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ORIGINAL RESEARCH ARTICLE

Seasonality and long-term trends of NDVI values in different land use types in the eastern part of the Baltic Sea basin

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Abstract This study analyses changes in Normalized Difference Vegetation Index (NDVI) values in the eastern Baltic region. The main aim of the work is to evaluate changes in growing season indicators (onset, end time, time of maximum greenness and duration) and their relationship with meteorological conditions (air temperature and precipitation) in 1982—2015. NDVI seasonality and long-term trends were analysed for different types of land use: arable land, pastures, wetlands, mixed and coniferous forests. In the southwestern part of the study area, the growing season lasts longest, while in the northeast, the growing season is shorter on average by 10 weeks than in the other parts of the analysed territory. The air temperature in February and March is the most important factor determining the start of the growing season and the air temperature in September and October determines the end date of the growing season. Precipitation has a much smaller effect, especially at the beginning of the growing season. The effect of meteorological conditions on peak greenness is weak and, in most cases, statistically insignificant. At the end of the analysed period (1982—2015), the growing season started earlier and ended later (in both cases the changes were 3—4 weeks) than at the beginning of the study period. All these changes are statistically significant. The duration of the growing season increased by 6—7 weeks.

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1. Introduction

Long-term changes in vegetation are an important indicator necessary to understand the response of ecosystems to climate change. It is also important to know the changes of vegetation on the global and regional scale to more precisely foresee the future vegetation-climate feedbacks.

The in situ monitoring of vegetation is time-consuming and provides precise but spatially sporadic information. Remote sensing data can be used to analyse the vegetation dynamics on a regional and global scale. Vegetation indices are among the first products to be developed using satellite-derived data, therefore the long-term methodically homogeneous data series are available for analysis of vegetation changes during the last three decades.

A wide variety of indicators has been created to show vegetation greenness, and one of the most popular is the NDVI (Myneni et al., 1997). Like many other vegetation indices, NDVI is calculated using reflections from the surface in the near-infrared and visible spectrum (Kogan, 2001).

Vegetation status can be assessed using various sensors, one of which is the AVHHR (Advanced Very High Resolution Radiometer) installed in NOAA satellites. NDVI values have been calculated since 1981 (Stöckli and Vidale, 2004) and have been successfully applied in a variety of studies. NDVI can be used for the analysis of changes in vegetation over time and space, vegetation productivity, loss of plant habitat, for assessing the ecological impact of droughts or fires, and to better understand the human influence on natural processes (Dabrowska-Zielinska et al., 2002; Kogan, 1997; Pettorelli et al., 2005; Singh et al., 2003).

Vegetation greenness is strongly affected by air temperature and precipitation (Kogan, 1997). The level of impact is highly dependent on the plant and its developmental phase (Piao et al., 2006; Zhang et al., 2006). The start of the growing season in the Northern Hemisphere was found to be negatively correlated with average February—April temperatures. Meanwhile, the correlation between the average air temperature in August—October and the end date of the growing season is positive (Chen et al., 2005). Plants are also heavily influenced by rainfall anomalies. The effect is particularly strong in areas with precipitation deficit (Gessner et al., 2013), but even in areas with excessive moisture, precipitation still leads to higher vegetation greenness and is a limiting factor for vegetation development (Roerink et al., 2003).

Analysis of changes in vegetation conditions in the Northern Hemisphere in 1982—2008 showed that vegetation greenness increases at high latitudes because of changes in air temperature and solar radiation and that 64% of all changes in the growing season can be attributed to changes in various climatic parameters (Wu et al., 2015). It was also found that in the mid and high latitudes of the Northern Hemisphere, the growing season length increased by 2.6 days in 10 years, the starting date of the growing season advanced by about 1.61 days and the growing season end date became later by about 0.67 days (Park et al., 2016).

The length and timing of the growing season also depend on the type of land use. In the north-eastern USA the growing season starts by 1.7 days later per degree of latitude for forests and natural vegetation and 2.2 days later for urban and agricultural areas. Meanwhile, the date of the growing season ends earlier by 2.4 and 4.4 days per degree, respectively (Zhang et al., 2003).

The relationship between air temperature, precipitation and vegetation index values in the eastern Baltic region has been analysed in only a few studies. In Estonia, the relationship between the onset of the growing season and large-scale atmospheric circulation processes have been investigated (Aasa et al., 2004), while in Poland, the relationship between the average onset time of vegetation and the average air temperature was evaluated (Jablonska et al., 2015). The effect of droughts on vegetation conditions in the eastern Baltic region was also investigated (Rimkus et al., 2017). The relationship between the land surface, air and sea surface temperatures and various vegetation indices has been analysed in coastal areas in Poland (Chybicki et al., 2016). In Finland, the models developed using NDVI data are designed to analyse changes in nutrients needed by plants (Törmä et al., 2007).

This is a follow-up to an earlier investigation where the same NDVI database was used. We extended the database with data for 2014—2015 and added two new forms of land use (pastures and wetlands). In previous research, we analysed impact of the droughts on the plant growing conditions as well as other factors which leads to negative NDVI anomalies (Rimkus et al., 2017).

The main aim of this study is to evaluate the changes of various vegetation phenology indicators (start, end, duration, maximum greenness values and time at which it reaches maximum greenness) and its dependence on meteorological conditions (air temperature and precipitation) in the eastern Baltic Sea region. Another task is to assess differences in the dynamic of NDVI values and the response to meteorological forcing on different types of land use. Such kind of research was not carried out in the Baltic Sea region previously. This investigation is important due to the increasingly frequent periods of extreme climate conditions—droughts (in 2018 or 2019) or extremely wet periods such as the second half of summer and autumn 2017. Also, NDVI could be used for ecosystem monitoring and as an additional criterion for assessing the impact of extreme climatic events.

2. Data and methods

In this research, we define the eastern part of the Baltic Sea basin as an area between 53° and 60°N and from 20° to 30°E (Lithuania, Latvia, Estonia and a small part of Russia, Poland and Belarus) (Figure 1a).

The study area is located in the eastern part of the Baltic Sea basin. The territory can be characterised by a hilly landscape with many lakes. The highest point (346 meters) is in the southeast of the area. According to the Köppen classification, almost the entire territory belongs to the *Dfb* climate type (humid continental climate), which is characterised by warm summers (the air temperature of the warmest month is 16—18°C) and relatively cold winters (the air temperature of the coldest month is −3 — −6°C). Only in some parts of the Baltic Sea coastal zone the air temperature of the coldest winter month is close to 0°C and these areas belong to *Cfb* climate type (temperate maritime climate). The average annual precipitation amount is 600—800

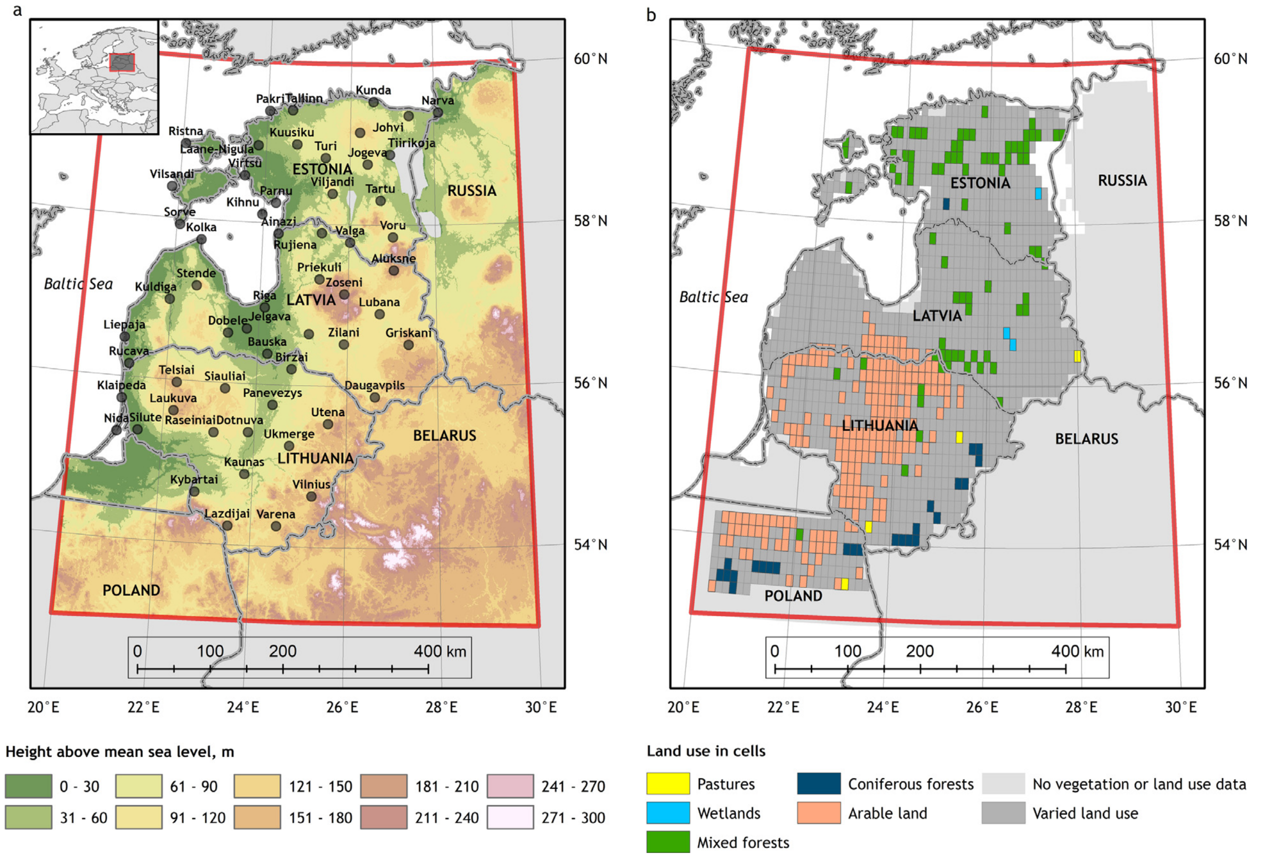

Figure 1 Study area and terrain height above sea level (a) and dominant land use in grid cells with stable land use according to CORINE CLC 1990 and CLC 2012 datasets (b). This figure is modified from preceding research (Rimkus et al., 2017) by adding pasture and wetland grid cells.

mm. There are no significant seasonal differences, but usually slightly larger precipitation amount is recorded in the second half of the summer and early autumn.

Vegetation condition in this study was assessed using NDVI (Kogan, 2001) (Formula (1)):

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

where NIR is the reflection in the near-infrared spectrum (0.70—1.0 μm) and VIS is the reflection in the visible (red) range of the spectrum (0.58—0.68 μm). The NDVI values range from -1 to $+1$. The largest values are in the areas with the highest greenness (up to 0.8—0.9 in tropical rainforests). Values close to 0 are typical for vegetation at the beginning and the end of the growing season. Negative NDVI values are typical for water, snow and clouds (Jackson and Huerte, 1991; Singh et al., 2006).

The growing seasonal phenology and its long-term change analysis were done using weekly 1982—2015 NDVI values retrieved from the US National Oceanic and Atmospheric Administration's (NOAA STAR NESDIS) database. Measurements on NOAA-7, NOAA-9, NOAA-11, NOAA-14, NOAA-16, NOAA-18 and NOAA-19 satellites were performed using an AVHRR sensor. The resolution of NDVI dataset is $0.144 \times 0.144°$. Due to major data gaps in 1994 and 2004, these years were not used in the analysis. After removing the cells where the NDVI values were equal to 0.999 (water), a total of 2621 grid cells were obtained, covering the study area (Figure 1b).

The long-term trends and seasonality of NDVI were analysed for different land use types. The CORINE datasets with reference years 1990 (CLC 1990) and 2012 (CLC 2012) were used to identify land use changes during the study period in Estonia, Latvia, Lithuania and northwestern Poland (Figure 1b). CORINE Land Cover data is not available for Russian and Belarusian territories.

To reduce the number of CORINE land use classes the mixed forests and transitional woodland-shrub areas were joined with broad-leaved forests, and a mixed forest vegetation class was formed. It was considered that the land use class is dominant if it covers at least 50% of the cell's area (Rimkus et al., 2017). Five types of land use were distinguished (321 cells in total): pastures (4 cells), wetlands (3 cells), mixed forests (80 cells), coniferous forests (25 cells) and arable lands (209 cells) (Figure 1b). The number of pasture and wetland cells was small, but these cells were spatially distributed and the changes in the NDVI values in these cells were consistent, thus we decided to include these land use types in our study.

It was considered that land use in particular NDVI cells was stable if CORINE land-use classes were the same in at least 80% of the cell's area. From the set of cells with stable land use, only the cells with single dominant land use types were used in the analysis.

In this study, we used NDVI value of 0.2 as a threshold of the growing season. In all analysed land use types the NDVI values during the cold season are below 0.2 regardless of whether there is snow cover or not. Therefore, the crossing of the 0.2 threshold already shows changes in vegetation. This threshold was also applied by White et al. (2009) to determine the start of the growing season. The average date of maximum greenness in the analysed area was also determined. In this case, maximum greenness time was defined as a week when the peak values of NDVI are reached. Differences in seasonal vegetation dynamics in different types of land use were evaluated.

Pearson linear correlation analysis was used to assess the impact of air temperature and precipitation amount on NDVI values during individual months of the year throughout the study area, as well as on different types of land use. The effect of meteorological parameters on the beginning and the end of the growing season and on the time of maximum greenness was assessed. The relationship between meteorological parameters and NDVI was estimated using monthly precipitation and air temperature data retrieved from the UK Climate Research Centre database CRU TS v. 4.01. In order to spatially and temporally unify the data sets for analysis of the relationship, we calculated the monthly NDVI values from weekly data and used bivariate interpolation implemented in R package "akima" (Akima and Gebhardt, 2016) to downscale air temperature and precipitation data from $0.5 \times 0.5°$ cells to NDVI grid cells ($0.144° \times 0.144°$).

Changes in the beginning, maximum greenness and end time of the growing season from 1982 to 2015 were evaluated. The statistical significance of the changes was assessed using the non-parametric Mann-Kendal test. Changes were considered statistically significant at $p < 0.05$.

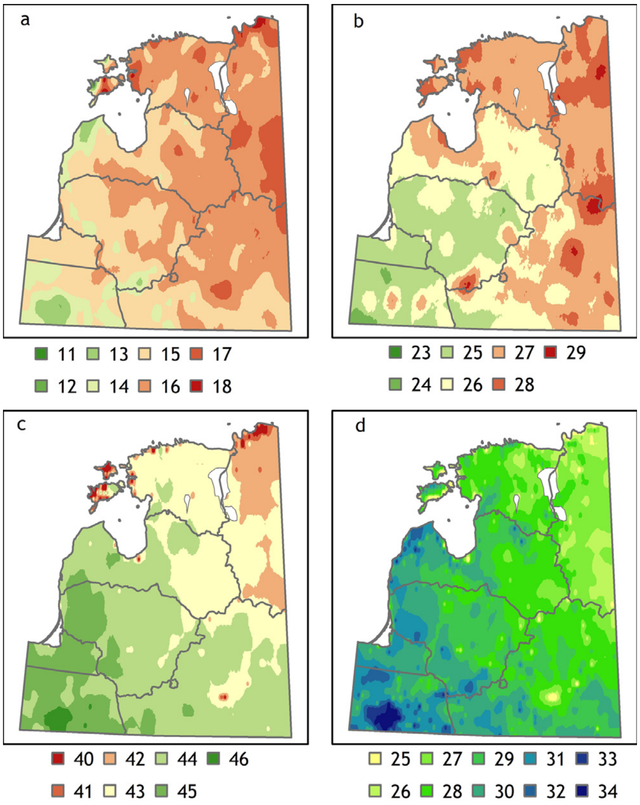

Figure 2 Average dates of onset of the growing season (a), maximum greenness (b), end of the growing season (c) as well as the duration of the growing season (d) in the eastern part of the Baltic Sea basin.

3. Seasonality of NDVI

On average, the earliest start of vegetation (week 11—12) was observed in the southwestern part of the region as well as in some areas in northwestern Latvia. Towards the northeast, the onset of vegetation starts later and in some areas the NDVI values reached 0.2 only by week 17, i.e., a month and a half later. In most of the investigated areas, the growing season began in the middle of April (week 15 and 16) (Figure 2a). The western part of the region showed the greatest fluctuations in the onset of vegetation, while the eastern part had the lowest variation. This is because the growing season in the southwestern area may already start in early March after a particularly warm second half of winter (e.g., 1990) or at the end of April (or even in May) after a late spring (e.g., 1987 or 1996). Meanwhile, in the eastern part of the area, even in warm spring, snow cover duration is longer and more stable, thus the growing season rarely started in March.

The time of maximum greenness is similarly distributed: from week 23 (early June) in the southwest to week 29 (mid-July) in the east (Figure 2b). During the period of maximum greenness, NDVI values in the majority of the analysed area were 2—2.5 times higher than at the onset. The time from the beginning of vegetation to maximum greenness is most dependent on the type of vegetation and is highest in coniferous forests and lowest in arable land.

Due to higher latitude and the weaker impact of the relatively warm Baltic Sea in autumn, NDVI values in the northeast of the area fell below 0.2 on average during the first decade of October (Figure 2c). This can be explained by lower average temperature, earlier start of killing frosts and snowfall. Meanwhile, the growing season in the west and southwest extends to the end of October and in some places to mid-November (week 44—46). This distribution of onset and end of vegetation causes large differences in the duration of the growing season: from six months in the northeast to more than eight months in the southwest (Figure 2d). The southwestern part of the territory is characterised by the largest fluctuations in the growing season end dates. Due to the strong warming effect of the Baltic Sea, the first frosts are recorded here only in December, and the first snowfall in late December or even January.

Analysis of the NDVI seasonality in different types of land use showed that on average the start of vegetation is very similar in almost all land use types (weeks 14—15) (Figure 3). This means that the onset of vegetation depends on the meteorological conditions of a particular year, but little depends on the type of vegetation. The standard deviation of vegetation start dates ranged from 2.0 weeks in wetlands to 2.4 weeks in arable land. On average, 0.2 threshold in coniferous forests was reached 2—3 weeks earlier. In addition, the standard deviation of the onset of vegetation in this type of land use is significantly greater (3.9 weeks). It should be emphasised that in coniferous forests,

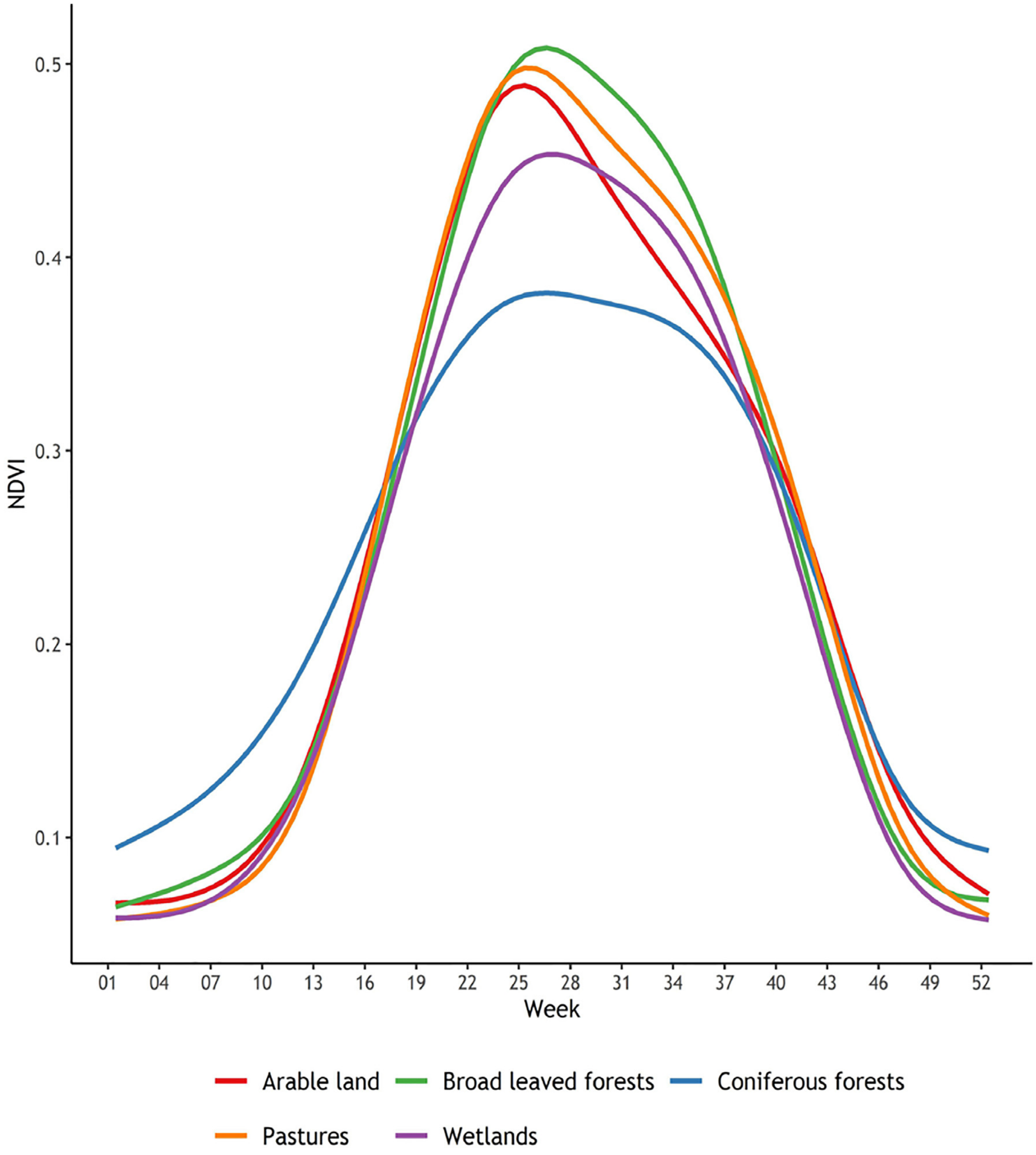

Figure 3 Seasonality of NDVI values in different land use types in the eastern part of the Baltic Sea basin from 1982 till 2015.

an NDVI value rise at the beginning of the year is more related to snow melt (i.e., change in reflection from tree canopy) than to actual changes in tree greenness.

Maximum greenness in pastures and arable land was observed earlier (second half of June) than in other land uses (Figure 3). In pastures, this is related to haymaking; meanwhile, it can be related to the end of cereals flowering on arable land. In wetlands and deciduous forests, maximum greenness was reached on average 2—3 weeks later—in mid-July. In coniferous forests, peak times are difficult to distinguish and the time of maximum greenness varied between mid-June and the second half of August (Figure 3). It should be noted that there is a statistically significant correlation between the time of vegetation onset and maximum greenness in arable lands ($r = 0.52$; depending on the time of sowing) and pastures ($r = 0.44$), whereas no significant correlation was found in other land uses.

The highest average NDVI values during maximum greenness were reached in deciduous forests (0.5); slightly lower in pastures and cultivated land. Due to less vegetation in wetlands, the average maximum of NDVI values is about 0.45. Meanwhile, coniferous forests have the lowest maximum greenness during the summer months (on average NDVI values do not exceed 0.4). The standard deviation of the maximum greenness dates varied from 2.1 (arable land) to 2.6 weeks (pastures). Again, coniferous forests (4.3 weeks) are the exception, where the time of maximum greenness is not very clearly expressed.

After the period of maximum greenness, the strongest decrease in NDVI values is in arable land, which is related to the colour changes of the cereals in the milk and dough development stages. Later the change slows down and after harvesting and plowing, new grass grows. For other land uses, NDVI values begin to decline strongly in early September, and the growing season for all types of land use end at similar times (in the second half of October). The standard deviation of the end of the growing season was the smallest, ranging from 1.6 in wetlands to 2.1 weeks in arable land. In coniferous forests, this value jumps to 2.6 weeks.

Coniferous forests stand out among the other types of land use. Here, the annual amplitude of NDVI values was the smallest, less than 0.3. In addition, real changes in greenness are even smaller due to the interception of snow by the forest canopy, i.e., tree crowns are covered by snow in winter.

4. Relationship between NDVI values and meteorological parameters

Air temperature in February and especially in March is the most important factor determining the beginning of the growing season. Pearson correlation coefficients between the mean February—March air temperature and the March NDVI value in most of the analysed area exceed 0.5, and the mean value of correlation coefficient r is 0.65 (Figure 4a). The highest values of the correlation coefficients are in the southern-southwestern part of the region, where the beginning of vegetation is often recorded in March. Here, r values are greater than 0.8. A statistically insignificant correlation ($r < 0.34$) was recorded in March on the northeastern outskirts of the study area, where vegetation does not begin in March, even in a year with an unusually warm winter and early spring. It should be noted that regions with coniferous forests have lower values of correlation coefficients.

April NDVI values mainly depend on average March—April air temperatures. In the majority of the analysed area, the correlation coefficient values are greater than 0.5 and the average r value reaches 0.64 (Figure 4b). The correlation coefficients are statistically significant in almost the entire territory, and the highest correlation was found in the western part of the region. Moving eastward, the relationship weakens but remains statistically significant.

In all analysed land use types, the air temperature is a major determinant of NDVI values during the onset of vegetation. The average correlation coefficient in arable land and pastures in both March and April is 0.74—0.78; in wetlands and mixed forests, it is 0.59—0.61 and in coniferous forests, it decreases to 0.5.

Precipitation has a much smaller effect on the beginning of vegetation because snow melt is sufficient to start vegetation. In most of the area, the relationship is not statistically significant. On the other hand, a weak statistically significant relationship in some parts of the region is more closely related to the fact that February—March precipitation is positively correlated with air temperature: warm weather during this time of year is mostly determined by advection of a warm and moist air mass from the sea.

The relationship between air temperature and NDVI values decreases as the growing season begins. The most important determinant of maximum greenness on arable land is the time of vegetation onset and, accordingly, the start of field work, so the correlation between the NDVI values of a given month and air temperature is the smallest among all forms of land use. Meanwhile, in coniferous forests, the correlation coefficient increases and reaches 0.6—0.7 during the period of maximum greenness.

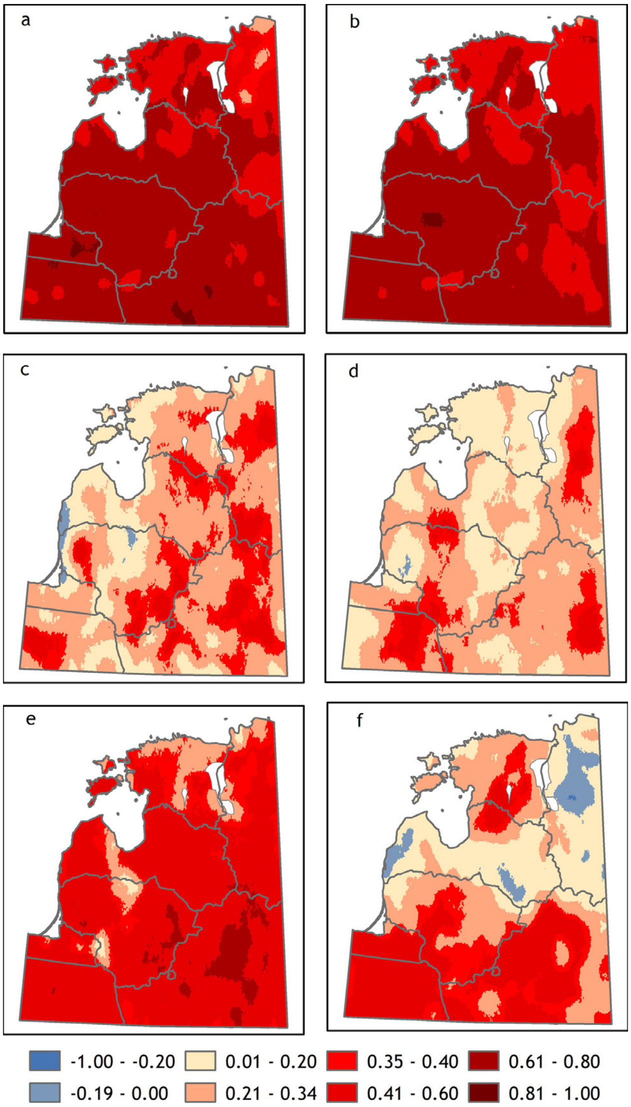

Figure 4 Correlation between February—March mean air temperature and March NDVI values (a) and March—April air temperature and April NDVI values (b); the correlation between air temperature in July (c) and precipitation amount in May (d) with NDVI values in July; the correlation between air temperature and NDVI values in September (e) and between precipitation amounts in August and NDVI values in October (f). The correlation is significant at $p < 0.05$ level when $|r| > 0.34$.

The correlation coefficients between July air temperatures and NDVI values for most of the analysed area do not exceed 0.4 (Figure 4c). The closest correlation between air temperature and NDVI in summer is in the eastern part of the analysed region and in the southern part of Lithuania, as well as on the western slopes of the highland in Western Lithuania. Correlation coefficient values here are larger than 0.4. The lowest values of the correlation coefficients are determined in the coastal areas, central Lithuania and Latvia. These regions are dominated by arable lands and their developmental phase is largely dependent on the time the fieldwork starts.

The relationship between precipitation and maximum NDVI values in summer is also statistically insignificant in the most part of the investigated area (Figure 4d). The closest relationship relates the maximum NDVI values to the amount of precipitation in late spring. Slightly higher and statistically significant positive correlation coefficient values are found only in the eastern and southwestern parts of the region, where r values in some locations are greater than 0.4. This connection is explained by the fact that in summer vegetation can be adversely affected by both excess and deficit of precipitation.

On the western slopes of the highland in Western Lithuania, the amount of precipitation is usually higher than in the surrounding areas and correlation coefficient values between precipitation rate and NDVI are negative. Meanwhile, on the leeward side of the highlands, the average summer rainfall is lower (Foehn Effect), and the correlation coefficient values here are positive and statistically significant ($r > 0.4$) (Figure 4d). This indicates that optimal rainfall is important for greenness in summer.

At the end of the growing season, the importance of air temperature to NDVI values increases again. This relationship is strongest in September. In the most part of the analysed area, correlation coefficient values between air temperature and NDVI values in September are greater than 0.4, and the mean r value for the entire area is 0.47 (Figure 4e). In October, the effect of air temperature is slightly weakening.

The highest positive correlation coefficients are found in the southeastern and southwestern parts of the region as well as in the coastal areas. Here, in some parts, r values are greater than 0.7 or 0.8. The weakest links are in Central Lithuania and Latvia where arable land dominates the type of land use. At the end of the growing season, the importance of air temperature to vegetation, although smaller than at the beginning of the growing season, is significantly higher than in summer. This indicates that higher air temperatures in spring and autumn determine the timing and length of the growing season.

In early autumn, coniferous forests have the highest correlation coefficient between air temperature and NDVI values ($r = 0.6$—0.8). Slightly less significant values are found for pastures, arable land and mixed forests, while meteorological conditions have the least impact on vegetation in wetlands.

At the end of the growing season, the relationship between precipitation and NDVI remains relatively weak, although higher precipitation amounts in late summer and early autumn result in higher NDVI values in large parts of the region. The closest correlation between August precipitation and October NDVI values is observed in Estonia and the southern regions of the analysed area. Here, in some areas, r values exceed 0.5 (Figure 4f). The weakest links are in most of Latvia as well as in the northeast of the region. Besides that, drier weather conditions in September and October lead to early killing frosts, which brings an end to the growing season.

5. NDVI-derived phenology trends

The onset, end and duration of the growing season are strongly affected by regional climate change. Air temperature rise in the study area was observed during the period of investigation. The largest positive changes in air temperature were recorded in early spring and late summer (Jaagus et al., 2014). In February—April (early spring) air temperature increased by 1.3°C, while in August—September an increase of average air temperature during the investigation period was found to be even higher (1.9°C). The mean annual air temperature in the study area has increased by 1.4°C during this period.

It was found in this research that there is a significant shift in the growing season start dates in 1982—2015. On average, the onset of vegetation in all types of land use started three to four weeks earlier than at the beginning of the study period (Figure 5a). Those changes are statistically significant ($p < 0.05$) according to the Mann-Kendal test. Differences in land uses are not significant. Only the dynamics of changes in coniferous forests differ from the others. Here, since 1997, the time at which the NDVI value of 0.2 has been reached has changed dramatically. This is due to the increasingly shorter and more volatile snow cover. For this reason, the AVHRR sensor can detect conifer greens earlier.

The years with the earliest start of vegetation are associated with the abnormally warm March. The relationship between the start of vegetation and early spring air temperature is very strong throughout the entire study area. During the years when the average air temperature in March—April is close to 4°C, the growing season starts on average at 10—11 weeks; meanwhile, when the air temperature is below 0°C, the growing season may start in the 18th week (Figure 6a).

The date of maximum greenness was found to be almost unchanged for 34 years in all types of land use (Figure 5b). Statistically significant changes were recorded only in pastures. In this type of land use the maximum greenness is reached by 2.7 weeks earlier than at the beginning of the investigation period. This is related to the earlier onset of mowing time. The most pronounced variations in the maximum greenness time were observed in coniferous forests. Here, the time amplitude of maximum greenness reaches up to 14 weeks during the analysed period. Large fluctuations were also recorded in wetlands (amplitude of 9 weeks) (Figure 5b). In other land uses, the amplitude was 6—7 weeks. The time of maximum greenness throughout the area is most dependent on the average temperature in April—May ($r = -0.67$). If the average temperature in late spring and early summer is below 10°C, the maximum greenness is reached in mid-July, and when the average temperature approaches 13°C, the maximum greenness is recorded in mid-June (Figure 6b).

It was determined that the growing season ends later (by 3.4 weeks on average). Coniferous forests stand out again, changes there exceeded five weeks (Figure 5c). This difference with other forms of land use can be explained by the later formation of permanent snow cover. In other land uses, the changes were very similar (3—3.5 weeks). A relatively close relationship was recorded between the average

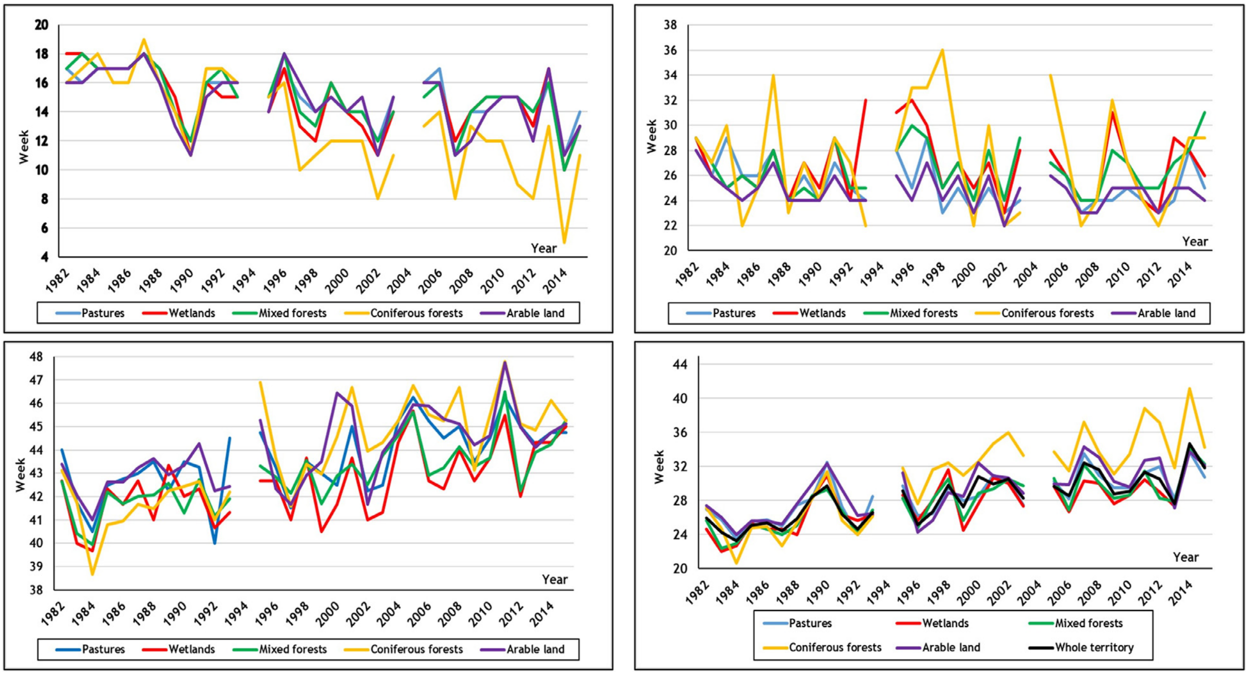

Figure 5 Changes in the beginning (a), maximum greenness (b), end (c) dates of the growing season and duration of growing season (d) for different types of land use 1982—2015.

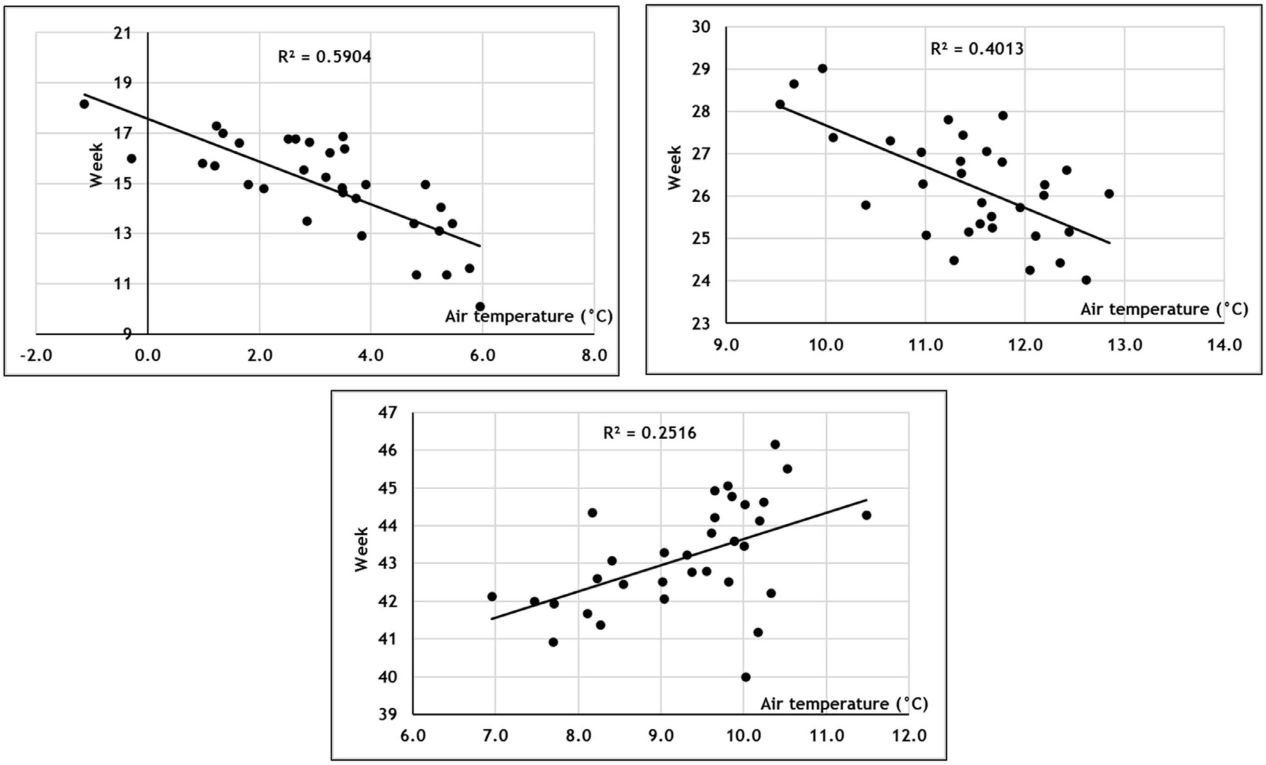

Figure 6 Relationship between the mean March—April air temperature and the start of growing season (a); the mean April—June air temperature and maximum greenness date (b); the mean September—October air temperature and the end of the growing season (c).

air temperature in September—October and the end of the growing season ($r = 0.52$) (Figure 6c). However, this relationship is much weaker than in spring. As the changes in the average air temperature in September—October are not very pronounced in the analysed area (Jaagus et al., 2014), the changes in the vegetation end time could be related to later frosts and snow cover formation. The amplitude of the end of the growing season in different land uses is 6—7 weeks (in coniferous forests about nine weeks).

The average duration of the growing season in the study area varied from 23 weeks in 1984 (very early end of the growing season) to 35 weeks in 2014 (very early start of the growing season in February and March) (Figure 5d). The duration of the growing season throughout the analysed territory increased by 6—7 weeks. The smallest changes were recorded in pastures (6.1 weeks) and the largest changes were in mixed forests (7.3 weeks). Extreme changes in the coniferous forest should be attributed to changes in snow cover regime.

6. Discussion

The main drivers of the growing season indicators (onset, end time, time of maximum greenness and duration) are mainly the distance from the Baltic Sea and latitude. In regions, located near the Baltic Sea, the air temperature is usually higher during the early spring and autumn, this leads to a longer growing season, while in higher latitudes, the lower air temperatures recorded during spring and autumn leads to a later start of the growing season and an earlier end of vegetation. It can also be attributed to the effect of longer snow cover duration at higher latitudes (Tateishi and Ebata, 2004). Analysis of NDVI seasonality in different types of land use shows that the onset and the end of the growing season hardly depend on the type of vegetation. However, there are differences between land uses during the time of maximum greenness — the highest NDVI values were reached earlier in pastures and arable lands than in the other types of land uses.

Late winter and early spring air temperatures determine the time of the beginning of vegetation, while March air temperature plays a big role in further vegetation development during the early stages of the growing season in most of the analysed territory. Similar conclusions were made in other studies in the Baltic Sea region (Ahas et al., 2000). Also, the influence of air temperature on NDVI values in spring is highest in pastures and arable lands. During the summer, air temperature has less impact on vegetation conditions—correlation coefficient values between July air temperature and NDVI in most cases are insignificant. At the end of the growing season, the impact of air temperature on vegetation greenness is more significant than during the summer. Higher air temperature in September—October leads to a longer growing season.

The amount of precipitation is a less important factor for growing season start and end dates and time of maximum greenness time. This is typical in higher latitudes in the Northern Hemisphere. In other studies, it was also found that air temperature is a more limiting factor for plant growth than precipitation (except arid and semi-arid areas) (Hatfield and Prueger, 2015; Jeong et al., 2011; Zhao et al., 2018). During the summer, higher positive correlation coefficients between precipitation amount and NDVI were found in areas where the amount of precipitation is usually lower; while in areas with a higher amount of precipitation, r values are lower. This means, that during the summer, the optimal amount of precipitation is important for the development of vegetation. Finally, higher precipitation in late summer and early autumn prolongs the growing season.

At the end of the study period (1982—2015) in all types of land use, plants turned green 3—4 weeks earlier than at the beginning of the period. These rates were found to be greater than the average change of the growing season starting date in the Northern Hemisphere from 2003 until 2013 (3.2 ± 1.7 days per decade) (Zhao et al., 2015). The earlier start of the growing season also was observed in Europe by 0.54 days/year in 1982—2000 (Stöckli and Vidale, 2004). The reason for this is increasing air temperature. The observed changes may be also partly explained by the fact that the beginning of the study period coincided with a period of cold and snowy winters (1982—1988). In all these winters, the snow cover did not melt until the last decade of March, so the growing season started later. In contrast, the end of the investigation period was characterised by warm winters with short episodic snow cover. Although a longer study period would allow adjusting determined trend values, the overall trends would not change significantly.

In another study, it was found even small positive trend (later start of the growing season) in Lithuania territory during period from 2000 until 2016 (Jin et al., 2019), while almost no changes were observed in *Df* climate type in Europe (almost the whole investigated area belongs to this climate type according to Köppen's climate classification) in 1982—2010 (Zhang et al., 2014). It shows, that the results of trend analysis highly depends on the duration of the investigation period. Differences in trends between 1982—1999 and 2000—2011 in western Central Europe were discussed in Fu et al. (2014).

However, the time of maximum greenness remained almost unchanged during the 34 years studied. Statistically significant changes were found only in pastures, and it is related to earlier mowing. The end of the growing season was reached later by 3—4 weeks in most types of land uses during the analysed period from 1982 until 2015. Compared to other studies in the Northern Hemisphere, these changes were found to be bigger (Zhao et al., 2015). The later formation of snow cover, as well as later frosts formation, could also affect the end of the growing season. The growing season's duration during the 34 years increased by 6—7 weeks on average. The highest increase was recorded in mixed forests, while lowest in pastures. Similar patterns were found in other researches (Zhao et al., 2015) and with continued global warming, the growing season is very likely to be prolonged even more (Hatfield and Prueger, 2015; Linderholm, 2006). In our study region, the changes in air temperature (especially in the first half of the year) are also evident (Jaagus et al., 2014) and it leads to changes in dates of the growing season.

These changes in the growing season's duration could cause various consequences. For example, due to the longer growing season, the soil carbon availability may increase because of the more litter fall and by allowing early winter soil frosts (Brooks et al., 2004). The longer growing season will also increase gross primary productivity and net primary productivity and because of that soil carbon decomposition may increase as well. This means that despite the longer growing season the magnitude of terrestrial carbon sink may not change significantly (Piao et al., 2007). The longer growing season also may not mean higher productivity of boreal forests, as due to increasing temperatures these forests are more affected by water stress, especially in the southern part of region. The negative effect of water stress is predicted to become more intense and frequent in the future (Ruiz—Pérez and Vico, 2020). The longer growing season could lead to more frequent frost days during the growing season while the total number of frost days should decrease (Liu et al., 2018).

However, there are still some limitations that should be considered in future studies. Satellite data still have some weaknesses—the sensitivity of the radiometer (in this case AVHRR) changes over time and the satellite's orbital movement can affect the geometry of the sensor (Zhou et al., 2001). Also, near-infrared and visible light channels of AVHRR are affected by aerosols, especially ozone and water vapour (Zhou et al., 2001). Finally, NDVI values can be distorted during a long period of cloudy weather (Huete et al., 2002; Stöckli and Vidale, 2004). It also should be noted that we used only a few grid cells for analysis of changes in pastures and wetlands. Therefore, the results could change if we include more grid cells in the analysis. However, the trends values in pastures and wetlands differed little from the other forms of land use.

7. Conclusions

The earliest growing season starts in the southwestern part of the analysed territory, while in the northeast part of the region, plants turn green about six-seven weeks later. Similar patterns remain for the dates of maximum greenness and the end of the growing season (in the opposite direction). The main factors determining territorial differences are the distance from the Baltic Sea and latitude. The growing season varies from six months in the northeast to eight months in the southwest.

The start and the end times of the growing season are very similar for all analysed land use types. Maximum greenness was reached earliest on arable land and pastures. The highest NDVI values during the period of maximum greenness were observed in deciduous forests.

February to March air temperature is the most important factor determining the start of the growing season. The relationship between meteorological indicators and maximum greenness time is weak and statistically insignificant in the most part of the area. The relationship between the end of vegetation and the air temperature is stronger (the strongest correlation in September). The correlation between precipitation and NDVI values is weak throughout the whole growing season, since vegetation can be negatively affected by both excess and deficit of precipitation.

With the rise of air temperature in the analysed region, the onset of the growing season at the end of the study period began by 3—4 weeks earlier and ended on average more than 3 weeks later than in 1980's. The duration of the growing season increased by 6—7 weeks. The changes were statistically significant. Maximum greenness time remained almost unchanged.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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