlier start of the growing season in the first period compared to the last two periods. In the second and third period, the trend towards an earlier start of the growing season slowed down, and in two of the regions, the northern and southern oceanic, the trend towards an earlier start of the growing season was even reversed during the last decade, probably consistent with a reported global and regional warming slow down the last decade, as well as increased precipitation as snow during the winter periods.

Correlation between temperature and the start of the growing season varied from −0.56 (April) in southern oceanic region to −0.79 (16 May–15 June) in the northern intermediate region.

The warming in the four-week period before the start of the growing season varied from 0.7 ± 1.1 °C in the northern intermediate region to 1.8 ± 0.9 °C in the southern intermediate region, which might partly explain the variation in the start of the growing seasons in Fennoscandia.

Comparison between the NDVI3g and NDVIg in the period of 1982–2006 showed similar patterns for most of the area, except for some coastal rocky areas and mountainous areas, which showed a later start of the growing season based on NDVI3g data, while areas with an earlier start were located mainly in the low altitude oceanic and southern intermediate regions.

These results clearly show that the NDVI3g dataset is highly suitable for revealing regional trends caused by the effects of a warming climate and sparks interest in a deeper analysis for the dynamics of the entire growing season, as well as the identification of key driving factors concerning phenology in Fennoscandia.

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Conflicts of Interest

The authors declare no conflict of interest.

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