Seminar series nr 191

IMPACTS OF STRESSFUL WEATHER EVENTS ON FOREST ECOSYSTEMS IN SOUTH SWEDEN

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2010
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Master Degree-thesis, 2010

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Contents

Summary

Coniferous as spruce (more specifically Norway spruce, *Picea abies*) and deciduous species like European beech (*Fagus sylvatica*) and oak (*Quercus* spp.) co exist in south Sweden. In perspective of climate change, species composition of Swedish forests is assumed to change.

Observed climate on the period 1950-2010 prove that a general warming trend is occurring in southern Sweden, and that vegetation growth period is getting longer. From the observed weather data, annual precipitation and minimum temperature in spring are highlighted in order to analyse the response of the three tree species. Extreme years are distinguished.

Responses from the trees are studied in terms of onset and end of vegetation period and length of vegetation period, for each species, using observations from satellite data (MODIS) for the period 2000-2009. Variations observed during extreme years constitute the basis for an interpretation of the species-specific response to climate events, qualified as stressful for the vegetation.

Further on, the discussion is relating stressful weather events with tree defence capacity and biotic stresses (e.g insect outbreaks) and their role in a disturbance system. Links to forest ecosystem are made through processes like regeneration, competition and migration. Climate change projections are analysed in order to study the potential reactions of the three species in South Sweden with climate shifts according the observations made in the previous parts.

Keywords: physical geography, geography, forest ecosystem, stressful weather events, trees responses.

1. Introduction

1.1 Swedish forest ecosystems

Forest biodiversity in the south of Sweden (approximately 55°N-58°N) is relatively high in comparison to the boreal vegetation zone located up north of the country. The geographical situation of this area allows a quite large biodiversity that refers to a nemoral vegetation zone. In the south of Sweden, different types of forest have to be considered. A great part of the area is covered by spruce and pine dominated coniferous forests, but at the contrary of other northern regions, there are also mixed types. On the western coast and in the very sout of the country, spruce and pine share the forest cover with deciduous species. Some areas are species richer with the presence of hazel, lime, birch and beech. A part of the southeastern region is covered by small remanants of pure deciduous forest (Björse & Bradshaw, 1998).

Those different types of forest have a great importance for the region. Indeed, biodiversity is needed for ecosystem services (Hector & Bagchi, 2007). Managed forests and spruce forest have lower biodiversity than oak and beech forest.Also, economic values of Swedish forests should not be neglected since they are used for timber production and recreation functions (Yrjölä, 2002). The need to protect that biodiversity is often taken into account in the sustainable management practices of large private or public owners.

Some phenomena are difficult to integrate. Disturbance regimes are complex, due to many interactions between climate impacts and anthropogenic impacts among other processes, which makes it difficult to account for in forest management. A disturbance is an event that disrupts ecosystem structure, composition and processes by notably causing biomass destruction. It relates to the ecosystem traits and their characteristic time scales (Seidl et al).

Climatic conditions are changing and this will be likely to affect disturbances, and thereby conditions for forest to develop (IPCC, 2007). Moreover in southern Sweden, the location is close to the vegetation limit separating a temperate zone from a boreal zone, then it is supposed to be sensitive to climate variations (Caplat et al, 2008).
Global change might increase the intensity of some disturbances, suppress others, or create new ones (Dale, 2001; IPCC, 2007). Indeed, global climate change implies shifts in weather events that could become more intense (e.g. rainfalls, windstorms) and/or more frequent (IPCC report, 2007). Climate extremes (e.g. maximum/minimum precipitation, maximum temperature) would therefore be more stressful for the vegetation. A stressful weather event is an event directly linked to climate and which creates stressful conditions for a plant to grow. Larcher (translated in Dobbertin, 2005) defines stress as “a significant deviation from the condition optimal for life”

More frequent stressful weather events are likely to lower the trees vitality. Lower tree vitality leads to a lower defence capacity to other stress factors like insects’ outbreaks (e.g. bark beetles on spruces) or pathogenic fungi. These other stresses can be more harmful causing more damage than the direct weather extreme events, eventually leading to tree mortality. Disturbances in forest ecosystem are hypothesised to occur more frequently with these concatenating processes.

In southern Sweden, stressful events causing disturbances in forest ecosystems are usually droughts, spring frosts or windstorms. These events lead to decreasing tree vitality and then favour spruce bark beetles attacks (Larsson, 1989; Rouault, 2006) and proliferation of pathogenic fungi (Schlyter, 2006).

1.2 Aims of the thesis

Southern Sweden has a species diversity in forest ecosystems. Thereby, assessing the consequences of weather events on trees makes sense in a biodiversity conservation reflexion and in management projections. European beech (*Fagus sylvatica*), oak (*Quercus*) and Norway spruce (*Picea abies*) are the most dominant species in the south of Sweden (Prenctice et al. 1991). Beech and oak represent a large advantage for biodiversity, larger than Norway spruce monoforests. Compared responses of the three species to stress related to extreme weather could provide an evolution of forest ecosystems in the future. It could help to discuss the importance of stressful weather events in the future on forest composition in southern Sweden.

This thesis aims to:

- Analyse climate trends over the last 60 years
- Highlight weather variations with annual temperature and annual precipitation measurements
- Analyse the three tree species’ start, end and length of the growing season over the last decade.
- Compare interannual variations in weather and tree phenology
- Test which extreme events that have had impacts on trees
- Analyse if it is possible to detect trees responses to stressful weather events by remote sensing of species-specific phenology
- Discuss climate change impact on trees responses and disturbance regimes.

2. Materials and Methods

2.1 General presentation

The climate of southern Sweden is analysed by using gridded observed temperature and precipitation climate dataset; tree response is given by satellite data. The results are then discussed in relation to litterature (figure 1).

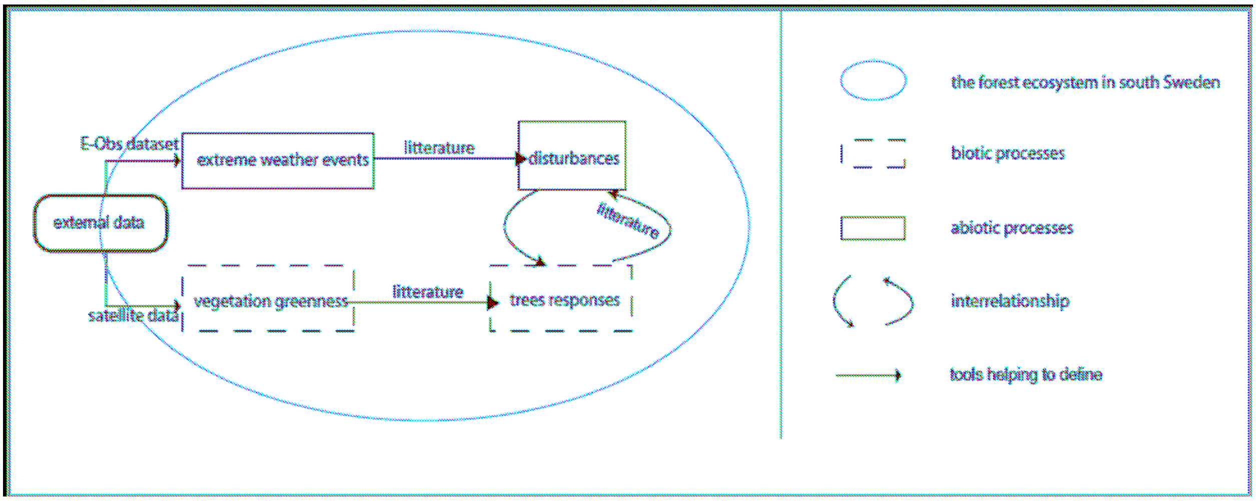

Figure 1. General presentation of methods used in this study : from the data to an interpretation

2.2 Regional Climate Indices for South Sweden

2.2.1 General information

Data from the E-Obs dataset version 2.0 are used to determine climate indices. The E-Obs dataset is available via the EU-FP6 project ENSEMBLES (Haylock et al. 2008). It includes gridded information from European weather observations such as daily mean, maximum and minimum temperatures at two meters above the ground, and daily precipitation.
The records go from 1950 to 2010, so for a 60 complete years period (reference period). These data have been extracted and climate indices have been computed afterwards in MATLAB. Data are ploted on gridcells of 0.22 degrees, with 12 gridcells in longitude and 16 in latitude (192 grid cells) (figure 2).

Southern Sweden has the warmest temperature range in Sweden (7°C average annual temperature for 1961-1990, in the southermost part). The length of the growing season can reach 210 days in the very south. The boreo-nemoral conditions present there are conditions for a mixture between summergreen broadleaved trees and evergreen needleleaved trees (Ahti et al. 1998).

The scripts on MATLAB for building indices were written in loops so that the operation can proceed over for every year of the 60-years reference period. Then I obtained a matrice with the climate indices extracted from the loop for every year, and every grid cells (i,j).

From these records and for the period 1950-2010, many indices have been produced.

All the following indices have been calculated for each gridcell. In order to calculate regional mean values, the average values of all grid cells have been calculated, for all the climate indices.

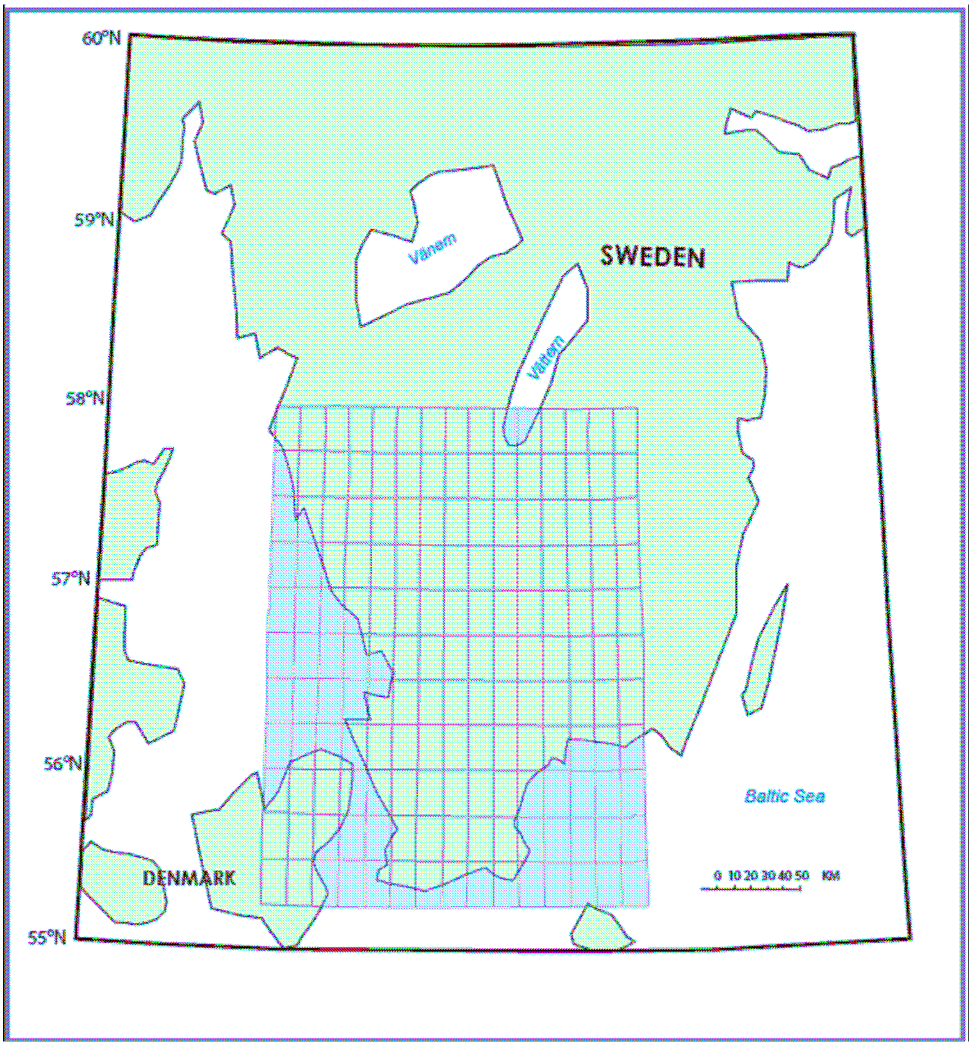

Figure 2. Studied area : gridcells (in grey) from the European gridded observed dataset (E-Obs) providing climate data all over southern Sweden

2.2.2 Calculation of the climate indices: characterizing the climate over the last 60 years

- <u>Annual</u> values for every year within the period 1950-2009

  - mean temperature ('meantemp') : it is calculated by doing the average of all daily mean temperature using a loop for every year

$$meantemp = \frac{dm1+dm2+dm\mathit{n}}{sum(days)}$$

This is run in a loop taking every year one after each other; dm1 is the daily mean temperature for day 1 of one year, *n* being the number of recording days (normaly 365). Temperature is given in degree Celsius (°C);

- minimum temperature: it is calculated by doing the average of all daily minimum temperature using a loop for every year. Same calculation as for 'meantemp', except using the daily minimum temperature;

- maximum temperature: it is calculated by doing the average of all daily maximum temperature using a loop for every year. Same calculation as for 'meantemp', except using the daily maximum temperature;

- precipitation ('precip') : it is calculated by accumulating the daily precipitation

  precip = dp1 + dp2 + dp*n*

  This is run in a loop taking every year one after each other; dp1 is the precipitation recorded for day 1 of one year, *n* being the number of recording days for a year. Precipitation is given in millimetres (mm).

▪ Definition of the seasons, for every year
(the definitions have been based on the Swedish Meteorological and Hydrological Institute thresholds definition, SMHI 2007)

- first day of spring : first day of a seven-day period when the mean temperature changes to above 0°C
- first day of summer : first day when the daily mean temperature is rising to above 10°C
- first day of autumn : first day of a four-day period when the daily mean temperature is within the interval of 0-10°C, after July (from the 213th day of the year)
- first day of winter : first day of a tree-day period when the mean temperature changes to below 0°C
  The cessation of each season is marked by the onset of the following one.

▪ Definition of the vegetation period, for every year
  - first day of the vegetation period : first day of the four consecutive days with a temperature above the threshold of 5°C

2.2.3 Definition of spring coldness and annual dryness

Drought and cold spring were chosen as two main weather events that could be stressful for the vegetation quite frequently in south Sweden. Among other weather events, those are the easiest to evaluate through climate data (minimum temperature and sum of precipitation needed).
To define them, I realised a statistical work from the dataset described above, to highlight the most extreme years regarding temperature and precipitation. These events are defined annually in order to analyse which year has been the most stressful on trees.

The tree drought is not analysed here but it is related to meteorological dryness, i.e. low amount of annual precipitation. Spring coldness is related to daily minimum temperature during the months of March, April and May.

The method used to define those thresholds is using average values and anomalies. The statistical work, by definition, attests to relative thresholds only relevant for this time period and this area.
That method uses the average value of one climate index, for the reference period and for the whole area. Statistical anomalies are calculated from this average value, on a particular period that is studied. The reference period is 1950-2009, and the period studied is 2000-2009.
Anomalies are calculated at the regional scale here, meaning that only regional averages are taken into account, and no differences are made regarding the space, but only regarding the time. The average value concerning the minimum temperature and the minimum precipitation has been calculated for the 60 years period and then, for each year of the latest period the difference is calculated from this average value.

2.3 Vegetation Indices

2.3.1 Satellite data

Satellite data are used to define the vegetation indices. They are extracted from MODIS data, measures from the Normalized Difference Vegetation Index.

"*NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light*" (NASA definition [1]).

Remote sensing can help to construe the phenology of a vegetation area, thanks to records of the "greenness" of the zone. From what appears on the satellite imagery to a proper definition of the vegetative season, there are several steps that are processed by the software TIMESAT ver. 2.3. (Eklundh & Jönsson, 2010). Those steps are explained below.

In this study, satellite data products from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument onboard the Terra satellite were used. The MODIS tile, labeled H18V03, was used for extraction of data for the period of March 2000 to December 2009.
I used satellite data from the Swedish monitoring sites for European beech (*Fagus sylvatica*), oak (*Quercus*) and Norway spruce (*Picea abies*). They might react differently to weather events since they have a different seasonal functioning (deciduous and coniferous).
Monitoring sites are sites of 250x250 meters where one species stand phenology is observed by satellite. Data from 81 monitoring sites in the south of Sweden, were collected from

[1] Available on the NASA website :
http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php

March 2000 to December 2009 (2000-2009 period). 53 sites concern spruce, 9 for oak and 19 for beech (figure 3).

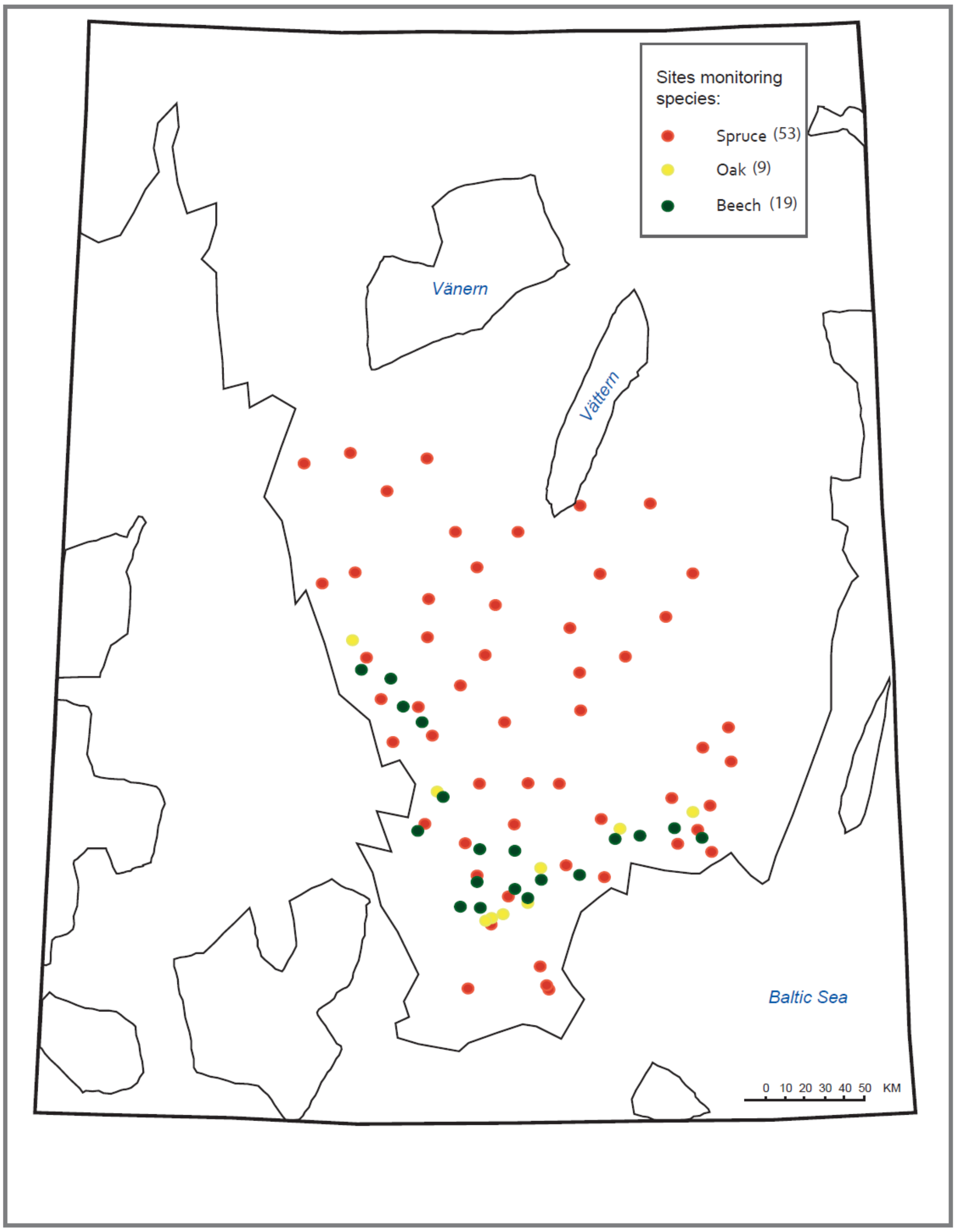

Figure 3. Spatial distribution of the 81 monitoring sites providing satellite data for the phenological parameters used in the study, classified according the main species on the site

2.3.2 Phenological parameters: quantifying the seasonal vegetation progression

MODIS data were processed with the software TIMESAT that has been developed for fitting mathematical functions to time-series of satellite data in order to outline the seasonal progression of vegetation development.
One model fit was used in this study: Savitzky-Golay. The Savitzky-Golay (SG) filtering, using a relatively narrow window size, is able to capture rapid changes by local fitting. On the other hand, it is more sensitive to noise. The data were fitted using upper envelope-

weighted least-squares methods, assuming negative biased noise, and data were weighted according to the quality indicators ensuring that cloudy or otherwise low-quality pixels had minimum influence on the fitting.

These data are processed to define the start and the end of the growth season. With TIMESAT, one can define these limits, and two thresholds were applied for the start and the end of the season: 60 % and 90 %. It means that the start of the season will be defined as the increase to these two levels measured from the minimum levels on the fitted curve. The end of the season would be the decrease.

The data are fitted under two different combinations. I used both thresholds to obtain:

- the phenology from the SG function and a 60 % threshold ('phenologySG60')
- the phenology from the SG function and a 90 % threshold ('phenologySG90')

One satellite observation is recorded for each 8-day period i.e. only one observation is recorded per 8-day period. There is then 46 periods of satelite observations per year.The phenological parameters used in the results are converted in days, in order to simplify the results. Then, outcomes from TIMESAT have been converted by doing some operations.

- the start of the season is given in days by: $Yn = (obs - n\text{x}46) \text{ x } 8$
- the length of the season is given in days by: $Yn = obs \text{ x } 8$

"Y" is the value in days, "obs" is the original values from the satellite data fitting, and *"n"* is the range year of the record.

The vegetation development processes are represented by phenological parameters produced in TIMESAT. In this study, these parameters were used:

1. time for the start of the season
2. time for the end of the season
3. length of the season

These parameters permit to define vegetation periods, which have been observed on 81 sites, for 10 consecutive years. A MATLAB database was created from these new measures: two matrices, corresponding to the two methods used for fitting the data; the matrices are double array of 10x11x81 corresponding to 10 years, 11 measures and 81 sites.

Phenology parameters concern the three tree species (oak, spruce, beech) and are useful to characterize the vegetation behaviours. Indeed, stressful events are expected to influence the greenness recorded by satellite technology.
In order to analyse the vegetation processes according to climate events, the space resolution for the phenological parameters have been related to the space resolution of the climate dataset. In MATLAB, a matching phase has been processed in order to find the 81 monitoring plots out of the 192 grid cells of the climate indices dataset.

2.4 Correlation between Climate Indices and Vegetation parameters

Correlations have been run between the climate indices ‘vegetation period onset’/‘autumn onset’ and satellite based vegetation indices ‘time for the start of the season’/’time for the end of the season’.
The study aims to analyse the reactions of three tree species according to some shifts in climate observed the past decade (2000-2009). A relationship between the vegetation observations and the climate indices is qualified with the help of statistical correlations, run on the two databases that were built in the previous phases.

Here, the Pearson’s coefficient was used to obtain the most relevant correlations.
It was used in order to qualify and quantify the relationship between chosen climate indices and 3 phenological parameters.

The Pearson sample correlation coefficient (r_p) is:

$$r_P = \sum(x_i - \bar{x})(y_i - \bar{y}) \Big/ \left\{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2\right\}^{1/2}$$

where $\bar{x} = n^{-1} \sum x_i, \bar{y} = n^{-1} \sum y_i$.

A Pearson’s correlation is construed as linear, and can be positive or negative.

This equation has been run on MATLAB to assess the correlation between climate indices and phenological parameters. Chosen climate indices were vegetation period and autumn onset. Correlations have been calculated for all monitoring sites and all years of the period 2000-2009. Then the distinction has been made between all sites according the species, so the correlation coefficient can be compared according different trees.

2.5 Variations in vegetation parameters in relation with climate indices

Vegetation parameters’ variations are shown according the occurrence of the extreme weather events defined in this study.

For the event “spring cold”, warm and cold springs are separated in relation to anomalies.
Two boxplots are designed in MATLAB showing variations in:

- the time for the start of the season (parameter 1)
- the length of the season (parameter 3)

One box shows NDVI values for years concerned by cold spring, the other one shows NDVI values for regular years. NDVI values are converted in days value.

For the event “annual dryness”, annual precipitation above the reference period average are separated from annual precipitation below the reference period average. Two boxplots are designed in MATLAB, showing variations in:

- the time for the end of the season (parameter 2)
- the length of the season (parameter 3)

One box shows NDVI values for years concerned by dryness, the other one shows NDVI values for regular years. NDVI values are converted in days values.

3. Results

3.1 Warming in Southern Sweden over the last 60 years

The graph (figure 4) produced from the E-Obs dataset showing annual mean temperature and annual precipitation for every year within the period 1950-2010.

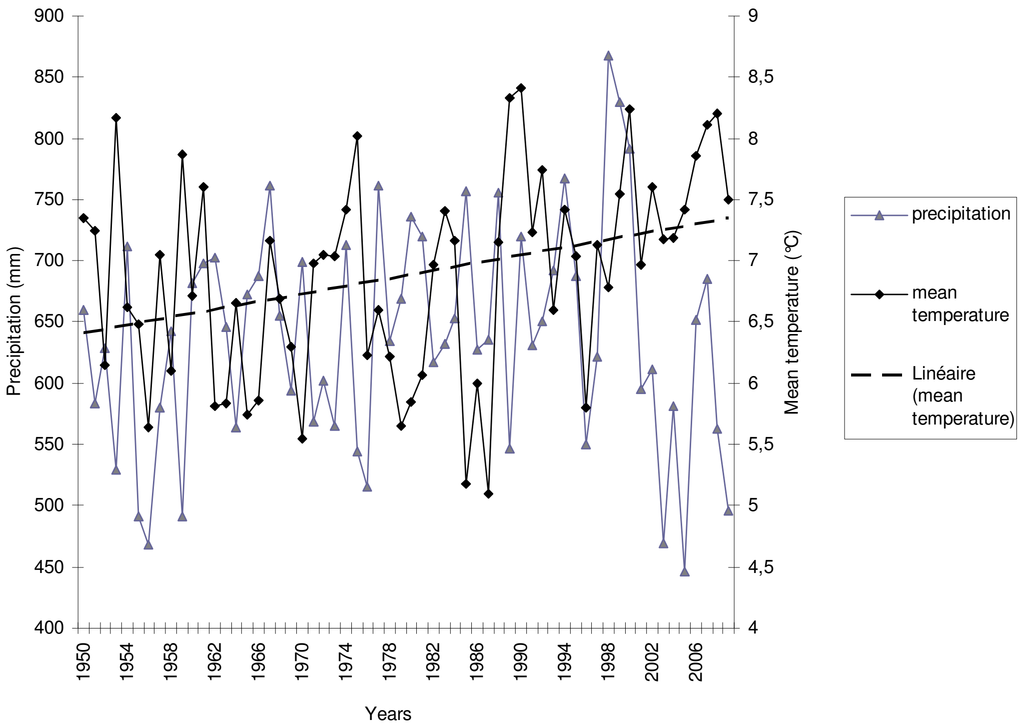

Figure 4. Mean temperature and Precipitation for southern Sweden for the last 60 years, from the European gridded observed dataset (E-OBS data)

The regional climate index over the last 60 years showed a warming on the studied area. The regional mean temperature ranges between 5.1°C, in 1988 (the lowest) and 8.42°C, in 1991 (the highest). The last 20 years (1990-2010) record lots of high temperatures in comparison with the rest of the period. The 1990-2010 period shows an average mean temperature of 7.4°C, whereas the period before (1950-1989) has an average mean temperature of 6.6°C.

A simple linear regression is used to highlight the temperature rise occurring for this period. The mean temperature has risen from 1950 until now, according to the linear regression equation (y):

$$y = 0{,}0158x + 6{,}4017$$

There seem to be no real stable changes regarding precipitation over the 60 years. The annual precipitation ranges between 446.6 mm for the year 2005 (the lowest record) and

868.1 mm in 1998 (the highest). A large drop of the annual amount of precipitation is noticeable after 1998 and records are really low for the whole last decade (2000-2010) in comparison with the other decades. The average of annual precipitation for the period 1950-1999 is 648.4 mm, and is 589.1 mm for the 2000-2010 period.

Over the last 60 years, the climate is shifting towards higher temperature. The last decade was the warmest of the period. The last decade was also the driest in terms of annual precipitation.

3.2 Relevant climate indices related to vegetation processes

3.2.1 The start of the Vegetation Period (climate indices from E-Obs dataset)

3.2.1.1 For southern Sweden (all grid cells) and 60 years (reference period)

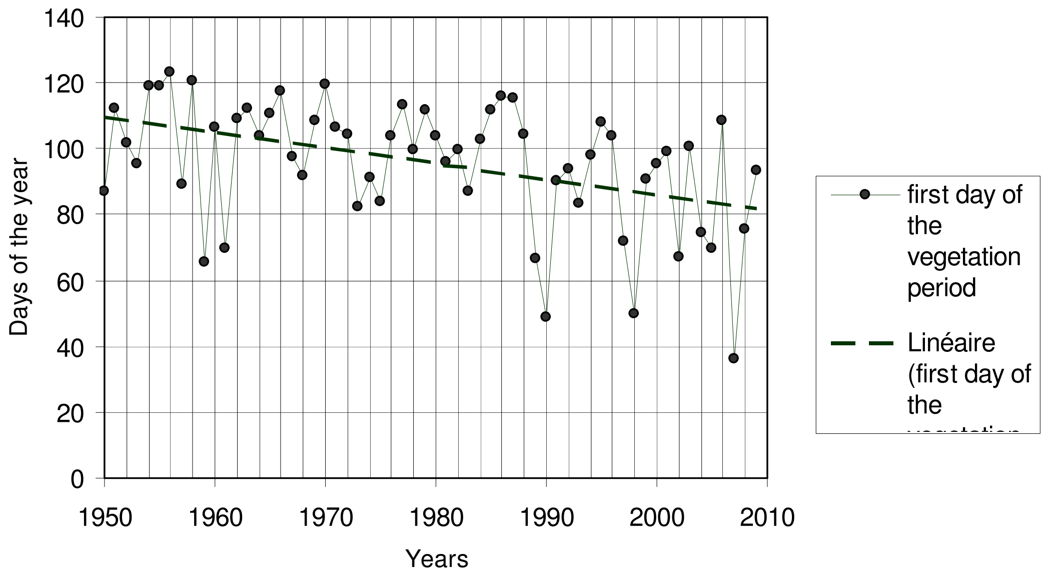

Figure 5. First day of the vegetation period: first day of the year when the temperature is above the threshold of 5°C four days in a row from the European gridded observed dataset (E-Obs data)

Here is the onset of the Vegetation Period (*vp*) defined as the first day of a four-days period where the temperature rises to over 5°C. There is a large inter-annual variability and some large differences are observed from one year to the next one (e.g 1959, 1960 with 66th day and 106th day respectively).

As a consequence of the regular warming observed previously, the vegetation period tends to start earlier. A simple linear regression line has been traced, y(*vp*):

$$y(vp) = -0.467x + 109.87,$$
$$r^2(vp) = 0.1844$$

The linear regression is negative and proves a change in the onset of the vegetation period.

3.2.1.2 Geographical gradient

The vegetation period starts earlier in the south of the country, because warm temperature occurs earlier than in northernmost parts. Here are maps showing the effect of latitudinal gradient on the start of the vegetation period, for the years of the earliest and the latest vegetation period of the last decade.
The years for the earliest and the latest onsets of the vegetation period for the last decade were chosen in order to show the range that can occur between two different years. The earliest regional record for 2000-2009 was for 2007 (36th day) and the latest was for 2006 (108th day) (see figure 5).

The climate gradient is well showed on the two maps. Usually, the south of Sweden records earlier onset than the north (figures 6 and 7). Above latitude 56°N, a delay in the onset is observed in comparison with the southernmost area. Thus the northernmost parts record the latest onsets of the area (above 57.5°N, it ranges from 70 to 115 days). A small continental gradient could be assumed given that most of the coastal areas record also earlier onsets of *vegetation period* (clear on figure 6). The inland areas benefit from warm temperature later than the areas near the western coast.

However, the records for the year 2006, with a late vegetation period onset (showed in figure 7), are less distinct from one to another, especially in the inlands. From the southernmost parts to 57.5°N, the onset of the vegetation period ranges between 105 and 110 days, except for some areas near the western coast (between 100 and 105 days). Above 57.5°N, a large inlands area records a vegetation period onset from the 115th day.

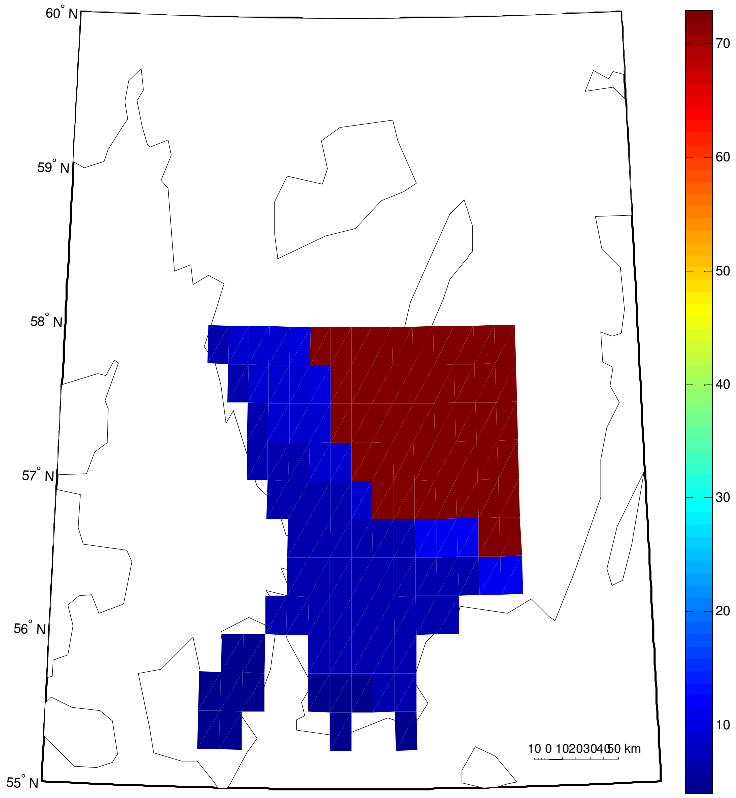

Figure 6. Time for the onset of vegetation period for the year 2007 (days). 2007 is the year of the earliest vegetation period onset for 2000-2009

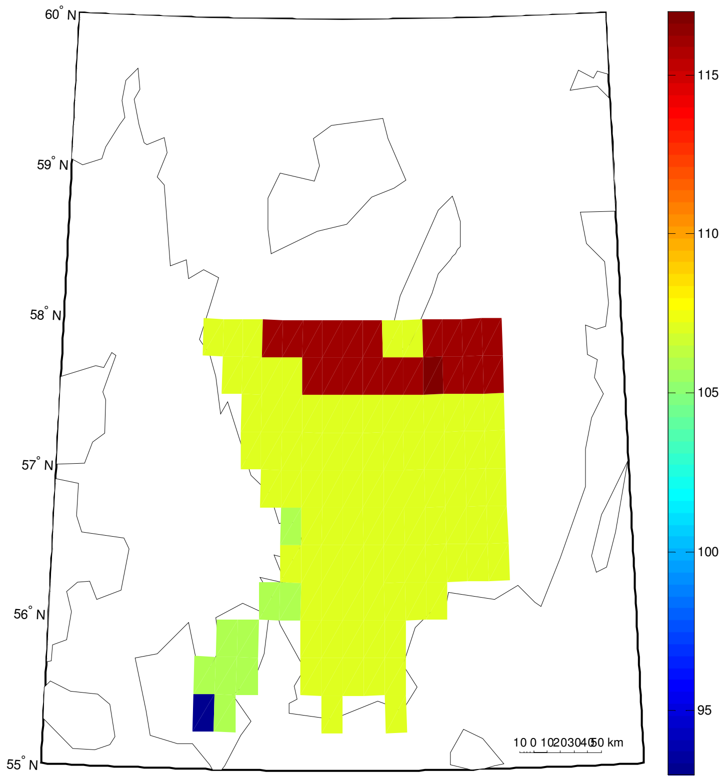

Figure 7 Time for the onset of *vegetation period* for the year 2006 (days). 2006 is the year of the latest *vegetation period* onset for 2000-2009.

3.2.1.3 Correlation with the satellite signal for the season's onset (time for the start of the season)

Correlation has been analysed between the climate index vegetation period and the start of the season observed with satellite imagery (MODIS data).

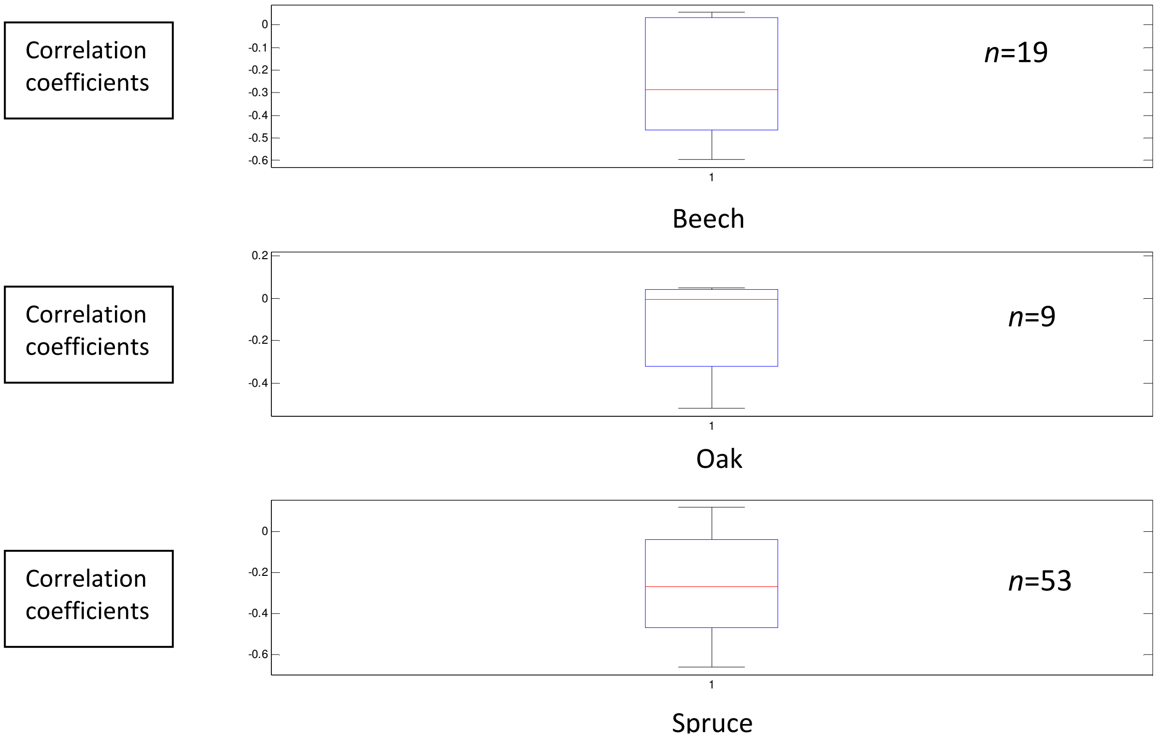

Figure 8. Boxplot: linear correlation coefficients between the climate index vegetation period and the phenological parameter time for the start of the season, for the period 2000-2009. Correlation coefficients are shown for each monitoring sites (vertically).
Boxplots are showing the variations between sites. *n* is the number of monitoring sites for each species.

The correlation coefficient between the start of the season for beech and the climate index vegetation period is -0.24, which is weak. However, 42.1 % of the beech sites record a rather strong negative correlation (smaller than –0.3) for the start of the season.
The correlation coefficient between the start of the season for oak and vegetation period is: -0.15, which is really weak. The correlation coefficient between the start of the season for spruce and vegetation period is : -0.27, which is also weak.

The 3 tree species show weak linear correlations with the index vegetation period. However, some sites have shown a deeper correlation (e.g beech). The negative correlation means that if the onset of the vegetation period is late (high value in days) the NDVI value (phenological parameter) will be low.

3.2.2 The start of autumn (climate indices from E-Obs data)

3.2.2.1 For southern Sweden (all grid cells) and 60 years (reference period)

The start of autumn can be roughly used to define the end of the most active vegetation period. It is a climate index built from the E-Obs dataset (see methods).

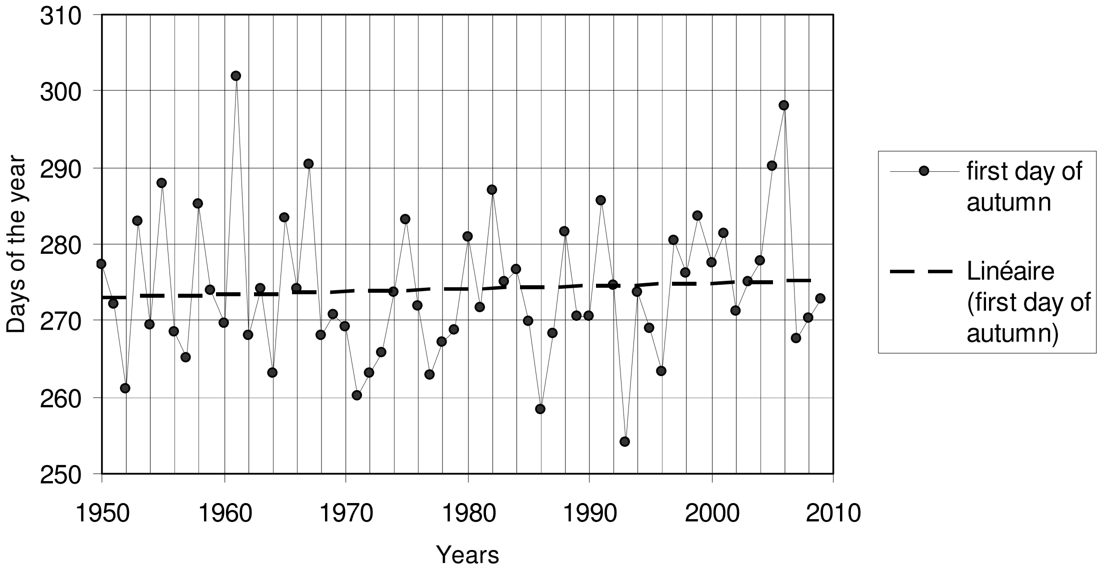

Figure 9. First day of autumn : first day of a four-days period after July when the daily mean temperature is within the interval 0-10°C from the European gridded observed dataset (E-Obs data)

The onset of autumn (*aut*) is pretty regular over the last 60 years. The linear regression equation y(*aut*) is :

$$y = 0{,}0379x + 199{,}13$$
$$r^2 = 0{,}005$$

The linear regression equation has very low values which shows no significant trend. However a small delay in the onset of autumn. It means that the decline of the vegetation season stops later, and combined with an early vegetation period onset (figure 5), it creates a longer vegetation growth period.

3.2.2.2 Geographical gradients

A climate latitudinal gradient is also noticeable for the autumn onset. The years of the latest and the earliest onsets of autumn are chosen to show the gradient. For the region, the latest autumn was in 2006 (298th day) for the last decade, and the earliest for the same period was in 2007 (268th).

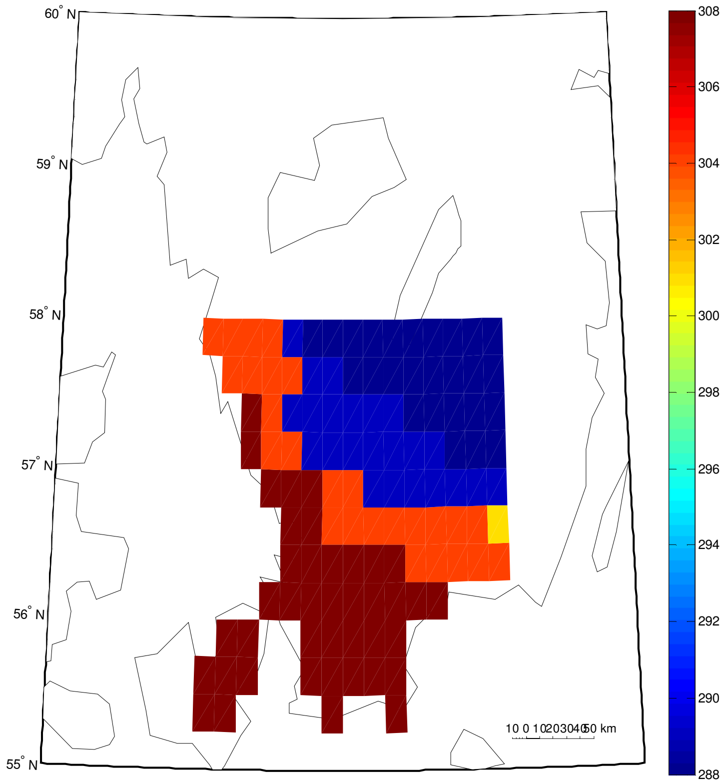

Figure 10. Time for the onset of autumn for the year 2006 (days). 2006 is the year of the latest onset of autumn for 2000-2009.

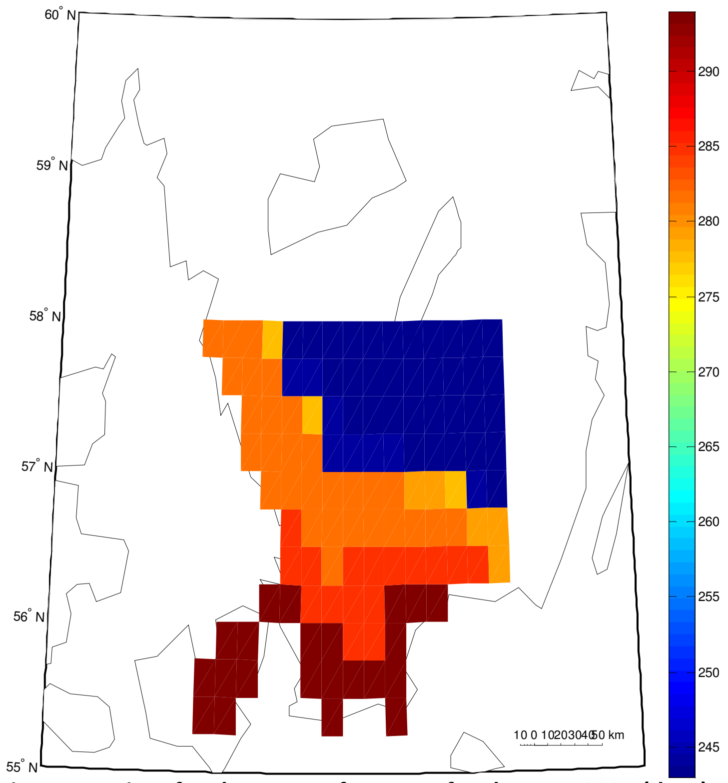

Figure 11. Time for the onset of autumn for the year 2007 (days). 2007 is the year of the earliest *onset of autumn* onset for 2000-2009.

The start of autumn ranges in south Sweden for the last decade between the 245th day and the 308th day. The southern areas record a later onset of autumn than the northernmost parts, and the continental gradient observed in the previous section is also noticeable. Autumn starts earlier in the inlands than on the western coast: for 2007, the coastal records reach the 280th day whereas inlands at the same latitude, on the southern coast of the lake Vättern, the autumn sets on the 245th day.

3.2.2.3 Correlation with the satellite signal for the season's decline (time for the end of the growing season)

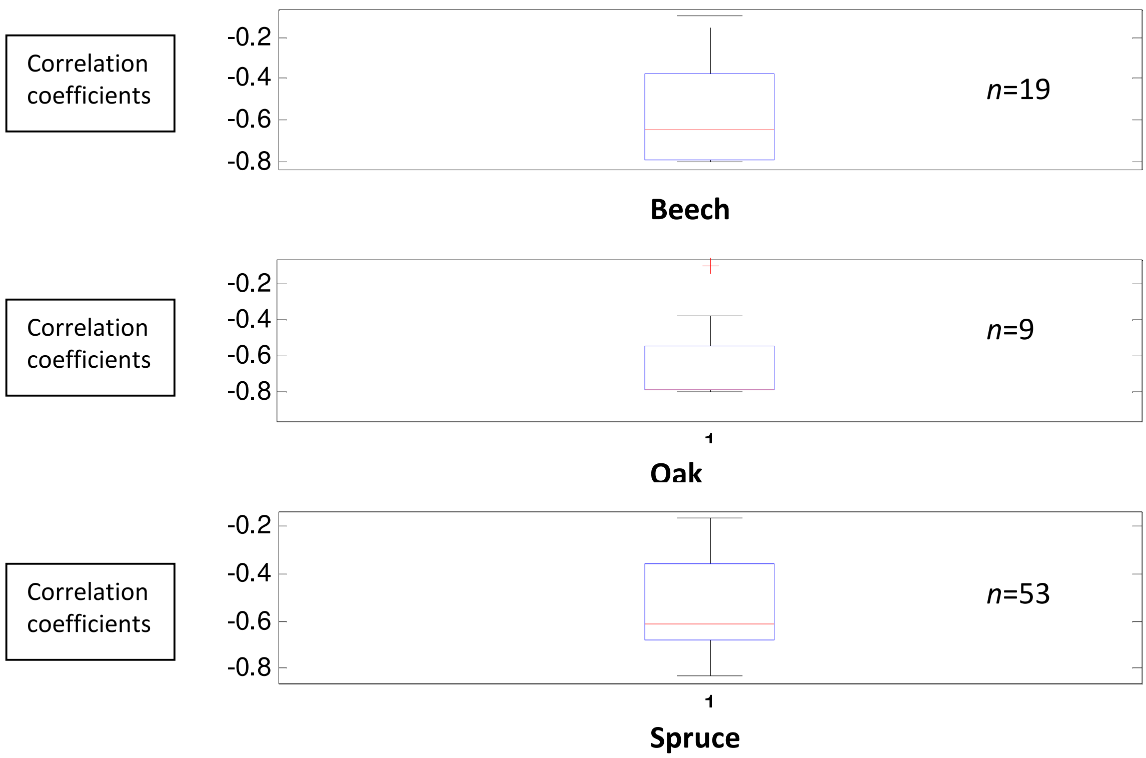

Figure 12. Boxplot: linear correlation coefficients between the climate index onset of autumn and the phenological parameter time for the end of the growing season, for the period 2000-2009. Correlation coefficients are shown for each monitoring sites (vertically).
Boxplots are showing the variations between sites. *n* is the number of monitoring sites for each species.

The average correlation coefficient between the end of the season for beech and the climate index onset of autumn is –0.60, which is a strong correlation. The average correlation coefficient between the end of the season for oak and the climate index onset of autumn is: -0.65, which is very strong. The average correlation coefficient between the end of the season for spruce and the onset of autumn is: -0.55, which is a high correlation.

The correlations are quite high. Strangely they are negative which means that onset of autumn and the time for the end of the season do not evolve in the same way.
When autumn shows small values (expressed in days), the end of the season shows large NDVI values.

3.2.3 Spring cold waves over the last decade

The “spring coldness” is defined here by anomalies observed on the period 2000-2009 in comparison with the reference period 1950-2010 (see methods). The years with the largest differences are considered to be the most extreme regarding spring coldness.

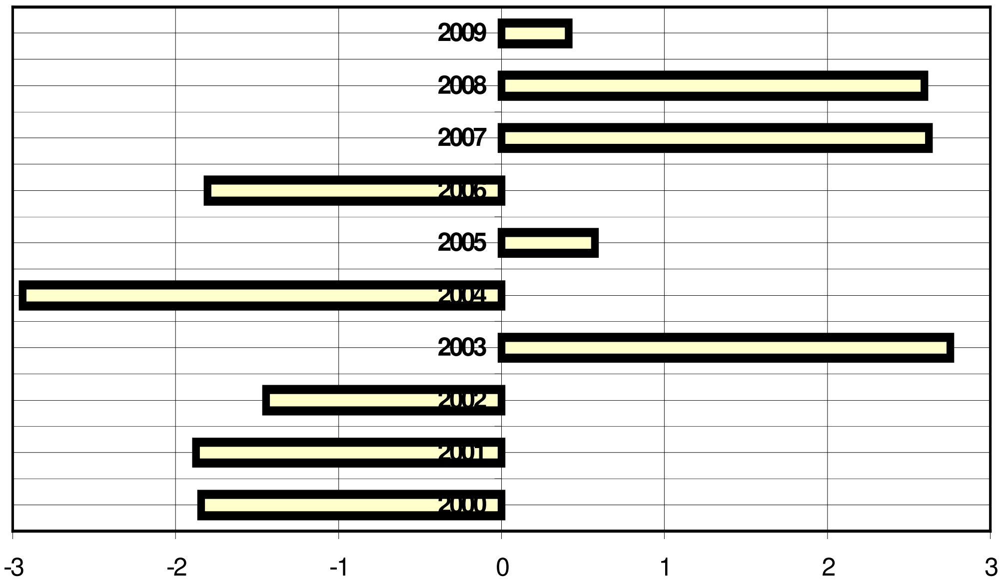

Figure 13. Anomalies for the period 2000-2009 concerning the annual minimum temperature for spring. Anomalies are calculated by doing: (annual value) – (average value 1950-2010), for each year.

The anomalies values concern the years 2000, 2001, 2002, 2004 and 2006. Indeed they are the ones on this period to record an annual minimum temperature for spring lower than the average value for the period 1950-2010. Those years record the lowest minimum spring temperature for the last decade.

Table 1. Minimum temperature recorded in spring (March, April, May) for each year of the last decade, in degrees Celsius. E-Obs data.

Years	Spring min temperature
2000	5.21
2001	5.18
2002	5.61
2003	9.81
2004	4.12
2005	7.63
2006	5.25
2007	9.68
2008	9.65
2009	7.47

The spring minimum temperatures are given in table 1. Year 2004 has recorded the coldest spring minimum temperature with 4.12°C. Then follow years 2001, 2000, 2006 and 2002 (table 1) for the most extremes records.

These coldest springs have to be related to the vegetation measures (satellite data) in order to study if a cold wave implies a response from the trees, especially different ‘behaviours’ from the three tree species. The vegetation period starts at spring so cold wave in spring could affect largely the phenological parameters.

3.2.4 Drought years

The “dryness” is defined here by anomalies observed on the period 2000-2009 in comparison with the reference period 1950-2010 (see methods).

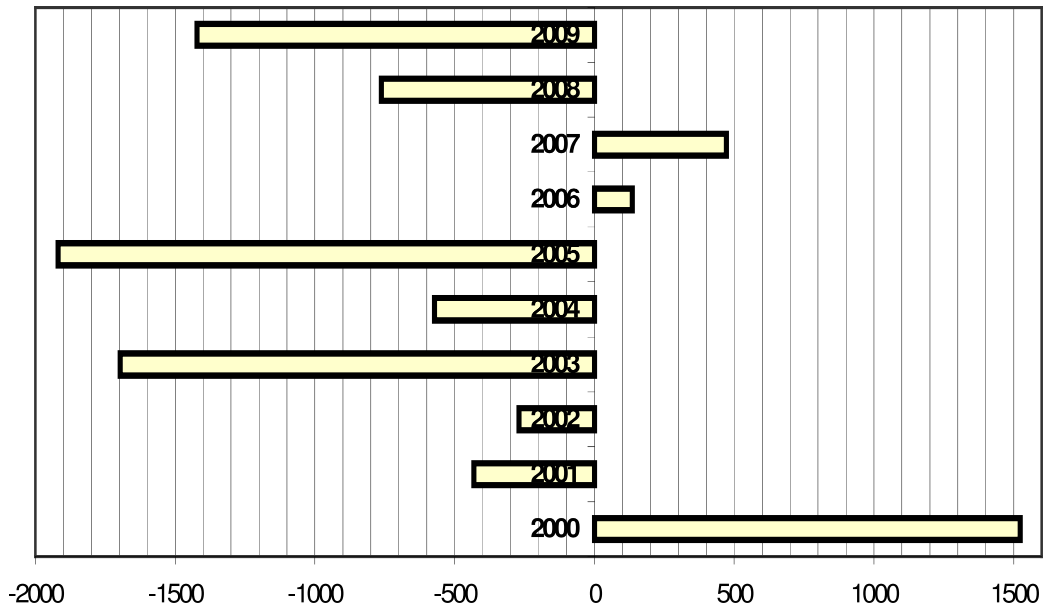

Figure 14. Anomalies for the period 2000-2009 concerning the annual precipitation. Anomalies are calculated by doing: (annual value) – (average value 1950-2010), for each year.

Regarding the reduction of annual precipitation affecting records during the last decade (figure 4), it is important to distinguish weak and large anomalies, because 70 % of the records are showing annual precipitation larger than the average amount of precipitation for the reference period. Only 2000, 2006 and 2007 show lower precipitation than this average. The anomalies exceeding the -1000 value are considered. Thus, the years 2003, 2005 and 2009, are highlighted as the driest for the decade. These years will be those to look over regarding relation between climate indices and vegetation analysis.

Table 2. Annual precipitation for each year of the last decade, in millimetres. E-Obs data.

Years	Precipitation
2000	790.91
2001	595.38
2002	611.60
2003	468.89
2004	581.36
2005	446.65
2006	652.12
2007	685.72
2008	562.30
2009	496.37

Year 2005 records the lowest precipitation with 446.6 mm; it is thus the most extreme years, and considered as the driest of the decade. Then follow the years 2003 and 2005 (table 2).

These observations attest that there is a clear change going on during this decade regarding maximum temperature. The ability to cope with more and more regular droughts is supposed to be a main feature of the forest ecosystem adaptability.

3.2.5 Monitored 'Greenness'

3.2.5.1 Start of the season

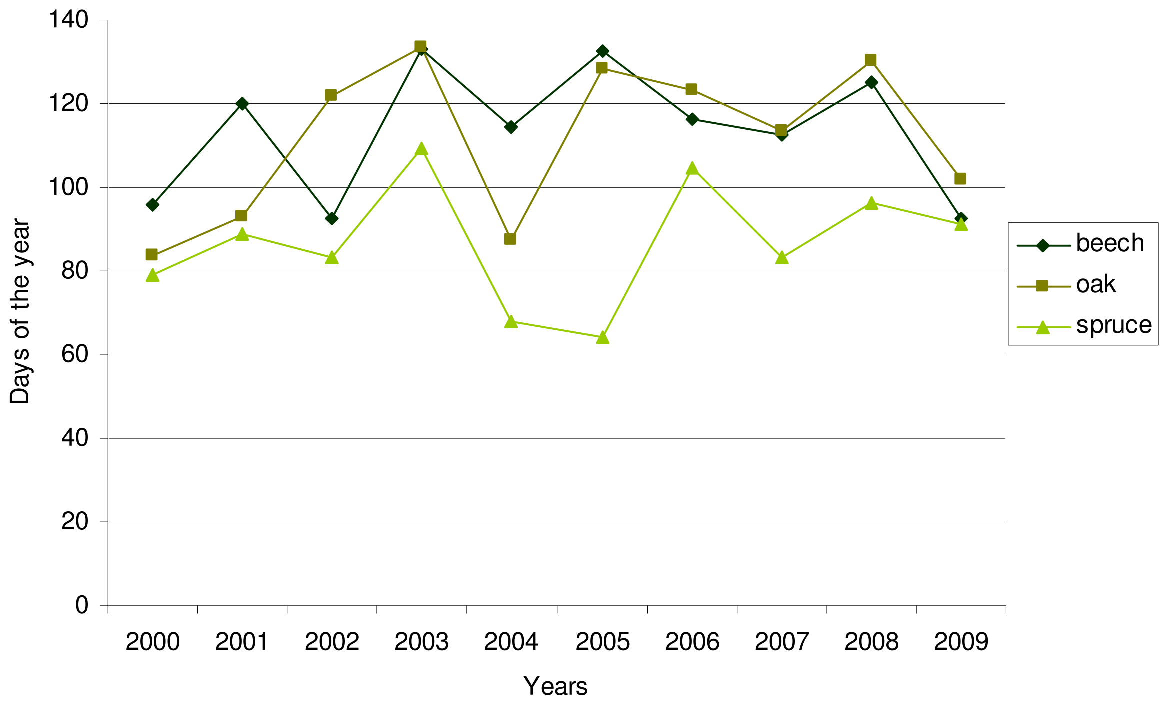

Figure 15. Start of the growth season (MODIS, satellite dataset) using the Savitzky-Golay filtering and a threshold of 60 % ('phenologySG60')

The spruce growth season starts earlier than the growth seasons of the beech and the oak. On the last 10 years, the average for the start of the season was on the 86th day for the spruce, on the 111th day for the oak, and on the 113th day for the beech.

The species growth season follow roughly the same pattern (figure 15), but some observations can be made. In 2002, records for beech and spruce show a drop in the start of the season, whereas the oak season is largely delayed this year (on the 92nd day in 2001, on the 122nd day in 2002).
Earlier onset of growth period is observed for all species for 2003: a drop of -13.9 % for the beech, -34.5 % for the oak, -38.1 % for the spruce, in comparison with the previous year.
Another difference concerns the spruce. The start of the season is then earlier in 2004 than in 2003 for all species, but it continues to be early for the spruce in 2005; meanwhile the beech and the oak season's starting days increase again (132nd day for the beech, 128th day for the oak, 64th for the spruce). This leads to a later onset for spruce in 2006.

One could say that the spruce season onset seems early. Spruce will start to photosynthesize earlier than beech and oak, since it is evergreen. However, a coniferous can appear green for a satellite, even though its vegetation activity has not started yet. The variations in the signal interpretation for spruce is linked with snow cover among other factors. However, budburst is better described by the 90 % threshold.

3.2.5.2 Length of the vegetative season

The MODIS dataset has been run with two fitting combinations (see methods), and large differences can be observed using the threshold of 60 % or 90 %. Here are two figures showing the main differences between the two methods.

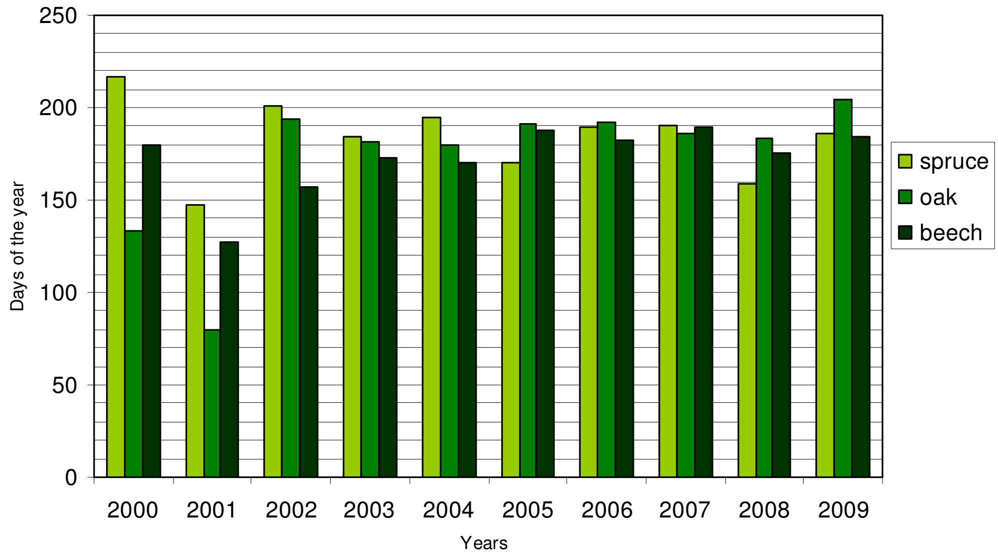

Figure 16. Length of the season (MODIS, satellite dataset) from TIMESAT smothing using the Savitzky-Golay filtering and a threshold of 60 %

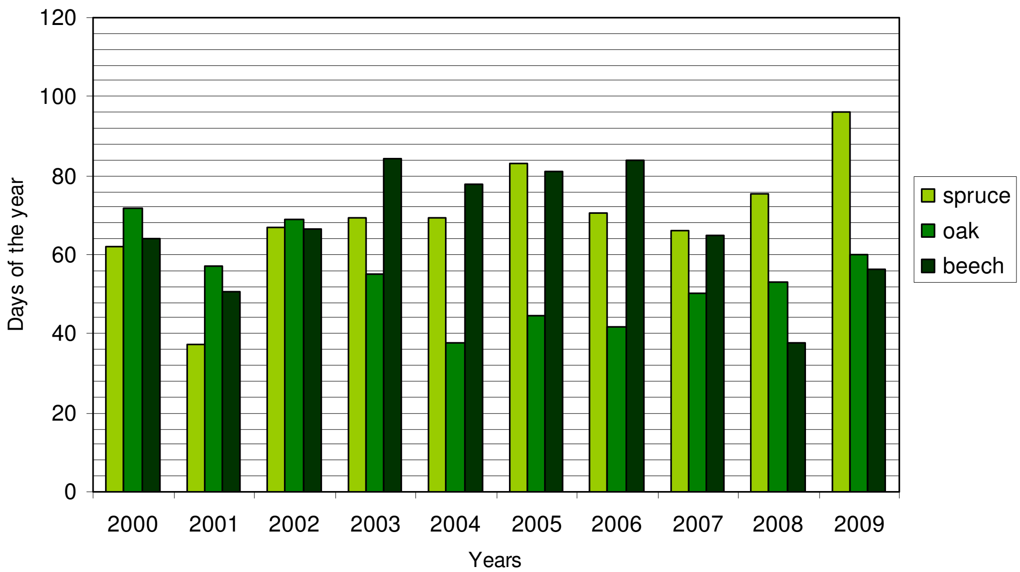

Figure 17. Length of the season (MODIS, satellite dataset) from TIMESAT smothing using the Savitzky-Golay filtering and a threshold of 90 %

Many satellite records over the last decade certify that a season of active vegetation lasts between 150 and 200 days for the three species (average over the ten years for the spruce, the oak and the beech respectively: 183, 172, 172). Nevertheless, there are differences

between the species. In 2000, the season for the spruce lasts over 80 days more than the oak season (figure 16).
Obviously the peak of the growing season is shorter defined by the threshold of 90 % (see methods), but there are also bigger differences between the species. Especially for the years 2003 to 2009, with the first method (figure 16), seasons of all species last the same with only a few days gap, unlike with the second method's results (figure 17). From 2003, gaps between species are enhanced with the 90 % threshold. When the oak has more often the longest season with the first method, it has the shortest one on the half of the period with the second threshold.
Variations observed in the length of the season with a 60 % threshold seem closer to the reality than with a 90 % threshold.

3.3 Variations in extreme events and their relation to monitored greenness

From the climate indices analysis, variations of two types of weather events have been highlighted for the last decade. The previous work regarding extremely low precipitation and extreme minimum spring temperature is used now to try to relate these events with the vegetation phenology observed by satellite.
Thereby extreme events leading to potential disturbances, and phenology parameters reflecting vegetation responses, an interrelationship between abiotic and biotic components of forest ecosystems in south Sweden could be attested (see discussion).

With the different thresholds for the satellite data smoothing, only the Savitzky-Golay filtering with the threshold of 60 % was kept to further on execute the following work.
All relations have been calculated for the three tree species. A distinction between the species is the most interesting for the study regarding the aim of defining different responses to disturbances.

3.3.1 The influence of spring temperature on the vegetation

3.3.1.1 Variations for the time for the growing season's start

The years with extreme spring cold, highlighted in the previous section, show a start of the season occurring later than the year without spring coldness (figure 18). Differences between species are clear. The spruce shows almost no variations between cold spring and regular spring.

The spruce season's onset does not seem to be delayed by a late cold wave. More extreme values are observed for the years without a cold spring: the season's onset ranges between the 80th and the 160th day for the years without coldness, whereas it ranges between the 80th and the 140th day (approximately) during the coldest years.
The oak shows large variations. The oak season's onset is delayed in cold years. The season's onset for oak ranges between the 100th and the 160th day for years without cold spring. Whenever there is lower temperature at that time, the season's onset ranges between the 120th and the 190th day (approximately).
The beech shows less variation: the season onset's is delayed during cold springs, but is less pronounced than for the oak. However, the maximum value for the beech season's onset is

largely delayed during cold years: the maximum value almost reaches the 180th day, whereas it is only on the 140th day during normal years.

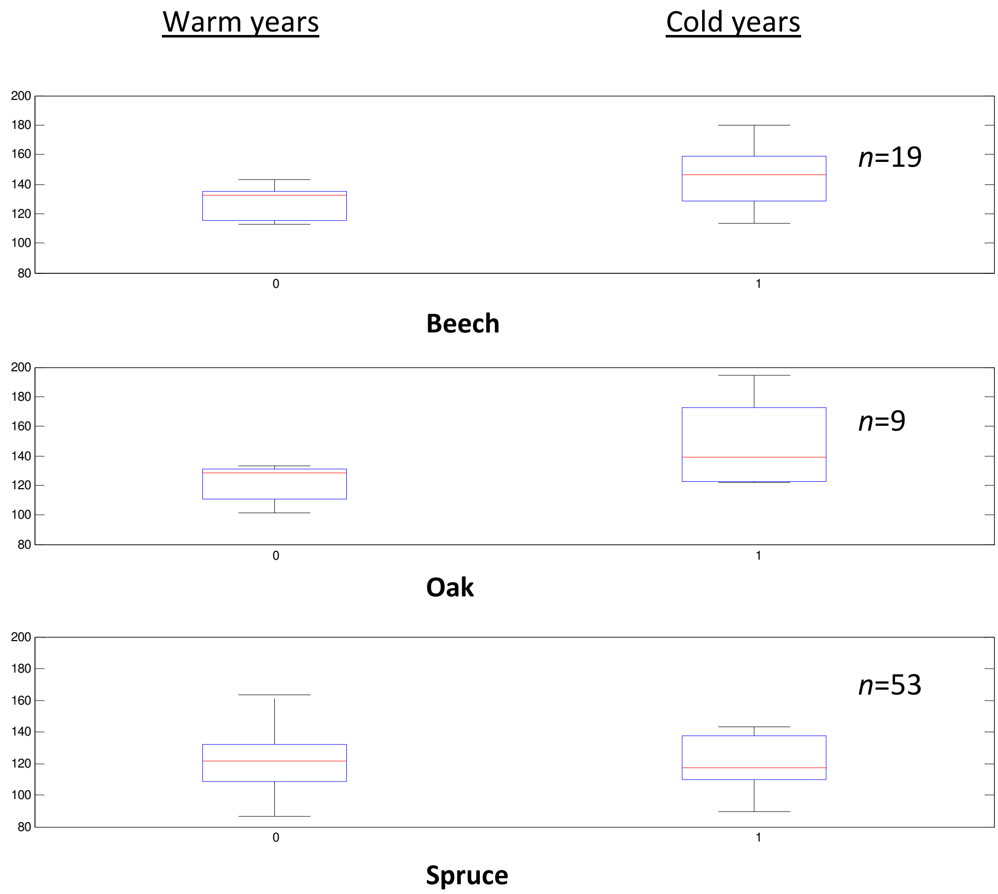

Figure 18. Boxplots : variations of the time for the start of the season (parameter 1) according the spring temperature. *n* is the number of monitoring sites for each species.
Days for the start of the season are shown vertically. 0 indicates warm springs and 1 indicates cold springs, in relation with the anomalies from the reference period average.

3.3.1.2 Variations in length of the growing season

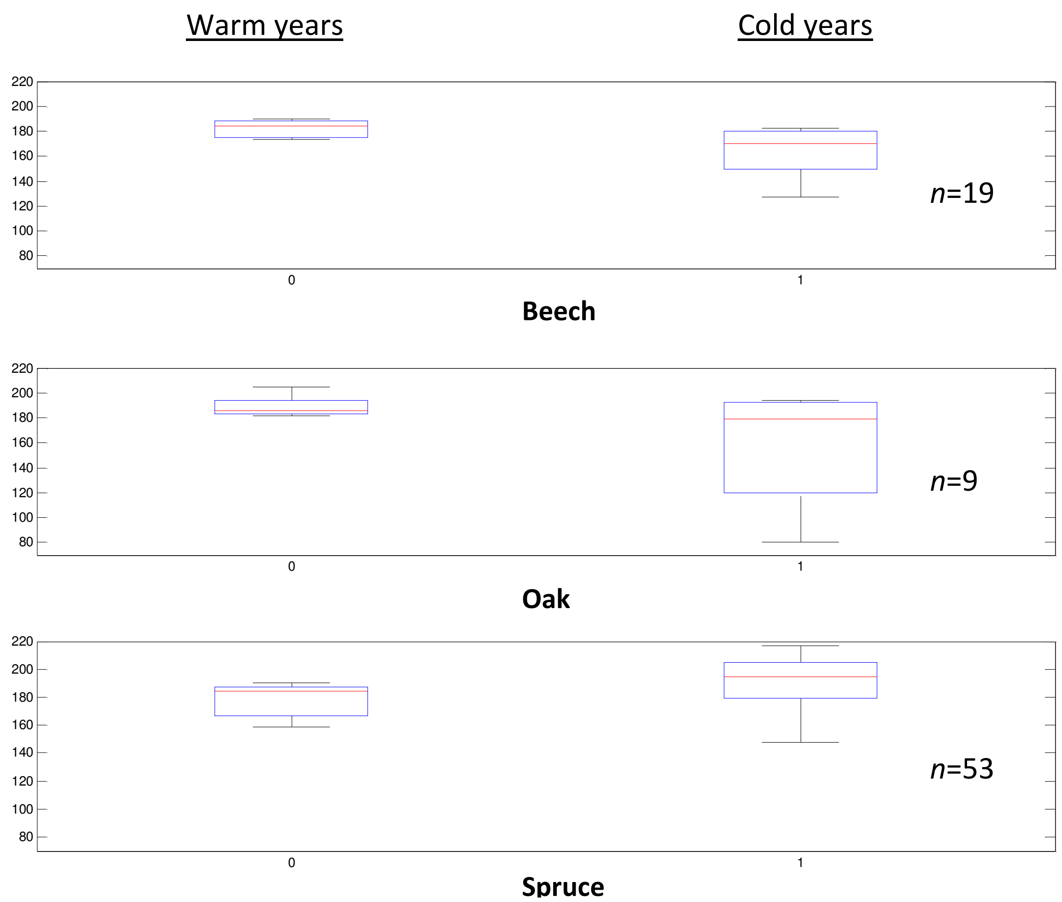

Figure 19. Boxplots: variations of the length of the season (parameter 3) according the spring temperature. *n* is the number of monitoring sites for each species.
Days for the length of the season are shown vertically. 0 indicates warm spring and 1 indicates cold springs in relation with the anomalies from the reference period average.

The length of the vegetation period varies between cold and normal springs. There is no significant change in time, but the ranges are affected. Values' ranges i.e the variations between sites are quite small for all species during normal years, about 40 days of interval between the records for a same species.

But for the coldest years, variations between sites are larger. The oak sites show the largest variation. The length of the season ranges between 175 and 200 days (approximately) on normal years. In cold years, it records a length ranging between 80 and 190 days.

One could assume that the individual scale i.e the monitoring sites scale is to take into account for the analysis of a late cold's impacts on species. Indeed, monitoring sites record lots of different values when the extreme spring cold occurs.

3.3.2 The influence of precipitation on the vegetation

3.3.2.1 Variations in time for the end of the growing season

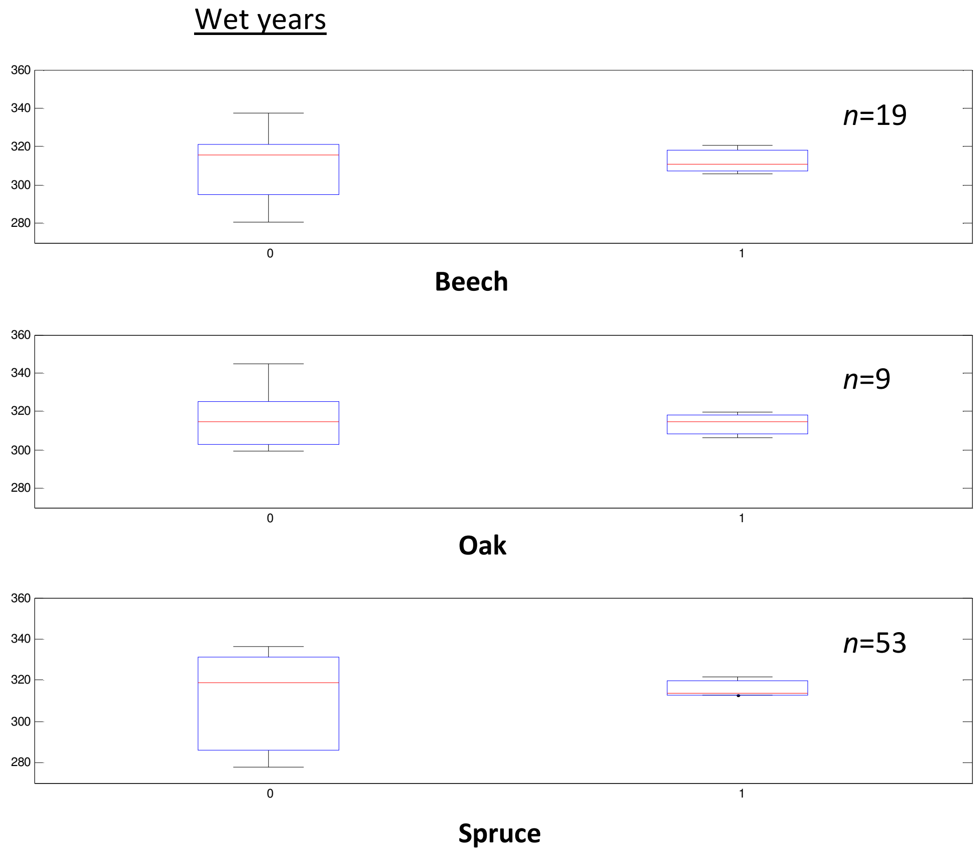

Figure 20. Boxplots : variations of the time for the end of the season (parameter 2) according annual precipitation. *n* is the number of monitoring sites for each species.
Days for the end of the season are shown vertically. 0 indicates wet years and 1 indicates dry years in relation with the anomalies from the reference period average.

The end of the season has been chosen to relate to precipitation because one could assume that the most impactful dryness occurs in summer, when the water availability (air and soils) is usually the lowest due to high evaporation. Impact on the vegetation should then be seen after summer, for the decline of the seasons.

Dryness seems to influence the end of the season for all species. When no dryness is recorded, the end of the season is spread in time: ranges are large. This is possibly due to the latitudinal gradient climate influenced. For example, spruce sites being all over the studied area, some sites in the south can record late decline, whereas in the north others would record earliest decline, and thereby shows a large range.
For the years recording dryness, the ranges for the end of the season are all largely reduced, for all species. Moreover, the 3 species adopt basically the same pattern. Approximately, the end of the season ranges between the 310th and the 325th day for the 3 species.

All sites record roughly the same time for a declining season when there is dryness. It would be assumed that dryness is of the same intensity all over the area, regardless the latitude.

3.3.2.2 Variations in length of the growing season

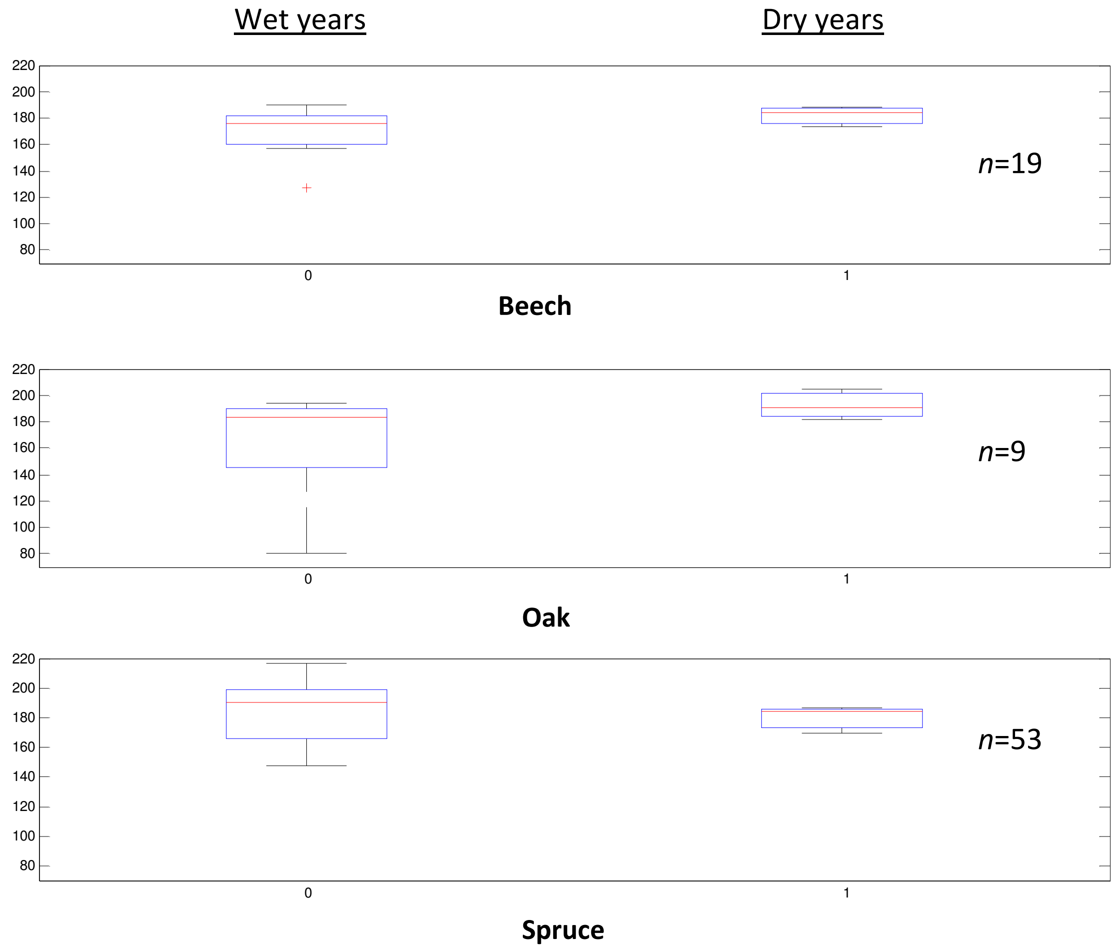

Figure 21. . Boxplots : variations of the length of the season (parameter 3) according annual precipitation. *n* is the number of monitoring sites for each species.
Days for the length of the season are shown vertically. 0 indicates wet years and 1 indicates dry years in relation with the anomalies from the reference period average.

Ranges in the length of the season are affected by dryness for all species records. Ranges are larger for normal years than for the driest years.
The beech shows the smallest range for the length on regular years, but is considerably reduced during dry years. The beech season lengths approximately between 170 and 190 days during years with extreme low precipitation, whereas it lengths between 150 and 185 days during wet years.

Half of values recorded by oak and beech are (substantially) higher during dry years. The spruce has lower value than the half of the values recorded in normal years. Spruce shows smaller season in driest years, even though variations are small, while it is the contrary for beech and oak.

4 DISCUSSION

4.1 Climate and species-specific tolerance

4.1.1 Species optimal climatic conditions

Optimal climate conditions are not the same for all species. Distinctions between tree species, physiological or biological, correspond to a particular environment. This environment is controlled by the climate (local climatic conditions). According to climatic parameters, tree species assimilate differently their needs. Annual net assimilation of trees (for tree growth) depends on "species-specific functions describing the effects of the seasonal temperature and drought regimes" (Prenctice et al. 1991). There is then a species-specific drought regime tolerance that could explain the different reactions of the vegetation progression observed during the driest years (figures 20 and 21). The length of a spruce season is relatively shorter than the other species' length because a smaller tolerance to dryness is assumed for this species.

Species respond differently to climate parameters, and the response can be seen through net assimilation: spruce has a response of net assimilation to daily temperature (parabolic) with temperature compensation points of -4°C to 36°C; whereas they are of -4°C to 42°C for other species (Prenctice et al. 1991).
Development of one species is then linked to climatic conditions and seasonality that fit the trees physiology. A certain margin is adapted for all species that allows trees from a same species to develop in conditions that are not perfectly fitting with their needs: it is the range within the maximum and the minimum limits.

This margin is different for all species. The capacity for a species to regenerate after a disturbance is included in the tree ability linked to climate parameters. Beech cannot regenerate if warmest-month temperature is below 16.5°C; the limit for the spruce concerns the coldest-month temperature (above -1.5°C, it cannot regenerate) (Prenctice et al. 1991). From this capacity limits, species develop according climatic limits. Spruce expansion goes northerly in Sweden than the two other species because it tolerates colder winter temperature. My results showed that the spruce season's onset is not delayed during extreme cold in spring. The coldest spring recorded a minimum temperature of 4.12°C: it is largely above the cold limit for growth and regeneration concerning spruce.

4.1.2 Trees vitality role for biodiversity

Trees are the support of numerous other species such as insects, birds, lichens etc. Interactions between all species are really important and show ecosystems health. A loss of a tree species would then lead to an overall biodiversity loss (Dale et al. 2001). In terms of ecosystem functioning, biodiversity is needed and therefore, we need to be careful with regeneration of major species that are the support for many others.

Health of trees is decisive for the existence of other species, such as epiphytes. The study of epiphytes is a good example that shows interactions between species, and interdependence that can be created between two species. For example, beeches are qualified as good hosts for epiphytes (e.g. lichens), and the decreasing vitality of the trees is a factor that favours their development. Thereby, interactions between species are a key element for an ecosystem biodiversity. Tree vitality defined as "the capacity of an organism to assimilate carbon, to resist stress, to adapt to changing environmental conditions and to reproduce" (Brang translated in Dobbertin, 2005) is then a factor of species dependant richness.

Also, some combinations of trees are good for each other, revealing that diversity in an ecosystem is favourable. Tree growth is influenced by the diversity of the stand it is located in. Some studies proved that spruce growth is more intensive in a stand where there is deciduous species (Baier et al. 2002). Beeches and oaks would therefore theoretically support spruce's development in southern Sweden, even though a mixture between spruce and aspen or birches is more common in southern Sweden.
Tree species diversity in a forest ecosystem being good for biodiversity, forest managers would therefore promote trees species richness in order to increase the potentiality of growth.

4.2 Stress and disturbances

4.2.1 Stressful event or disturbance?

In a large definition, a disturbance could be qualified as "any event that destroys biomass and thus frees up space for colonization" (Lavorel et al. 1997). Thus disturbances can permit the rejuvenation of certain areas, or can destruct biodiversity allowing only one species to survive in certain conditions.

A stressful event creates a high risk for the species life but that is possible to avoid at the single level, i.e an individual tree can survive to a stress while others are hardly impacted. At the contrary, a disturbance is lethal by definition at the single tree level. The main distinction is made in the scale at which the process occurs. A disturbance could be qualified of "catastrophic" if all individuals over a large space (stands, ecosystems) are killed (Caplat et al. 2008).

The results I obtained from climate data have defined extreme climate events in relation to the average of the reference period (1950-2010). Regarding those definitions, "stressful events" seems to be a better term than "disturbance" for the weather events discussed here. The weather events studied here can be considered as stressful for the vegetation. They could then be included in a disturbance regime if their intensity and frequency are high enough, and if the vegetation cannot defend according to their vitality. It depends also on the species targeted by the specific disturbance.

4.2.2 Disturbance system can include stressful weather events

A disturbance is included in a system. That implies lots of interactions between the components; in a disturbance system, a weather event provoking stress is combined with other factors (e.g resource availability reduction) to kill many individuals and have a large impact at the ecosystem scale.

A stressful climate event like a drought affects the growth of trees, but do not automatically destruct biomass. Destruction of biomass by tree mortality is often induced by combined stress factors. The drought of 2003 in Western and Central Europe, occured along heat waves. The summer was the warmest since 1500 (Rouault et al. 2006). Lack of precipitation and heat are two weater events that, combined, can be largely lethal for trees. For example, after 2003 reduction in growth (stem diameter growth) for beeches and spruces has been observed (Dobbertin, 2005), and the stress has been provoked by a reduction of water supply. Moreover, the heat wave and drought occuring that year weakened considerably tree defence capacity against insects. Water stress induced by these extreme events led to physiological changes for trees (Rouault et al. 2006).

The combining of factors is really important in a disturbance system and that is why our definition of “annual dryness” (see 2.2.3) cannot match with the actual stressful drought. Annual dryness is not relevant enough for a deeper analysis: other elements would have been needed to represent a system (e.g. soil water content would have represented the resource availability).

If a stress has large impacts on the vegetation, and if trees cannot overcome the hard conditions created by an extreme climate event, it is likely that combined with other factors such as water availability or soils conditions for example, this stress becomes a disturbance and kill individuals (figure 22). There is a limit defining the ability of a species to defend against one stress, like a “point of no return” in the process where no defence is possible (Kullman, 1997).

A tree response to defend against a particular stress could imply afterwards a disturbance. Indeed, the first stress factor can lower the overall defence capacity and then increase the tree sensitivity to other stresses that could occur, leading then to death and disturbance (Kullman, 1997).

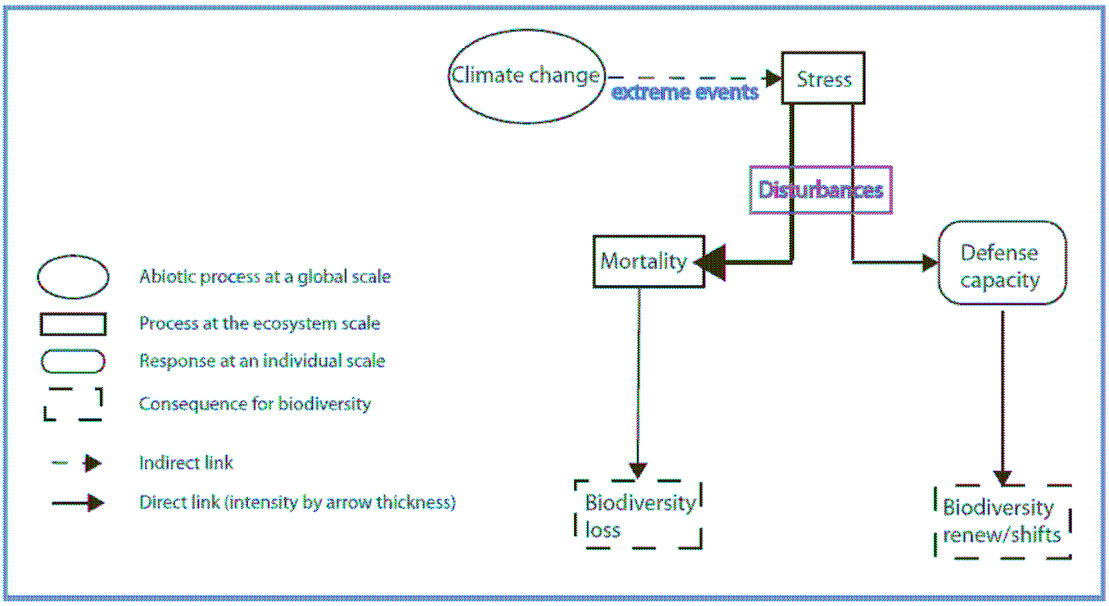

Figure 22. Global processes of the action of disturbances on biodiversity

4.2.3 Combining effects create disturbances

Tree vitality determines the trees responses to a stress. Even though disturbances kill trees at the individual level, it is a major factor of regeneration for the ecosystem scale and so is the main actor of the successional dynamics of species.
Combined effects of weather events and trees responses depending on tree vitality would affect a disturbance regime. The outcomes of a disturbance in a forest ecosystem depend on which species is targeted by the disturbance regime, and how plants life traits could respond (Caplat et al. 2008).

Combined extreme weather events do not allow the vegetation targeted by disturbances to adapt and respond to the system. Usually, disturbances are “cascading”: a drought weakens individuals and creates good conditions for insects to develop; insect infestation will increase dead wood and then increase fire risks; increasing fire occurrence will increase landslides risk (Dale, 2001). According to my results, dryness in southern Sweden affects mostly spruce (figures 20 and 21). If we relate tree vitality and length of the season observed (satellite data), and if we assume that “annual dryness” is a good indicator for drought, it is likely than drought in south Sweden induces less regeneration for spruce. Length and onset of growth season variations have shown that low annual precipitation could reduce spruce vitality (see results). Weaken spruce is likely to be targeted by increasing insects attacks, especially bark spruce beetles (Larsson, 1989).

Abiotic processes, i.e. weather events, and biotic processes can follow one after each other, and their effects can combine together. A storm might kill some trees and create dead wood that is a source for other species and organisms (like insects, fungi –all sparoxylic species). From individuals’ death, other species are favoured thanks to the disturbance. For example, 20 % of saproxylic species directly dependent on dead wood with bark are red listed in Sweden (Schroeder, 2007). Disturbances represent then a large advantage of disturbance for forest biodiversity notably in Sweden, by killing trees individuals and creating growth conditions for other species.

4.2.4 Responses complexity and disturbances consequences on biodiversity

With a chain of extreme weather events, species that cannot adapt to new conditions will be unable to compete with other species that are adapted. These latter species can for example start a migration and extend their range, thanks to the outcome of a special disturbance (Caplat et al. 2008). The interrelationships between tree vitality and disturbance response is complex. A disturbance system including various disturbances and their effects’ spread, in time creates new conditions for competition and changes in plants life traits.

Some species will benefit from direct or indirect effects of climate change impacting disturbances and plants life traits, other will be disadvantaged. For example, windstorms could affect the tallest trees, but the consequences could be the creation of gaps by the fall of tall trees and thereby lead to smaller trees death. Space would be then freed and regeneration phase, or understory vegetation development could start (Caplat et al. 2008). Spaces freed up by a disturbance are like a new ground for the most competitive species to develop in the new conditions implied originally by climate change. Yet, a disturbance could also destruct some species units that are already dominant and then allow other species to develop, which would be an advantage for biodiversity.

Species responses might still match with past disturbances and not directly with recent processes, because vegetation responses might be on a longer-term period than climate effects. Progressive responses over time are aiming to reach more optimal conditions. But this is only possible if climate is stable enough to establish a kind of equilibrium (Kullman, 1997). Changes in species physiology aiming to adapt to a change in environmental conditions are not occurring with the same time scale as these environmental changes (specifically climate change).

4.3 Climate change impact on biodiversity

4.3.1 Climate control on vegetation life processes

Global climate induces local climatic conditions to which vegetation can adapt according to physiological behaviours of species. Indeed, environmental conditions determine resource availability (micro climate, water balance, phenology), which in turn influences physiological response (assimilation, respiration, nutrient uptake) and then act on biomass change (growth, allocation, senescence) (Rötzer et al. 2005). Tree species with different optimal conditions can coexist.
Beeches, oaks and spruces co exist in southern Sweden, and thereby must compete. A species extends within its two limits zone determined largely by the climate, through different mechanisms: dispersal, competition, disturbance; the “combined effects” of disturbances, biotic interactions and climate change act largely on species range shift (Caplat et al. 2008).

However, management practices are really important to allow co existence notably between spruce and the other species. Spruce forest largely present in the south of the country would be reduced without the management actions. A current debate concerns the relation between climate projections and the species kind that should be planted.

4.3.2 Climate change projections for southern Sweden

The south of Sweden being located in the very north of the temperate zone and close to the boreal vegetation zone is therefore very sensitive to a climate change, since climate has a large influence on vegetation dynamics.

From the IPCC reports, different degrees and different scenarios for global change are assumed. SMHI have produced scenario projections for the south of Sweden.
The different reports predict a warming in Sweden: the annual mean temperature would increase between 2.5 and 4.5 °C by 2071-2100 in comparison with 1961-1990 (Persson et al. 2007). This projection matches with the trend presented in the results (figure 4).
Temperature change would be higher during the winter, because of the snow cover reduction. Stressful weather events given by climatic extremes are affected by these changes. The coldest days in winter are the most affected by this change: the minimum

temperature in winter would rise. In the south of Sweden during summer, warm days are projected to show a larger change than for colder days. With these projections, spruce regeneration would be weakened, beech regeneration would be enhanced, and oak expansion would be favoured (Prenctice et al. 1991).

Extreme weather measurements expected to be affected, stressful events related to temperature (e.g. drought or heat waves), would know some shifts in their occurrence and intensity on the period until 2100. The rising winter minimum temperature for south Sweden would be likely to reduce hard cold waves. In spring (March, April, May) the temperature rise for south Sweden would already reach over 5°C, which means warm enough for the vegetation to start an active phase. If cold waves are decreasing in winter, they are also reducing in spring. Thereby, better conditions would be set for growth periods. Scenarios project an increased length of vegetation period of 1-2 months and up to 3 months for southern Sweden (Persson et al. 2007).

The annual mean precipitation would increase with about 10-20 % until 2100. The highest increase would occur in winter (different intensity according the scenarios). However during the summer, southern Sweden is expected to have less precipitation for the century than today. Droughts are supposed to be the worst in summer (Persson, 2007). The climate seasonality influences largely the distribution of species and their own phenology. The season the most affected by climate change would be an important factor to define which species will suffer the most according to its related-seasonality-specific-needs. Our definition of dryness being annual, the most important impacts could not be evaluated. Summer dryness would have been more relevant to analyse extreme peaks of dryness and their consequences on trees.

If precipitation decreases in summer in the south of Sweden, dryness frequency would increase largely and droughts would follow one another. Less precipitation during summer means a lack of water during the warmest period of the year, which would be warmer than today. Water availability depends on precipitation during summer, but also on the previous period. Water storage in soils could also be large due to increased precipitation during the rest of the year, so a projected drought is hard to establish.

4.3.3 Changing seasons and competition adaptation

In this study, a delay of autumn was observed (see results). It means that the drop of the temperature occurs later in the year. Autumn is related to the end of the vegetation cycle, and returning to a dormancy phase (winter). If this special phase is delayed because of the rising length of a warm temperature period over the years, trees could develop a longer active vegetation period and physiological shifts could be observed.

Oak has a great expansion rate with warmer summers and longer growing season, while beech needs warmer summers and winters (Prenctice et al. 1991). A rising length of warm period as showed in my results (figures 5 and 9), is favouring the expansion of oak and beech. At the opposite, spruce would contract with warmer winters (Prenctice et al. 1991).

Also, a warmer summer could imply the oak's expansion, as well as the beeches´ if the winter is not tough. It could also induce the reduction of spruce in southern Sweden, pushing its optimal conditions limits towards the north, with a warmer winter (Prenctice et al. 1991)

Reduced spruce vitality linked to a warmer climate is affecting its competition range.
A warmer climate would induce less regeneration capacity for spruce that suffer a disturbance generated by bark beetle taking advantage from their low vitality.

4.3.4 The warming trend in Sweden would affect forest composition

Changes in mean and extreme climate parameters would have a large impact on the specific vegetation such as the three species I focused on in this study. I have observed records of annual precipitation (figure 4) and the lowest records were observed for the last decade (2000-2009). This observation could match with the decreasing summer precipitation trend projected by IPCC (Persson et al.2007).

I obtained that the species growth seasons occurred later in the year after 2003. 2003 was the year of the worst drought of the decade in large parts of Europe (Rebetz et al. 2006) and appeared also in our results (468.9 mm in a year, third lowest for the reference period after the amounts for 1956 and 2005; figure 14, table 2). This kind of drought provokes a large stress to the ecosystem and induces a change in trees phenology: spruce, oak and beech record an earlier active season the next year (figure 15).
More summer dryness would inevitably weaken specific species that have high water requirement. Spruce has been highlighted as weaken by dryness, and beech substantially favoured (figures 20 and 21). Indeed, spruce has been described as very susceptible to insects during dry summers. Extreme conditions and water stress led to massive damage of spruce bark beetle on trees because this species was dramatically weakened by weather extremes (Rouault et al, 2006).

5. Conclusions

I analysed annual weather for the last decade in terms of precipitation and spring temperature. Some years were highlighted as extreme and related to vegetation progression observed through satellite data. I used the start, the end and the length of the growing season for beech, oak and spruce . Differences of vegetation progression between the species were observed. However, distinctions between coniferous (spruce) and deciduous (oak, beech) behaviours were not really outlined.

Annual definition of weather events as I used in this study were not specific enough in order to fully understand the vegetation response. The seasonality range of vegetation –especially of beech, oak and spruce- must match with the seasonality range of the weather events, so an evaluation could be done on the same time range level. Here the vegetation phenology studied concerned the active season, so approximately on a time range of 200 days.
Weather events were analysed annually. That time level does not really fit the reality because stressful weather events can impact trees on small time scales and other processes can occur during the rest of the year. A drought has large harmful impacts on vegetation

during summer when the water availability is reduced. Trees can be affected by a summer drought even if there is high precipitation for the rest of the year. Responses to these stresses will determine the occurrence of disturbance.

However, some patterns have been pointed out. The years defined as extreme in terms of low precipitation or minimum spring temperature were recording variations in the time for the start and the end of the season, as well as for the length of the season.
It seems that spruce was the most negatively affected by low precipitation, whereas it was not influenced by cold springs. Oak was particularly affected by cold springs, with a later start and a shorter growing season. Beech was also affected.

In the perspective of a global climate change, these results have been considered relevant. Climate change will change the intensity of vegetation stressful events related to climate and their frequency. Trends towards warming were shown in this study. The growth period is becoming longer because the vegetation period starts earlier and ends later due to a longer warm period. Southern Sweden is affected by these changes and its proximity to boreal zone makes it really interesting to observe.

Spruce being the most negatively impacted of the three studied species by global warming, it is likely that its distribution would be pushed towards northern regions. Already, forest managers in south Sweden think about sustainability of forest ecosystem, and problems with planting spruce are discussed. Species dependent to this coniferous like lichens and birds are also likely to be pushed northwards. Deciduous species will take the lead in southern Sweden and with them another ecosystem will develop.

It is difficult to evaluate what kind of disturbances will be the most affected by climate change because many factors are to take into account in a disturbance regime analysis. The time range of trees adaptability to changing climate conditions, and the time range of the actual change in the intensity of weather events are not the same. Therefore, trees should be more affected and disturbances should become more intense and more frequent. Regeneration of species will depend on the species-specific adaptability and on the nature of stressful events.

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