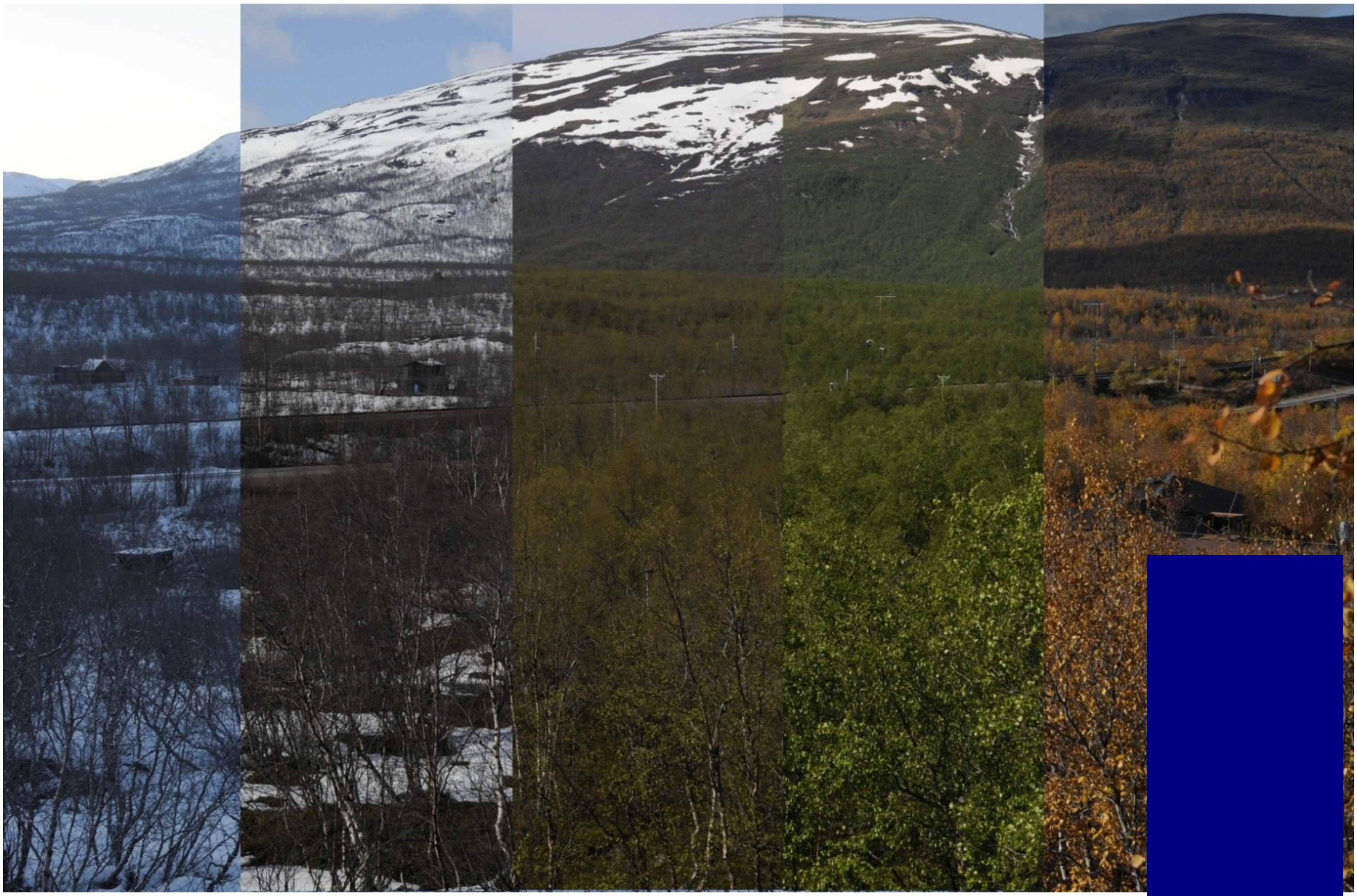
Student thesis series INES nr 250

DEFINING PHENOLOGY EVENTS WITH DIGITAL REPEAT PHOTOGRAPHY



Johannes T Jonsson

2012

Department of

Physical Geography and Ecosystems Science

Lund University

Sölvegatan 12

S-223 62 Lund

Johannes T Jonsson (2012)
Defining phenology events with digital repeat photography.
Bachelor degree thesis, Seminar series 250, 15 credits in physical Geography and Ecosystem Analysis

Department of Physical Geography and Ecosystems Science, Lund University.

Defining phenology events with digital repeat photography.

Johannes Jonsson

Bachelor degree thesis in Physical Geography and Ecosystem Analysis

Supervisor: Lars Eklundh

Department of Physical Geography and Ecosystem Analysis

Lund University

2012

ABSTRACT

Phenology is the study of the timing of natural events such as leaf-out, bud burst and senescence relative to climate change. It is important to understand how the climate change will affect the timing of these events as it in turn affects the carbon-, nutrient- and the hydrological cycles. Field observations is the most common way to gather phenology data but the result is dependent on the skill of the observer and is very time consuming. Remote sensing has under the last decades been used more in phenology studies. However the low spatial and temporal resolution from satellite photos makes it hard to study local phenology. Therefore new methods have emerged to complement this. Digital repeat photography is a method which uses regular digital cameras mounted to capture the same area over a longer time period. The captured red, green and blue color values in the photographs can then be used to calculate the appearance of certain phenology events. This study provides a method how to quantitatively define the start and end of the growing season which can be used to indicate climate change. Phenology phases for four different mountain birch stands including canopy and understory in Abisko, Sweden, were studied using data from 2011. The calculated start of the growing season varied with two days between the different stands and follows the field observed phenology. The calculated color values from the photographs had a peak when all leaves were fully developed. The end of the growing season varied by six days between all birch stands. The senescence period was harder to define than the leaf-out event as it includes both the decrease from the colorization of leaves and when leaves fall to the ground.

Keywords: geography, physical geography, digital repeat photography, phenology, mountain birch

SAMMANFATTNING

Fenologi innebär studier av naturligt återkommande händelser som till exempel bladsprickning, knoppbristning och vissningen av blad. Det är viktigt att förstå hur klimatförändringen påverkar tidpunkten då dessa händelser sker eftersom det i sin tur påverkar kol-, närings- och den hydrologiska cykeln. Fältobservationer har varit den mest använda metoden för att samla in fenologiskdata men resultatet beror på observatörens färdighet och är mycket tidskrävande. Fjärranalys har under det senaste årtiondet blivit mer användbart i fenologistudier. Den låga spatiala och temporala kvaliteten av fjärranalysdata från satelliter har medförit att nya metoder utvecklats för att komplementera detta. Upprepad digital fotografering är en metod som använder vanliga digitalkameror monterade för att fotografera samma område under långa tidsperioder. De registrerade färgvärdena från fotografiernas röda, gröna och blå kanaler kan sedan användas för att definiera fenologiska händelser. Denna studie tillhandahåller en metod för att kvantitativt bestämma start och slut på växtsäsongen som kan användas för att indikera att klimatet förändras. Fenologiska händelser hos fyra olika fjällbjörkstånd samt krontak och björkens undre parti i Abisko, Sverige, har studerats för år 2011. Den beräknade starten av växtsäsongen varierade med två dagar mellan björkbestånden och följer fenologin som observerats i fält. De beräknade färgvärdena nådde sitt maximum när bladen var fullt utvecklade. Slutet på växtsäsongen växlade med sex dagar mellan de olika björkbestånden. Vissningsperioden var svårare att definiera än bladsprickningen då vissningen innehåller två händelser som sänker färgvärdena i bilderna: färgförändring av bladen samt lövfällning

Nyckelord: geografi, naturgeografi, digital repeat photography, fenologi, fjällbjörk

TABLE OF CONTENTS

1. INTRODUCTION

Phenology is the study of periodic events for example leaf-out, senescence, bud burst and fruiting in the life cycle of plants or animals (Cleland et al., 2007). Timing of phenology events is one of the easiest ways to study the species' response to climate change, for example advancing leaf-out dates, which is mainly due to higher spring air temperatures. Field observation has been the most common way to observe the timing of leaf-out and senescence but has its limitations as the result is highly dependent on the skill of the observer, it is hard to cover large areas and is very time consuming (Menzel, 2002). Cannell and Sparks (1986, 2002) have found that the rising temperatures from the recent years have an advancing effect on the leaf-out timing.

Phenology needs to be better simulated when modeling the carbon cycle; current models use growing degree days, leaf area index (LAI) and measured spectral reflectance from satellites to predict phenology for different species. The main problem when using these methods is the low spatial resolution (Ahrends et al., 2009) and the errors produced by models when simulating phenology, especially for deciduous broadleaf forests (Richardson et al., 2012). Phenology is a good way to inform the general public of climate change as it is an easy concept to grasp and has a high response with low temperature changes (Menzel, 2002).

Recent studies (Bares et al., 2009, Bater et al., 2011, Ide and Oguma, 2010, Richardson et al., 2007, Sonnentag et al., 2012, Sakamoto et al., 2011) have proven digital cameras and commercial web-cameras useful when studying phenology. Color indices using only the visible wavelength spectrum has successfully determined variations in phenology for crops, deciduous and evergreen forests. Digital repeat photography is useful to remote sensing as it can be used as ground truth just as field observations have been used. Nationwide networks containing various cameras at different locations have been set up to study phenology over large areas using digital repeat photography. Protocols for studies of different vegetation, involving students in phenology studies and complementation of remote sensing are some of the main goals for the USA national phenology network (Betancourt et al., 2007). Climate models use LAI, soil temperature, soil moisture and growing degree days (GDD) to determine leaf out and senescence dates. As different vegetation types have different limiting factors (soil moisture on tropical trees or soil temperature and available nutrients on high latitude trees) problems occur when trying to apply global schemes when determining phenology stages (Arora and Boer, 2005).

1.2 AIM

The aim of this study is to test a method for quantitatively defining phenology events with digital camera images using a deciduous mountain birch (*Betula pubescens* ssp. *czerepanovii*) forest in Abisko, Sweden as an example. The phenology events are delimited to the start and end of the growing season. The growing season is the phenology period when deciduous trees leave the dormancy period, start to produce leaves and the photosynthesis become active. The end of the growing season is defined to when the leaves fall to the ground. The choice of color indices used for this study was restricted to wavelengths of visible light.

Questions at issue:

- Can digital repeat photography be used to determine start and end of the growing season of mountain birch in sub-arctic regions?
- What are the benefits of using digital repeat photography compared to other phenological methods (remote sensing, field observations and field measured NDVI)?
- How is the possibility of extracting phenology data from digital red, green and blue images affected by the difference in light intensity created from dark clouds, fog and rain?

2. BACKGROUND

2.1 PHENOLOGY

Knowledge of phenology dates back to the royal court in Kyoto Japan 705 AD. In Europe the first study was located in south east of England and was carried out by the Marsham family, starting in 1736. The data includes flowering and leafing dates as well as the first appearance of migratory birds for each year (Sparks and Carey, 1995). Linnaeus also studied phenology and climate in his book *Philosophia botanica* published in 1751 (Menzel, 2002).

It is important to study phenology as the change from the vegetative stage to the active flowering stage and senescence influences the carbon uptake of the plant, the hydrological cycle and the nutrient cycle of deciduous forests (Ahrends et al., 2008). Ecosystem hydrology is affected by leaf emergence as the throughfall decreases and evapotranspiration increases. Autumn senescence affects fresh litter input when leaves fall to the ground. Also the albedo and the texture of the surface are affected (Richardson et al., 2012).

The first appearance of the leaves in spring (Leaf-out) can vary both between species and individuals of the same species. The timing of leaf-out is dependent on warm air temperatures and the time of exposure to sunlight (photoperiod) (Polgar and Primack, 2011). Colorization of deciduous trees occur earlier in response to high spring air temperatures and later if the high temperatures from the summer stay until autumn (Menzel, 2002). During senescence perennial trees allocate nitrogen and phosphorus for storage under the cold winter season. Shading of photosynthetic areas or colorization on the leaves helps to protect the tree from dangerous light levels according to the resorption protection hypothesis (Hoch et al., 2003). Senescence occur when the carbon or water (depending on restricting factor) lost by photosynthesis is larger than that gained from the environment or simply when the demands of the plant in terms of carbon or water cannot be fulfilled (Chapin, 2011). The variation of the timing of the leaf-out event can be explained by 50% of the North Atlantic oscillation in central and northern Europe (Menzel, 2003). Studies have found an advancement of the start of the growing season in the northern hemisphere from 1970 to 1994 (Keeling et al., 1996).

2.2 STUDY AREA

The digital camera used in this study is part of a network of optical sensors for studies of vegetation phenology. The network consist of four sites in Sweden (Abisko, Stordalen, Norunda and Fäjemyr bog) and one in Finland (Hyytiälä). The camera used in this study is situated the roof of a one story building in Abisko (Figure 1) (Latitude 68°35’37.17”, Longitude 18°81’64.97”) 340 m a.s.l.

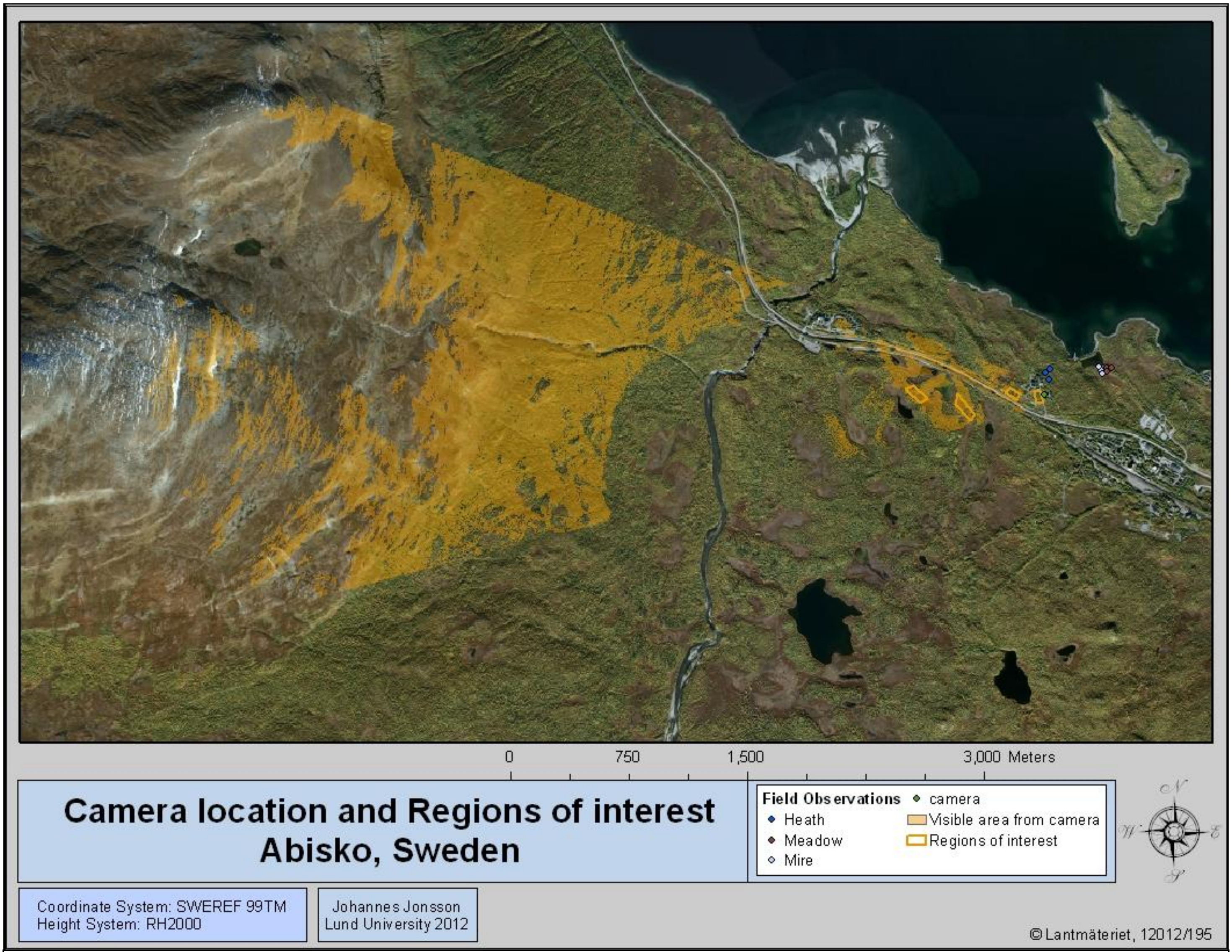


Figure 1 Study area with camera location and visible area in the photography highlighted, field observation locations and regions of Interest selected in the photographs.

2.3 VEGETATION

The vegetation in the study area consists mainly of a sub-arctic birch forest (*Betula pubescens* ssp. *czerepanovii*), has an average tree density of 1300 stems ha^{-1} and an average tree height of 4 m (Eklundh et al., 2011). The ground vegetation beneath the birches holds low nutrient heath, including evergreen shrubs, grasses, forbs, lichens and mosses (Johansson, 2006). Mountain birch has short shoots that expand in early spring with energy gained from the previous growing season. After the short shots have expanded long shoots begin to use the short shoots as a source for their own expansion (Wilsey and Saloniemi, 1999). The growth of mountain birch in high latitudes is mostly limited by nutrients, especially nitrogen. However at the beginning of the growing season the temperature is a more important factor. Mountain birch normally has a fast growth rate in the start of the growing season which is important for the survival in the winter season. Mountain birch seedlings have an annual growth rate of a few millimeters per year; this along with low nutrient environment makes colonization of new areas rare (Karlsson et al., 2005).

Temperature increases as low as 1°C over 40 years have brought forward the leaf-out date for mountain birch with 5.5 days at the Kola Peninsula in Russia. Studies have shown that the timing of colorization and leaf fall of mountain birch occur differently depending on the length of the growing season (Ovaska et al., 2005). Abisko has one of the lowest mean annual precipitation of Scandinavia due to the rain shadow created from the mountain range in the west (Johansson, 2006). During the study year (2011) the precipitation was 388 mm and the mean annual temperature was 1.6°C.

2.4 REMOTE SENSING AND PHENOLOGY

In the past three decades remote sensing using satellite and aerial photographs has been a popular technique when studying phenology events (Vierling et al., 1996, Goetz et al., 1994, Bin et al., 2008, Haralick et al., 1980). Indices that have been used are for example normalized difference vegetation index (NDVI) ((Junming and Wencai, 2011), LAI and enhanced vegetation index (EVI) (Ahl et al., 2006) When studying phenology with satellite remote sensing several problems have to be handled including aerosol and cloud contamination and viewing angle. The high spatial resolution makes it hard to study specific stands of vegetation and the low temporal resolution makes the data series insufficient when studying rapid phenological phases like leaf-out and senescence (Richardson et al., 2007). When studying canopy and ground floor vegetation with satellite NDVI errors may occur as they affect each other seen from above. Snow covered ground underestimates the NDVI giving a lower calculated photosynthesis of the canopy due to the high albedo of the snow (Jönsson et al., 2010).

Digital repeat photography with its high temporal resolution has proven itself successful when monitoring and determining leaf emergence, start of senescence and start of dormancy of tree species (Ahrends et al., 2008, Ahrends et al., 2009). Digital red, green and blue (RGB) cameras generally record values in a 24-bit RGB color map in an uncompressed RAW format. The 24 bit color map gives each color a range between 0-255 and can show up to 2^{24} different colors.

The color black is referred to as zero in all color bands and white as 255 in all color bands. As this format produces very large images the photos are often converted to other formats, for example JPG which uses the same color range as the raw format. Sonnentag et al (2012) tested this conversion and proved it not to affect relevant information when studying phenology. He also tested different cameras and said that the choice of camera does not exclude relevant information to phenology studies using digital repeat photography. Further, Sonnentag concluded that RGB cameras give the best photo-quality around 12.00 on clear skies.

2.5 COLOR INDICES FOR PHENOLOGY STUDIES

As the red, green and blue color channels vary with illumination and viewing angle different indices have been made to enhance the shift in certain colors for different occasions for example leaf-out and senescence (Sonnentag et al., 2012). Some of the indices that have been made in prior studies using the color values from RGB camera images to estimate the appearance of different phonological stages are:

- Green excess index (2G-rbi) which is correlated with the seasonal change in gross primary production and imitates the green values for all forests, except pine stands (Equation 1) (Richardson et al., 2007).

$$2G - rbi = ((R - Green) - (R - Red)) + ((R - Green) - (R - Blue)) \tag{1}$$

Where R-*Color* is color fraction index (Equation 3)

- Green red vegetation index (GRVI) give negative values for the dormant season and positive values during the growing season (Equation 2) (Mizunuma et al., 2011).

$$GRVI = \frac{Green - Red}{Green + Red} \tag{2}$$

- Color fraction (R-Color) indices (R-Green and R-Red), which have been found useful when identifying leaf foliage respectively autumn colorization of leaves as well as reducing illumination effects (Equation 3) (Ahrends et al., 2008).

$$R - Color = (Color)/(Green + Red + Blue) \tag{3}$$

Problems have been found when studying autumn senescence with these indices; neither 2G-rbi nor R-Color follow the rapid decrease in the color bands due to senescence resulting in a later leaf-out date than observed in nature (Richardson et al., 2007). For this study both 2G-rbi and R-Color have been used to reduce the illuminative effects cause by clouds, moisture on leaves and shadows. Mizunuma (2011) found that R-Color indices remove these weather disturbances more efficiently than 2G-rbi but yield varying results in different study areas (Sonnentag et al., 2012). Hue, Saturation and Luminance (HSL) have successfully been used instead of the RGB color range when studying phonological phases. RGB color values can easily be transformed into HSL values (Graham, 2008).

3. METHOD

3.1 DATA

Figure 2: Camera box mounted on roof
Photograph taken by: Hongxiao Jin

The camera used for this study was a Nikon D300s with a 23.6 x 15.8 mm CMOS sensor of 12.3 megapixels. This digital single-lens camera model uses a sensor self-cleaning system reducing the effects of dust (Nikon, 2011). The camera is placed in a protective shell to endure rain, moisture and snow (Figure 2). The photos were taken with aperture priority which means that a specific aperture value is chosen (7.1) giving the same pupil area for all photographs which determines the amount of light received by the sensor. In response to the amount of light collected by the sensor the camera automatically changes the shutter speed (Hasinoff and Kutulakos, 2008). The Image sensor (ISO) value was set to 200 for all photographs. The objective used was a 35mm lens (52 mm analog format) used with the focus set to infinity. The yellow cable seen in Figure 2 is connected to a remote battery that was changed at three occasions (July 1 2011, September 12 2011 and November 11 2011). The photos were stored in a memory card in the camera and exported as JPG data files.
The memory card was changed October 13 2011 and the time for photography capturing was changed minus one hour to wintertime. Three daily photos were captured from the dates September 17 2010 – November 28 2010, April 8 2011 – June 17 2011, July 1 2011 – September 15 2011 and October 12 2011 – November 30 2011. Due to a battery problem that occurred twice in the summer of 2011 some images were missing. Furthermore, the camera was turned off between the dates; November 28 2011 and April 8 2011 during the winter season.

Orthographic photographs (0.5m spatial resolution from 2008) and a laser scanned digital elevation model (DEM) (2m spatial resolution) over Abisko were received from the Swedish land survey (Lantmäteriet). From the DEM visible and non-visible areas seen from the camera position could be calculated (Figure 1). By studying the visible areas and the orthographic photograph in figure 1 the different regions of interest (ROI) could be recognized in the map and an approximated distance from the camera to each ROI could be calculated.

Field observations of phenology events for mountain birch were made in Abisko by field staff at three different mire and meadow sites in the year 2011 (Figure 1). The study areas were visited eleven times between June 10 2011 and October 5 2011. Three specific birches where studied at each of the mires and one specific birch at each meadow. The dates matched each other well on the two sites for all phenological stages; therefore one field observation reference scheme could be made to match the data from this study (Graph 2). The buds where rated from totally shut to leaf base and shaft visible, later in the growing season date for colorization, visible status (holes in leaves) and withering of the leaf was noted.

Solar zenith angels where calculated daily for 12.00 hours at the study location (Equation 4)

$$Cos\theta 2 = sin\delta sin\varphi + cos\varphi cos\omega \qquad 4$$

Where δ is the declination of the sun approximated as a perfect circle (Equation 5), φ is the latitude and ω is the hour angle (the angle the earth must turn to bring the meridian of the location directly under the sun).

$$\delta \ = \ -23.45° cos[360/365 * (n + 10)] \qquad 5$$

Where n is the day of years.

To see if the phenological method used in this study achieves similar results as methods using NDVI, field measured NDVI from a multispectral sensor (SKR-1850a) was used. The multispectral sensor is located in the Abisko a few kilometers from the camera (Latitude 68.36 Longitude 18.80) (Equation 6).

$$\mathrm{NDVI} = \frac{\bar{P}\ \mathrm{NIR} - \bar{P}\mathrm{RED}}{\bar{P}\ \mathrm{NIR} + \bar{P}\mathrm{RED}} \qquad 6$$

Where $\bar{\rho}$ is the average footprint reflectance calculated from the sensor, NIR is the reflectance in the near infrared wavelength spectrum and red is the reflectance in the red wavelength spectrum (Eklundh et al., 2011). Mean daily temperature, snow depth and daily precipitation was received from Abisko research station for comparison with the 2G-rbi values.

3.3 IMAGE ANALYSIS

The image analysis includes three steps; data structuring (using Faststone image viewer 4.3), Color index calculations (Figure A.1) (using Andes IDRISI 15.0) and phenology phase calculations (using Timesat (Eklundh and Jönsson, 2011)). JPG data were used instead of raw data files for convenience as they require less computer space.

The whole photograph sequence was closely studied and one photograph per day was chosen for analysis preferably the one taken around 12:00. If the photograph at noon was too cloudy or when snow or rain had covered the lens the photograph taken at 10:00 (five photographs) or 14:00 (nine photographs) was used depending on which one of the pictures had the least of these effects. Pictures with varying shadows, fog or clouds were not excluded as parts of the picture could be used. There were only four days (October 20 2011, November 7, 16 and 24, 2011) when none of the three photos could be used due to clouds, snow or rain. The photos were exported from the camera with a sequential number depending on what order the photograph was taken. To structure the data the photos were renamed giving each photograph the date and hour of when the photograph was taken followed by a sequential number (001-266).

All the photos could be imported to an imaging program and converted into raster format automatically using a script. The imported rasters were given the same resolution x=4288, y=2848 and a 24-bit color pallet. To be able to calculate the R-Color and the 2G-rbi index the RGB raster files needed to be split into separate red, green and blue raster files. From these three color bands a total RGB file could be created by adding each of the color bands together. The R-Color indices were created by dividing each color band with the total RGB file giving the factor of that color of all the colors in the image (Equation 3). The 2G-rbi index was then calculated with the R-Color values for all images according to Richardson (2007) (Equation 1). As the photographs include different kinds of vegetation, different regions of interest (ROI) need to be made of the areas wanted to be studied. Various polygons were created to exclude possible local growth variations. A vector file was manually digitalized from the photos creating different regions of interest (Figure 3). The different ROI had certain restrictions; the understory ROI should include the lower birch leaves and exclude the ground vegetation and the white birch stems as it might influence the color values of the leaves. Some stems were included due to the fact that the lower leaves were located very close to the stem. The ground vegetation is also included in some parts of the understory regions of interest as it can be seen thru the spaces between the leaves. The birch ROI 3 includes a birch stand on the north side of the main road and the ROI 4 a birch stand on the south side of the main road (Figure 1). All ROI polygons were made smaller than the area of interest making space for the movement of the camera and the vegetation so that it would contain the same area of interest even when the camera moved.

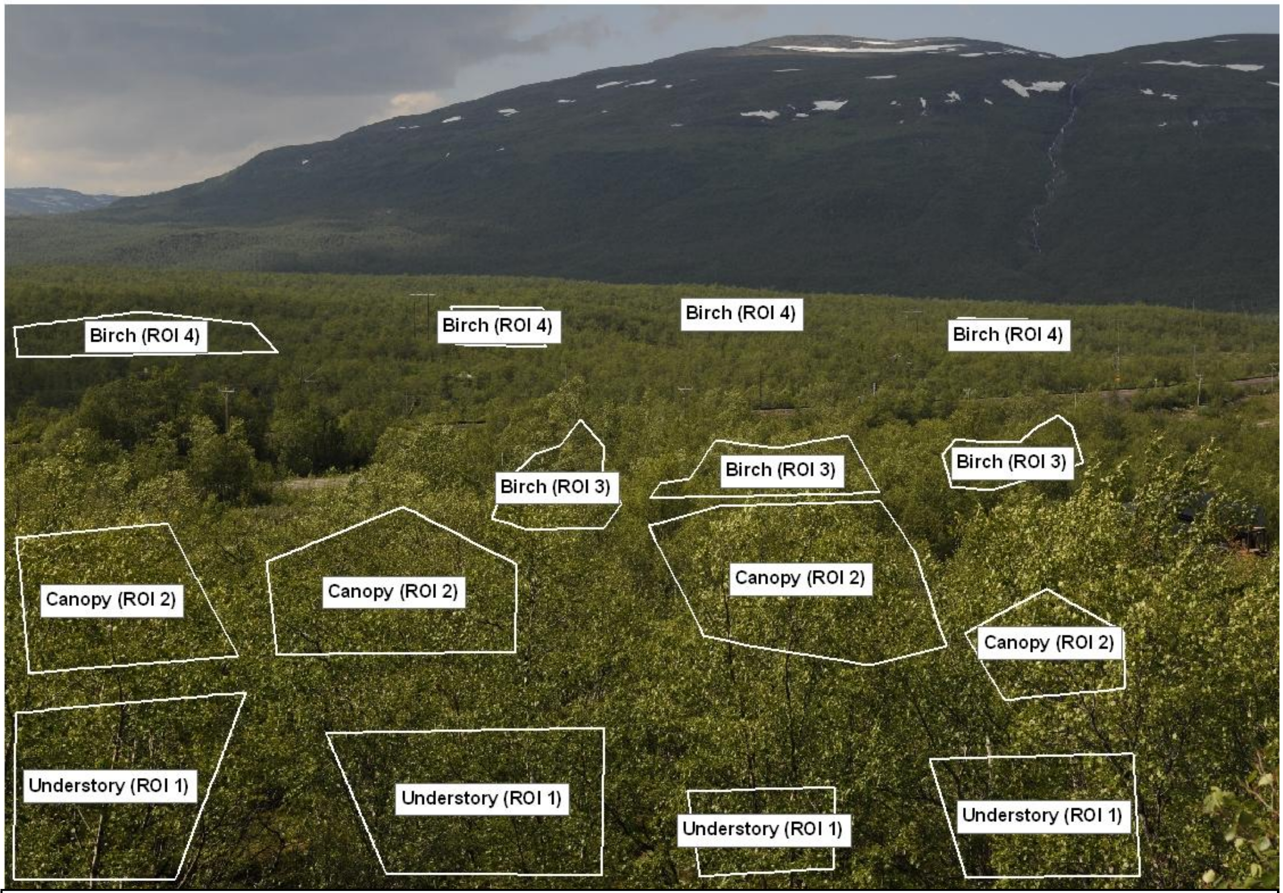
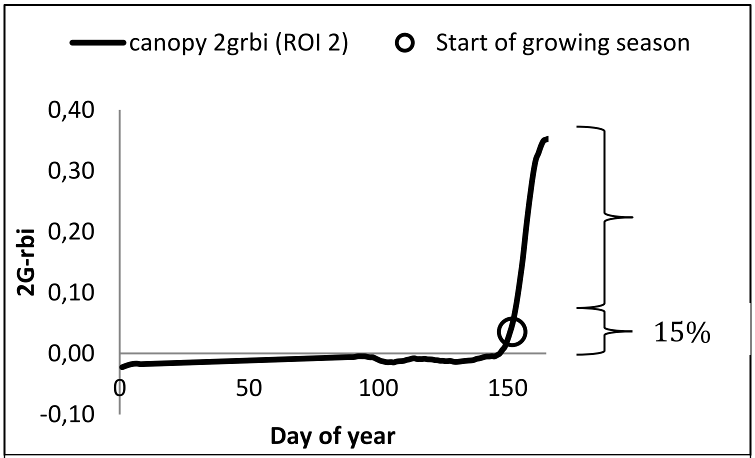


Figure 3 Regions of interest. ROI 1 = Understory of mountain birch (distance from camera 30m), ROI 2 = canopy of mountain birch (distance from camera 30m), ROI 3 = mountain birch (distance from camera 180m), ROI 4 = mountain birch (distance from camera 700m)

The pixel values in every ROI were summarized for each of the color bands (both R-Color and regular RGB) and 2G-rbi. A daily mean value was then calculated for each ROI. The missing 2G-rbi values were then interpolated linearly between the first and last value available images for each period. Interpolation of the values where made using the closest available dates for example day 332 2010 and day 74 2011 were used to interpolate the values for day 1-73 2011 (Graph 7). However, interpolation of day 335-365 2011 was made between day 334 2011 and day 332 2010 from the previous year instead of using a value from 2012 which was not available.

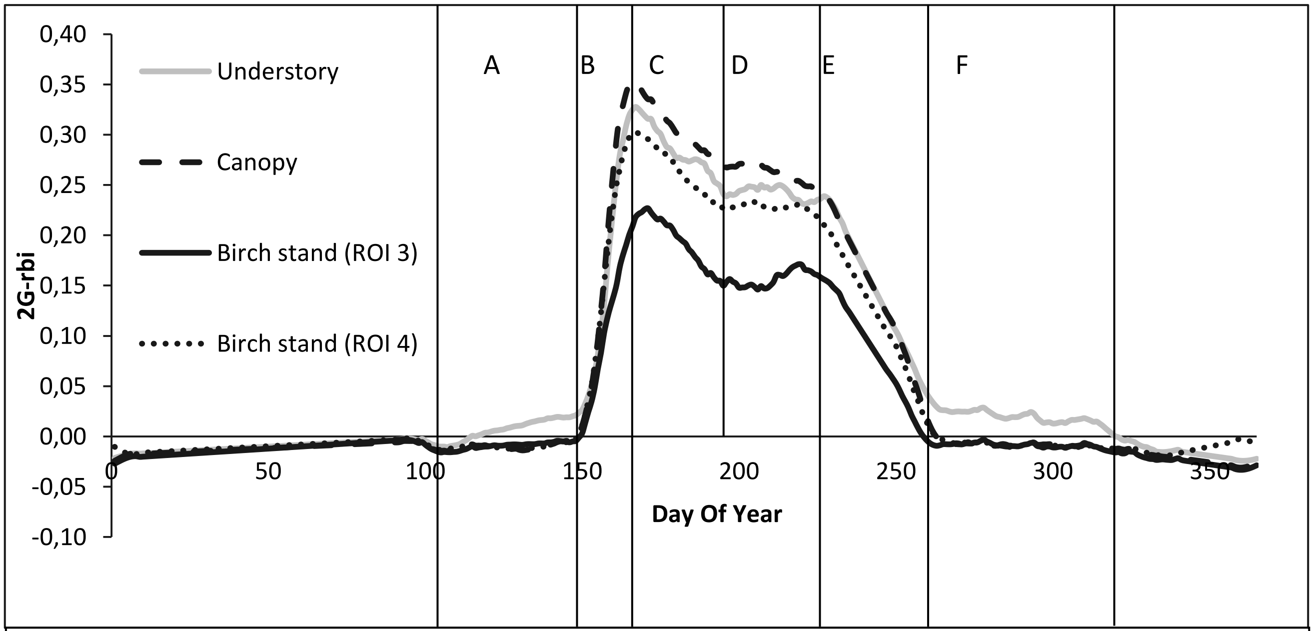
An adaptive Savitzky-Golay filter was used to smoothen the time-series of the 2G-rbi values for each ROI. The Savitzky-Golay filter is a simplified least squares-fit filter that uses a moving window to replace the old values with the average value from the moving window for each point value. Different window widths of the filter were applied until one smoothed out the lowering values caused by the dark clouds (width = 8). The filter replaces the original 2G-rbi with new values calculated from a quadratic polynomial equation fitted to the values according to the smoothing window (Eklundh and Jönsson, 2011).

The start of the growing season could then be defined as a 15% increase in amplitude from the spring minimum value of the Savizky-Golay filtered 2G-rbi values (Graph 1). The definition of the end of the growing season is a 15% decrease in amplitude from the autumn minimum value of the season. The value of 15% was chosen to match the start of the increasing 2G-rbi values for all ROI and to exclude the small increase in the understory ROI due to the influence of ground vegetation.



Graph 1: Definition for the start of the growing season as 15% increase in the 2G-rbi values from the minimum spring value

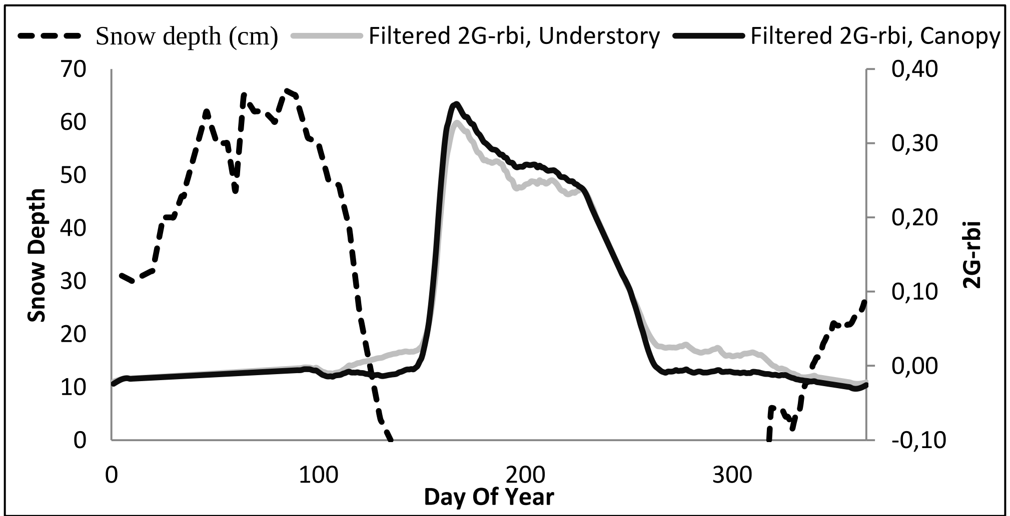
The start and end of the growing season is clear with its distinct rise and decline in the 2G-rbi graph and follows the phenology events from the field observations (Graph 2). The 2G-rbi values are stable during autumn and spring and have the most variations throughout the growing season (Graph 2). The 2G-rbi values rise as the leaves start to grow and decline when the leaves colorize and fall to the ground (noted from field and photography observations) (graph 2). The maximum of the 2G-rbi values occur at the same time as all of the leaves are fully developed (noted from field observations). The 2G-rbi values decrease in two steps, first at the end of the colorization period and secondly when the leaves fall to the ground. This was distinguished as the values fell at two different rates along with the field observations (Graph 2). The understory 2G-rbi values in ROI 1 started to increase 25 days (DOY 115-140) before the other birch stands and stayed active 56 days after the other birch stands had ended their growing season. This is probably an influence of the ground vegetation which starts to grow earlier in the season and stops to grow later. Further, no leaves were visible in the photographs on the understory birches during these two periods. The ground floor vegetation influence on the 2G-rbi values is excluded from the calculation of the start and end of the growing season. The early increase and the late decrease are both below the 15% change in amplitude chosen for the start and end of the growing season.



Graph 2: Savitzky-Golay filtered 2G-rbi and periods noted from field observations. A = Understory Increase, B = Leaf-out period C = Holes in leaves period (insect attack), D = Colorization period, E = Senescence period, F = Understory active.

During the growing season the birches studied in field had been attacked by insects, causing holes in the leaves. As these insects attacks are fairly common in this region the same insect scenario is applied on the birch stands in this study. During the colorization period gnawing caused by insects or larvae was noted from the field observations.

The Understory 2G-rbi starts to increase at the same time as the snow depth decreases (Graph 3). When the first snow comes (DOY 318) the understory 2G-rbi values fall to the same level as the other ROI (Graph 3). There was a time lag of 16 days from when the snow cover was gone until the start of the growing season (DOY 135-151).



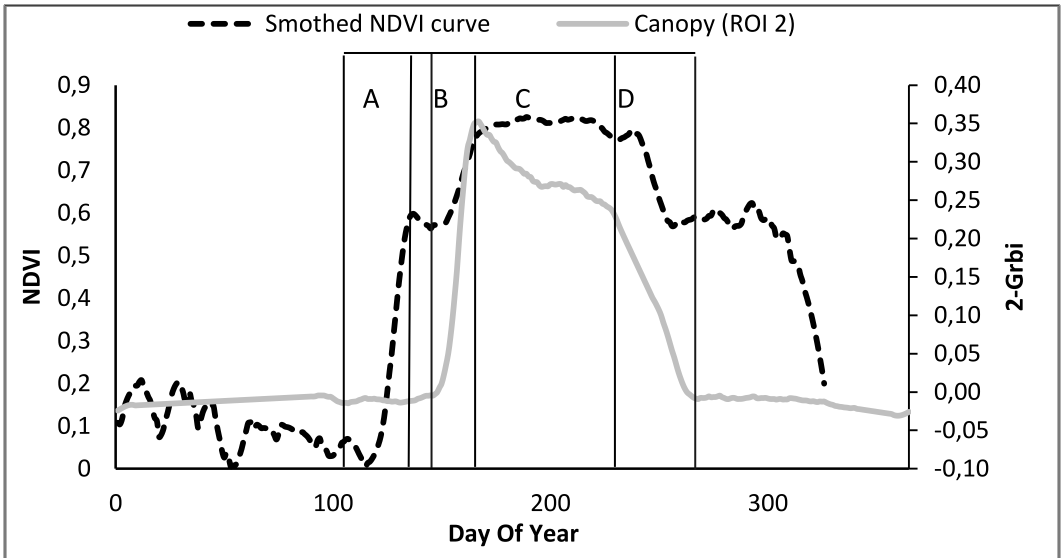
Graph 3: Snow depth from Abisko research station and filtered 2G-rbi from the Understory (ROI 1) and canopy (ROI 2).

The calculated start and peak of the growing season occurred with 2 days difference and the end varied with 6 days for all birch stands (Table 1).

Table 1: Calculated dates for the start, peak and end of the growing season 2011 in Abisko Sweden, DOY = day of year.

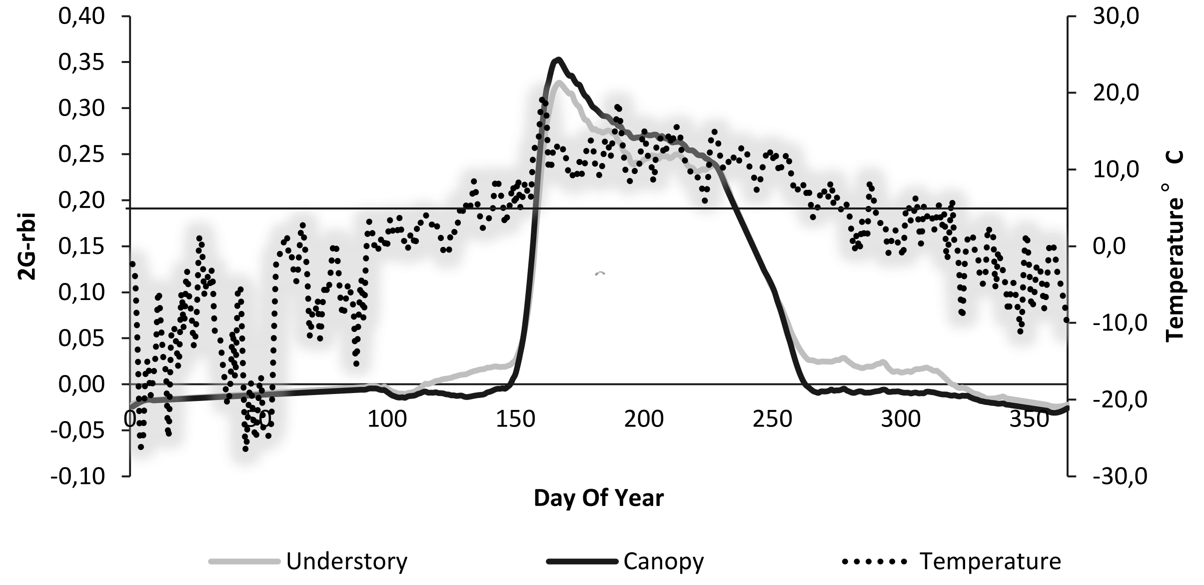
	Understory ROI 1	Canopy ROI 2	Birch stand ROI 3	Birch stand ROI 4
Start of growing season (DOY)	151	152	151	150
Peak (DOY)	176	176	175	174
End of growing season (DOY)	263	259	257	257

The snowmelt (DOY 114-135) shown in the NDVI graph (Period A, graph 4) does not appear on the 2G-rbi values for the ROI excluding the ground floor as they do in NDVI. This makes the 2G-rbi values created by digital repeat photography easy to understand as the snowmelt can be confused with the start of the growing season from NDVI measurements. The 2G-rbi values show a decrease during the growing season (DOY 164-185) which is not visible in the NDVI. Note that the NDVI tower is situated a few kilometers from the study area and could include variations that are not found in the study area and vice versa.



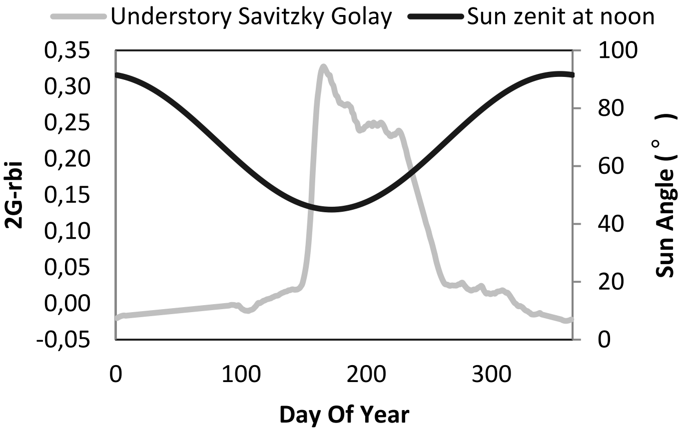
Graph 4: Smoothed NDVI from multi spectral tower measurement in Abisko 2011 and filtered 2G-rbi values from Birch Canopy (ROI 2). A = Snow melting period (DOY 206-261), B = Leaf-out period, C = Growing season, D = Senescence

The lag time after the ground has turned snow free until the start of the growing season could be due to the fact that the temperature has not reached a certain level to enable the growth of the mountain birches. After the increase in the NDVI graph created from the snowmelt (Period A, Graph4) until the start of the growing season there are 12-14 days (for the different ROI) with a temperature above 5°C until the calculated start of the growing season (Graph 5). The variation in the leaf-out timing could be due to local micro climates increases or decreases the air temperature.



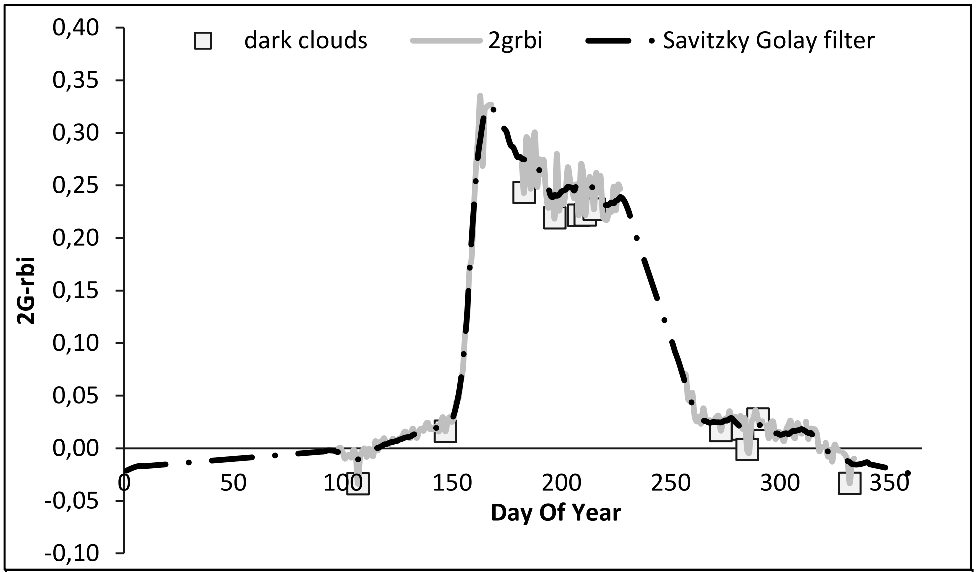
Graph 5: Daily temperature and filtered 2G-rbi for birch understory and canopy (ROI 1 and 2). The horizontal line is located at 5°C.

Because of the high latitude at Abisko the solar angle varies during one year from 91.39° to 44.91° (Graph 6). This could have some influence on the color values extracted from the photographs, when choosing the pictures especially in summer time when the solar angle varies from 49.88 to 46.36 between 10:00 to 12:00. The change in the solar angle during the growing season (17.7°) is rather small due to the short growing season. The largest solar angle change is in spring and autumn which are periods that are not interesting for this study because the birches are not active in this period.



Graph 6: Filtered 2G-rbi from Understory ROI 1 and Sun angle (°) values at 12.00 in Abisko, Sweden. 0° means that the sun is directly overhead (zenith) and values above 90° means that the sun is below the horizon.

Dark clouds, fog and shadows have a lowering effect on the 2G-rbi values (Graph 7). This is one of the explanations to the variations during the growing and dormant season. The time before the leaf-unfolding period and after the senescence is fitted well to the Savitzky-Golay filter curve and has few variations in the prior 2G-rbi values. The growing season however has higher variations; other factors that could influence this are colorization and insect attacks (creating holes and gnawing).



Graph 7: 2G-rbi without interpolated data, Dark cloud occurrences and the filtered Savitzky-Golay 2G-rbi values.

5. DISCUSSION

5.1 PHENOLOGY COMPARISONS

The leaf-out event matches well compared to the field observed phenology. When 75% of the leaves are fully developed the 2G-rbi curve has increased about 75% from its minimum value.
The 2G-rbi values first start to decline when the leaves colorize. After all the leaves have turned rust colored the 2G-rbi values starts to fall with a higher rate towards the dormancy level, and when it has reached that level almost all (66%) of the leaves have fallen to the ground.

The decrease of the 2G-rbi values in the late growing season is only shown in one step (DOY 216-262) for all birch stands except for the understory ROI. The understory shows similar two decreasing steps (DOY 213-221 and 227-261) as the NDVI. During the same time as the understory 2G-rbi values decrease for the first time a temperature drop occurs (DOY 212-226). When the temperature then increases (DOY 227-230), only the understory ROI has a positive response in the 2G-rbi values. This increase can be created by growth from the understory but also the white stems on the birches may have an increasing effect on the understory 2G-rbi values and none on the other birch ROI. Observations from the photographs in this period tell that the stems are more visible than earlier in the growing season. This would have an effect on the understory but not on the other ROI which does not include stems. Due to the fact that the 2G-rbi values decrease when the leaves fall to the ground the calculated date of when the growing season ends varies between the birch stands, mainly because the leaves will fall to the ground depending on factors like wind exposure which may vary locally. Further studies are needed separating these two periods to make the definition of this period more accurate, maybe thru other color indices or combined with NDVI. The NDVI values decrease more rapidly than the 2G-rbi values and give a better indication on when the leaves colorize respectively fall to the ground. Leaf colorization could be a better definition for the end of the growing season if it occurs more homogenously over larger areas than leaf fall.

The rise in the NDVI from day 114-135 comes from the snow melting period (Period A in graph 4). The period after the increase (DOY 135-148), also referred to as the “shoulder” by Eklundh et al. (2011) occurs at the same date as the ground clears from the snow in the camera images (DOY 135).

5.2 CAMERA POSITION

The camera is positioned close to a mountain birch in the lower right corner (Figure 3) that covers different parts of the picture depending on the time of year and wind conditions. The branches are sometimes part of the right side understory and canopy (ROI 1 and 2) and could have influenced the values from these two ROI. Only a small part of the large area covered in the photos was used in this study (Figure 1). More research is needed to analyze whether the birch stands further away from the camera can be measured with this technique successfully and how the color values vary with the distance from the camera. Field vegetation observations within each ROI would give valuable information of the understory influence on the canopy of the mountain birch. The canopy values could include understory and ground floor influences in the start and end of the growing season when the leaves are not fully developed respectively have fallen to the ground. The angle of the camera which is almost horizontal makes the influence of understory and ground floor on the canopy ROI smaller, because the vegetation behind the canopy in this angle is the canopy of another birch. Had the camera been in a steeper angle looking down on the canopy the influence from understory on the canopy had been greater.
Compared to other phenology studies using digital repeat photography (Richardson et al., 2007, Mizunuma et al., 2011, Sonnentag et al., 2012), various regions of interest for the same type of vegetation were defined for each area (understory, canopy and birch stands) excluding local growth variations that could be seen in the photographs.

5.3 INTERPOLATION

Because of the battery problems interpolation had to be made to be able to do the Savitzky-Golay filter which needed a full year of values to be computed. The Savitzky-Golay filter is a good filter to use as it smoothens the values and can if wanted be adjusted to the upper or lower casings to adjust for example lower value variations created by dark clouds (Graph 7). The values were not adjusted to any casings in this study as it is uncertain to what the higher casings depend on.

The occasions when the battery failure occurred were of great interest for this study as the peak of the growing season (DOY 169-181) and parts of the senescence period (DOY 228-254) needed to be interpolated. The winter season also needed to be interpolated but this did not give any important data loss for this study.

The 14 photographs that were excluded from the study were the photos with dark clouds, fog, snow or rain over the whole area. Photos with only some clouds or fog on the mountain side were used either way as they could be used for certain ROI. The occurrences of these weather phenomena were all represented with a lower 2G-rbi value (Graph 5) especially under the growing season when the variations were bigger. To make this method even more quantitative filtering of the dark-cloudy, foggy or rainy days can be done by comparing R-Color values (Equation 1) for each weather phenomenon.

Leaf senescence is harder to study with 2G-rbi index due to the many processes involved in this phenological stage like colorization, leaf loss and allocation of nutrients. The definition of the start of the growing season was set to 15% of the increase in altitude from the minimum value since this was the value that excluded the increase due to the influence from ground vegetation. Standardization of the definition of both the start and end of the growing season should be made to be able to compare different vegetation and study areas.

5.4 FIELD DATA

The collection of field data was done too late to evaluate the start of the leaf-out event. To see if the 2G-rbi values start to rise when the leaves start to emerge, field data would be needed from mid May when the snow cover is gone. Also field observations need to be made at least once a week as the leaves can go from shut to fully developed in a few days. It is also interesting to study day to day changes in the leaf-out event in different color indices. As of now when the first field observation was made in June, only the date for when the leaf base and stem were visible which matched well with the 2G-rbi maximum value (Graph 1). The field data was captured at the most 450 m north east of the camera position and may have variations that do not occur in the camera's field of view. Field observed phenology data was captured for different ground vegetation at the same place as for the mountain birches. However, a field excursion would have been needed to document exactly what ground vegetation there is below the birches to make further analysis. For the moment it is uncertain if the increase in 2G-rbi is due to the growth of ground vegetation, loss of snow cover or influenced by both of these factors.

5.5 INSECT OUTBREAKS

Insect attacks affect tree phenology as they often occur in the beginning of the growing season. Some spring feeding larvae must hatch at the same time as the bud burst occurs (Vindstad et al., 2011). During the growing season the birches studied in field had been attacked by insects, causing holes in the leaves. As the two moth species (*Epirrita autumnata* and *Operophtera burmata*) are fairly common (population peaks every ten years) in the Abisko region the same insect scenario is applied on the birch stands in this study (Karlsson et al., 2005). During the colorization period, gnawing was noted from the field observations which are caused by insects or larvae. Data from the field observations tell that holes in leaves were occurring in all leaves (DOY 182) and gnawing occurred simultaneously as colorization on all leaves (DOY 224). This is probably due to some kind of insect outbreak. It is unknown how this affects the 2G-rbi curve and rather hard to study as there are so many variations in the values during the growing period. It is not possible to see any of the holes or gnawed leaves on the photographs. Damage caused by *Epirrita autumnata* in 1954-1955 caused defoliation with mortality of 80-90% in Abisko and 5000 km^2 in northern Finland. Thirty years after the outbreak the forest in Abisko had yet not fully recovered (Tenow and Bylund, 2000).

The use of the R-Color index has proven itself useful in this study because it reflects the relative change to all the colors in the picture. For example if the blue and red values are lowered and the green values remain unchanged the picture will seem greener. However, this is not represented in the green color values. The R-Color index will however change because the picture is greener relative to the total color values (Red+Green+Blue). The R-Color index also has lower effect of changes in illumination. If the illumination increases this will result in a higher change of the RGB values but will not change the R-Color index as much if all the values increase at similar rates. During the growing season there were higher variations in the R-Color indices compared to the leaf unfolding period and senescence. It is important to mention that the values from day 228-254 are interpolated and may in reality include other variations not shown in the graphs.

All images produced by this method occupy 140 gigabyte of disk space including only one year of photos. When studying phenology it is important to have a high temporal resolution of the data. Other studies for example Jönsson (2010) studied phenology over eight years but higher temporal extents like 30 years by Ovaska (2005) is not rare in the Abisko region. The time needed to compute all the processes in this study was about two days using a regular personal computer with an external hard drive. Further methods are needed to filter images with snow rain and disturbances, preferably using the RGB color range to maintain the low cost of the method. Making the filtering quantitative could mean that only one photo per day is needed if the filtered days are not too many. Using only one photo per day will reduce the effects the sun angle has on the luminance. The images in this method are rasters and could with further studies and methodology be applied to aerial photographs giving each pixel a 2G-rbi value and a geographic coordinate.

Two regions of interest on the mountain side were excluded from this study due to the absence of field observations for confirmation. Further, the 2G-rbi values from the mountain gave a distinct rise in the start and end of the growing season at the same time as the other ROI but contained many peaks and drops during the vegetative and dormant phase.

Three photographs per day is a sufficient temporal resolution for this study, as there only where four days were none of the three photographs could be used due to bad weather (fog, snow or rain).

It is important to mention that the photographs have a visual value as well as a quantitative value. Manual analyses of the photographs should not be excluded. Also more events can be studied from the different color index graphs made in this study, for example lag time between different stages. Growing degree days or precipitation can be compared with the color indices to understand why and how the vegetation responses to temperature, precipitation or other factors.

6. CONCLUSION

The photographs can be used to determine the start and end of the growing season both visually and quantitatively with the 2G-rbi color index. The calculated events from the photographs correspond to the actual phenology events studied in field. It is also possible to study the phenology of different stands and parts of birches. This method includes both normalization of the color values (R-Color) lowering the illuminative effects and a greenness index (2G-rbi) which gives a distinct rise when the growing season starts and decline when the growing season ends. The start of the growing season varied by two days between the regions of interest and occurs when the leaves starts to expand. The end of the growing season varied by six days and occurs when 66% of the leaves have fallen to the ground. Digital repeat photography brings a low amount of work and is a more quantitative way to study phenology compared to field observations. The color index 2G-rbi is not affected by the snowmelt like the NDVI which can be confused with the start of the growing season as they show a similar increase in NDVI. The use of digital repeat photography is a good way to study phenology in sub-arctic environments because the short and rapid growing season gives great change in the color values over a short time. The effects of dark clouds, fog and rain lower the greenness index (2G-rbi) and are smoothed out by the Savitzky-Golay filter.

Acknowledgements

Thank you to Karin Larsson for the help with the DEM and aerial photography and Hongxiao Jin for photos of the camera location, solar angle calculation and NDVI data. Thank you to Anna Lindstein and Joel Lilljebjörn for the helpful reviews of this article. Also I would like to thank Annika Kristofferson for the phenology observations and climatic data from Abisko research station, also thanks to Lars Eklundh for all the support during this bachelor thesis.

REFERENCES

Ahl, D. E., Gower, S. T., Burrows, S. N., Shabanov, N. V., Myneni, R. B.and Knyazikhin, Y., 2006. Monitoring spring canopy phenology of a deciduous broadleaf forest using MODIS. *Remote Sensing of Environment,* 104**,** 88-95. doi:10.1016/j.rse.2006.05.003

Ahrends, H., Brügger, R., Stöckli, R., Schenk, J., Michna, P., Jeanneret, F., Wanner, H.and Eugster, W., 2008. Quantitative phenological observations of a mixed beech forest in northern Switzerland with digital photography. *J. Geophys. Res.,* 113**,** G04004. doi:10.1029/2007jg000650

Ahrends, H., Etzold, S., Kutsch, W., Stoeckli, R., Bruegger, R., Jeanneret, F., Wanner, H., Buchmann, N.and Eugster, W., 2009. Tree phenology and carbon dioxide fluxes: use of digital photography for process-based interpretation at the ecosystem scale. *Climate Research,* 39**,** 261-274. doi:10.3354/cr00811

Arora, V. K.and Boer, G. J., 2005. A parameterization of leaf phenology for the terrestrial ecosystem component of climate models. *Global Change Biology,* 11**,** 39-59. doi:10.1111/j.1365-2486.2004.00890.x

Bares, D., Mozny, M.and Nekovar, J., 2009. Digital web camera - a tool for phenological observations in the IPG Doksany. *Sustainable Development and Bioclimate: Reviewed Conference Proceedings***,** 63-64.

Bater, C., Coops, N., Wulder, M., Hilker, T., Nielsen, S., Mcdermid, G.and Stenhouse, G., 2011. Using digital time-lapse cameras to monitor species-specific understorey and overstorey phenology in support of wildlife habitat assessment. *Environmental Monitoring and Assessment,* 180**,** 1-13. doi:10.1007/s10661-010-1768-x

Betancourt, J. L., Schwartz, M. D., Breshears, D. D., Brewer, C. A., Frazer, G., Gross, J. E., Mazer, S. J., Reed, B. C.and Wilson, B. E., 2007. Evolving plans for the USA National Phenology Network. *Eos Trans. AGU,* 88. doi:10.1029/2007eo190007

Bin, T., Morisette, J. T., Wolfe, R. E., Feng, G., Ederer, G. A., Nightingale, J.and Pedelty, J. A., 2008. Vegetation Phenology Metrics Derived from Temporally Smoothed and Gap-Filled MODIS Data. *Geoscience and Remote Sensing Symposium, 2008. IGARSS 2008. IEEE International,* 3**,** III - 593-III - 596.

Cannell, M. G. R.and Smith, R. I., 1986. Climatic warming, spring budburst and frost damage on trees. *Journal of Applied Ecology,* 23**,** 177-191.

Chapin, P. a. M. a. P. V. (ed.) 2011: *Principles of Terrestrial Ecosystems*, Springer.

Cleland, E. E., Chuine, I., Menzel, A., Mooney, H. A.and Schwartz, M. D., 2007. Shifting plant phenology in response to global change. *Trends in Ecology & Evolution,* 22**,** 357-365. doi:10.1016/j.tree.2007.04.003

Eklundh, L., Jin, H., Schubert, P., Guzinski, R.and Heliasz, M., 2011. An Optical Sensor Network for Vegetation Phenology Monitoring and Satellite Data Calibration. *Sensors,* 11**,** 6678-7709.

Eklundh, L.and Jönsson, P., 2011. Timesat 3.1 Software Manual.

Goetz, S. J., Hall, F. G., Huemmrich, K. F.and Nickeson, J. E., 1994. Remote sensing of PAR interception and net primary production in trembling aspen and black spruce stands. *Geoscience and Remote Sensing Symposium, 1994. IGARSS '94. Surface and Atmospheric Remote Sensing: Technologies, Data Analysis and Interpretation., International,* 1**,** 249-251 vol.241. doi:10.1109/igarss.1994.399095

Graham, E., 2008. Budburst and leaf area expansion measured with a ground-based, mobile camera system and simple color thresholding. doi:10.1016/j.envexpbot.2008.09.013

Haralick, R. M., Hlavka, C. A., Yokoyama, R.and Carlyle, S. M., 1980. SPECTRAL-TEMPORAL CLASSIFICATION USING VEGETATION PHENOLOGY. *IEEE Transactions on Geoscience and Remote Sensing,* GE-18**,** 167-174.

Hasinoff, S.and Kutulakos, K. 2008: Light-Efficient Photography Computer Vision – ECCV 2008. *In:* Forsyth, D., Torr, P.andZisserman, A. (eds.), Springer Berlin / Heidelberg. (45-59 p).

Hoch, W. A., Singsaas, E. L.and Mccown, B. H., 2003. Resorption Protection. Anthocyanins Facilitate Nutrient Recovery in Autumn by Shielding Leaves from Potentially Damaging Light Levels. *Plant Physiology,* 133**,** 1296-1305. doi:10.1104/pp.103.027631

Ide, R.and Oguma, H., 2010. Use of digital cameras for phenological observations. *Ecological Informatics,* 5**,** 339-347. doi:10.1016/j.ecoinf.2010.07.002

Johansson, T., 2006. Temporal and spatial variability of carbon cycling in a subarctic landscape. *Faculty of science,* Doctoral Dissertation.

Jönsson, A. M., Eklundh, L., Hellström, M., Bärring, L.and Jönsson, P., 2010. Annual changes in MODIS vegetation indices of Swedish coniferous forests in relation to snow dynamics and tree phenology. *Remote Sensing of Environment,* 114**,** 2719-2730. doi:10.1016/j.rse.2010.06.005

Junming, L.and Wencai, S., 2011. Using NDVI and Air Temperature to Monitoring Winter-Wheat Phenology in Xingtai, Hebei, China. *Control, Automation and Systems Engineering (CASE), 2011 International Conference on***,** 1-4. doi:10.1109/iccase.2011.5997798

Karlsson, P. S., Weih, M.and Borg, C. 2005: Mountain Birch Growth in Relation to Climate and Herbivores Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests. *In:* Caldwell, M. M., Heldmaier, G., Jackson, R. B., Lange, O. L., Mooney, H. A., Schulze, E. D., Sommer, U., Wielgolaski, F. E., Karlsson, P. S., Neuvonen, S.andThannheiser, D. (eds.), Springer Berlin Heidelberg. (71-86 p).

Keeling, C. D., Chin, J. F. S.and Whorf, T. P., 1996. Increased activity of northern vegetation inferred from atmospheric CO2 measurements. *Nature,* 382**,** 146-149.

Menzel, A., 2002. Phenology: Its Importance to the Global Change Community. *Climatic Change,* 54**,** 379-385. doi:10.1023/a:1016125215496

Menzel, A., 2003. Plant Phenological Anomalies in Germany and their Relation to Air Temperature and NAO. *Climatic Change,* 57**,** 243-263. doi:10.1023/a:1022880418362

Mizunuma, T., Koyanagi, T., Mencuccini, M., Nasahara, K. N., Wingate, L.and Grace, J., 2011. The comparison of several colour indices for the photographic recording of canopy phenology of Fagus crenata Blume in eastern Japan. *Plant Ecology & Diversity,* 4**,** 67-77. doi:10.1080/17550874.2011.563759

Nikon, C., 2011. Nikon D300s Brochure.

Ovaska, J. A., Nilsen, J., Wielgolaski, F. E., Kauhanen, H., Partanen, R., Neuvonen, S., Kapari, L., Skre, O.and Laine, K. 2005: Phenology and Performance of Mountain Birch Provenances in Transplant Gardens: Latitudinal, Altitudinal and Oceanity-Continentality Gradients Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests. *In:* Caldwell, M. M., Heldmaier, G., Jackson, R. B., Lange, O. L., Mooney, H. A., Schulze, E. D., Sommer, U., Wielgolaski, F. E., Karlsson, P. S., Neuvonen, S.andThannheiser, D. (eds.), Springer Berlin Heidelberg. (99-115 p).

Polgar, C. A.and Primack, R. B., 2011. Leaf-out phenology of temperate woody plants: from trees to ecosystems. *New Phytologist,* 191**,** 926-941. doi:10.1111/j.1469-8137.2011.03803.x

Richardson, A., Jenkins, J., Braswell, B., Hollinger, D., Ollinger, S.and Smith, M.-L., 2007. Use of digital webcam images to track spring green-up in a deciduous broadleaf forest. *Oecologia,* 152**,** 323-334. doi:10.1007/s00442-006-0657-z

Richardson, A. D., Anderson, R. S., Arain, M. A., Barr, A. G., Bohrer, G., Chen, G., Chen, J. M., Ciais, P., Davis, K. J., Desai, A. R., Dietze, M. C., Dragoni, D., Garrity, S. R., Gough, C. M., Grant, R., Hollinger, D. Y., Margolis, H. A., Mccaughey, H., Migliavacca, M., Monson, R. K., Munger, J. W., Poulter, B., Raczka, B. M., Ricciuto, D. M., Sahoo, A. K., Schaefer, K., Tian, H., Vargas, R., Verbeeck, H., Xiao, J.and Xue, Y., 2012. Terrestrial biosphere models need better representation of vegetation phenology: results from the North American Carbon Program Site Synthesis. *Global Change Biology,* 18**,** 566-584. doi:10.1111/j.1365-2486.2011.02562.x

Sakamoto, T., Shibayama, M., Kimura, A.and Takada, E., 2011. Assessment of digital camera-derived vegetation indices in quantitative monitoring of seasonal rice growth. *ISPRS Journal of Photogrammetry and Remote Sensing,* 66**,** 872-882. doi:10.1016/j.isprsjprs.2011.08.005

Sonnentag, O., Hufkens, K., Teshera-Sterne, C., Young, A. M., Friedl, M., Braswell, B. H., Milliman, T., O'keefe, J.and Richardson, A. D., 2012. Digital repeat photography for phenological research in forest ecosystems. *Agricultural and Forest Meteorology,* 152**,** 159-177. doi:10.1016/j.agrformet.2011.09.009

Sparks, T. H.and Carey, P. D., 1995. The Responses of Species to Climate Over Two Centuries: An Analysis of the Marsham Phenological Record, 1736-1947. *Journal of Ecology,* 83**,** 321-329.

Sparks, T. H.and Menzel, A., 2002. Observed changes in seasons: an overview. *International Journal of Climatology,* 22**,** 1715-1725. doi:10.1002/joc.821

Tenow, O.and Bylund, H., 2000. Recovery of a Betula pubescens Forest in Northern Sweden after Severe Defoliation by Epirrita autumnata. *Journal of Vegetation Science,* 11**,** 855-862.

Vierling, L. A., Deering, D. W.and Eck, T. F., 1996. Nadir and bidirectional surface measurements of Arctic tundra: site differentiation and vegetation phenology early in the growing season. *Geoscience and Remote Sensing Symposium, 1996. IGARSS '96. 'Remote Sensing for a Sustainable Future.', International,* 4**,** 1897-1900 vol.1894. doi:10.1109/igarss.1996.516835

Vindstad, O. P. L., Hagen, S. B., Jepsen, J. U., Kapari, L., Schott, T.and Ims, R. A., 2011. Phenological diversity in the interactions between winter moth (Operophtera brumata) larvae and parasitoid wasps in sub-arctic mountain birch forest. *Bulletin of Entomological Research,* 101**,** 705-714. doi:doi:10.1017/S0007485311000277

Wilsey, B. J.and Saloniemi, I., 1999. Leaf Fluctuating Asymmetry in Tree-Line Mountain Birches, Betula pubescens ssp. tortuosa: Genetic or Environmentally Influenced? *Oikos,* 87**,** 341-345.

APPENDIX

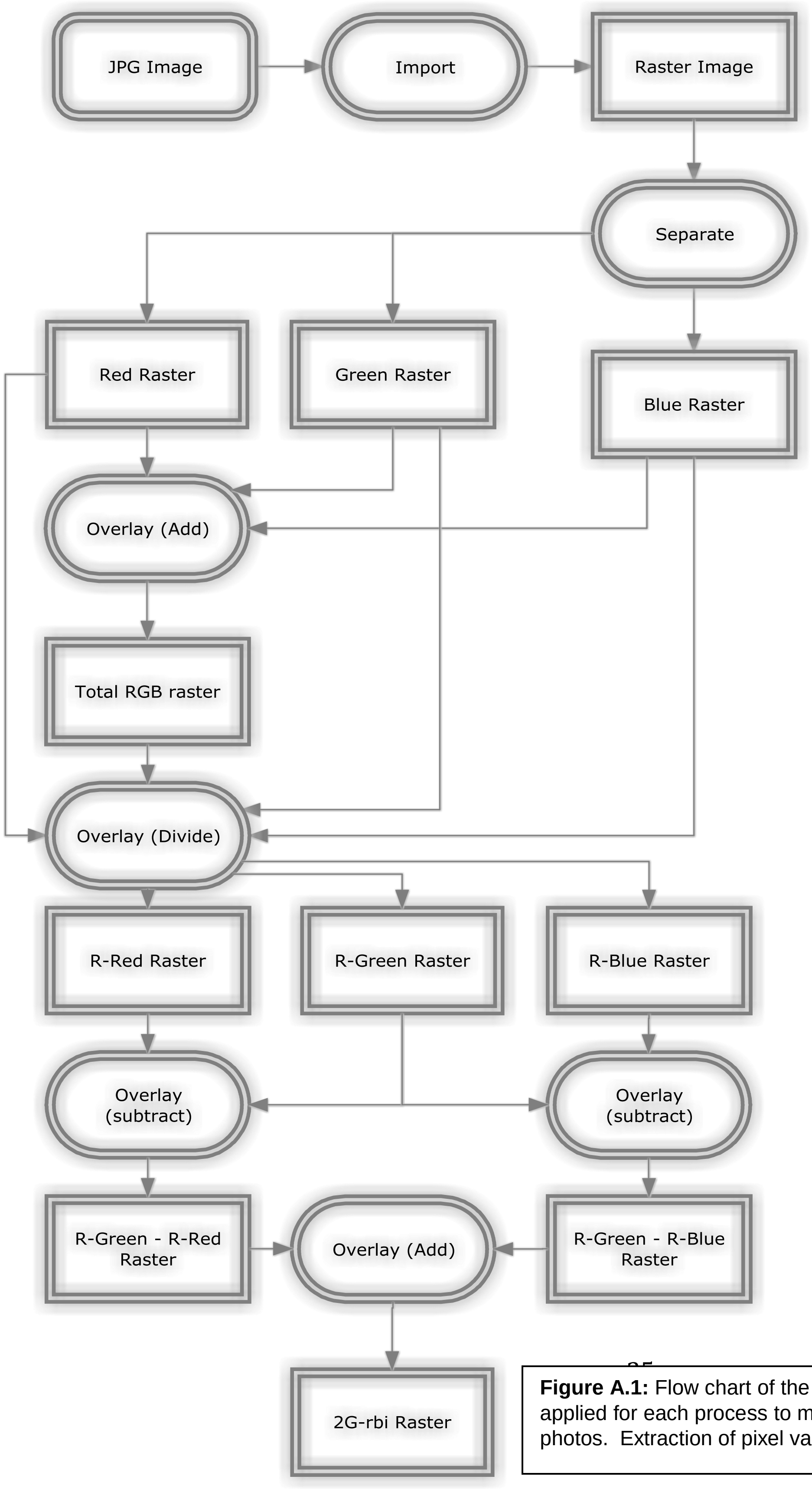


Figure A.1: Flow chart of the process to calculate 2G-rbi for one image. Scripts were applied for each process to make the whole calculation automatic for all the available photos. Extraction of pixel values and filtration is not included in this flow chart.

Institutionen av naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden.
Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (www.nateko.lu.se/masterthesis) and through the Geo-library (www.geobib.lu.se)

175 Hongxiao Jin (2010): Drivers of Global Wildfires — Statistical analyses
176 Emma Cederlund (2010): Dalby Söderskog – Den historiska utvecklingen
177 Lina Glad (2010): En förändringsstudie av Ivösjöns strandlinje
178 Erika Filppa (2010): Utsläpp till luft från ballastproduktionen år 2008
179 Karolina Jacobsson (2010):Havsisens avsmältning i Arktis och dess effekter
180 Mattias Spångmyr (2010): Global of effects of albedo change due to urbanization
181 Emmelie Johansson & Towe Andersson (2010): Ekologiskt jordbruk - ett sätt att minska övergödningen och bevara den biologiska mångfalden?
182 Åsa Cornander (2010): Stigande havsnivåer och dess effect på känsligt belägna bosättningar
183 Linda Adamsson (2010): Landskapsekologisk undersökning av ädellövskogen i Östra Vätterbranterna
184 Ylva Persson (2010): Markfuktighetens påverkan på granens tillväxt i Guvarp
185 Boel Hedgren (2010): Den arktiska permafrostens degradering och metangasutsläpp
186 Joakim Lindblad & Johan Lindenbaum (2010): GIS-baserad kartläggning av sambandet mellan pesticidförekomster i grundvatten och markegenskaper
187 Oscar Dagerskog (2010): Baösberggrottan – Historiska tillbakablickar och en lokalklimatologisk undersökning
188 Mikael Månsson (2010): Webbaserad GIS-klient för hantering av geologisk information
189 Lina Eklund (2010): Accessibility to health services in the West Bank, occupied Palestinian Territory.
190 Edvin Eriksson (2010): Kvalitet och osäkerhet i geografisk analys - En studie om kvalitetsaspekter med fokus på osäkerhetsanalys av rumslig prognosmodell för trafikolyckor
191 Elsa Tessaire (2010): Impacts of stressful weather events on forest ecosystems in south Sweden.
192 Xuejing Lei (2010): Assessment of Climate Change Impacts on Cork Oak in Western Mediterranean Regions: A Comparative Analysis of Extreme Indices
193 Radoslaw Guzinski (2010): Comparison of vegetation indices to determine their accuracy in predicting spring phenology of Swedish ecosystems
194 Yasar Arfat (2010): Land Use / Land Cover Change Detection and Quantification — A Case study in Eastern Sudan
195 Ling Bai (2010): Comparison and Validation of Five Global Land Cover Products Over African Continent

196 Raunaq Jahan (2010): Vegetation indices, FAPAR and spatial seasonality analysis of crops in southern Sweden

197 Masoumeh Ghadiri (2010): Potential of Hyperion imagery for simulation of MODIS NDVI and AVHRR-consistent NDVI time series in a semi-arid region

198 Maoela A. Malebajoa (2010): Climate change impacts on crop yields and adaptive measures for agricultural sector in the lowlands of Lesotho

199 Herbert Mbufong Njuabe (2011): Subarctic Peatlands in a Changing Climate: Greenhouse gas response to experimentally increased snow cover

200 Naemi Gunlycke & Anja Tuomaala (2011): Detecting forest degradation in Marakwet district, Kenya, using remote sensing and GIS

201 Nzung Seraphine Ebang (2011): How was the carbon balance of Europe affected by the summer 2003 heat wave? A study based on the use of a Dynamic Global Vegetation Model; LPJ-GUESS

202 Per-Ola Olsson (2011): Cartography in Internet-based view services – methods to improve cartography when geographic data from several sources are combined

203 Kristoffer Mattisson (2011): Modelling noise exposure from roads – a case study in Burlövs municipality

204 Erik Ahlberg (2011): BVOC emissions from a subarctic Mountain birch: Analysis of short-term chamber measurements.

205 Wilbert Timiza (2011): Climate variability and satellite – observed vegetation responses in Tanzania.

206 Louise Svensson (2011): The ethanol industry - impact on land use and biodiversity. A case study of São Paulo State in Brazil.

207 Fredrik Fredén (2011): Impacts of dams on lowland agriculture in the Mekong river catchment.

208 Johanna Hjärpe (2011): Kartläggning av kväve i vatten i LKAB:s verksamhet i Malmberget år 2011 och kvävets betydelse i akvatiska ekosystem ur ett lokalt och ett globalt perspektiv

209 Oskar Löfgren (2011): Increase of tree abundance between 1960 and 2009 in the treeline of Luongastunturi in the northern Swedish Scandes

210 Izabella Rosengren (2011): Land degradation in the Ovitoto region of Namibia: what are the local causes and consequences and how do we avoid them?

211 Irina Popova (2011): Agroforestry och dess påverkan på den biofysiska miljön i Afrika.

212 Emilie Walsund (2011): Food Security and Food Sufficiency in Ethiopia and Eastern Africa.

213 Martin Bernhardson (2011): Jökulhlaups: Their Associated Landforms and Landscape Impacts.

214 Michel Tholin (2011): Weather induced variations in raptor migration; A study of raptor migration during one autumn season in Kazbegi, Georgia, 2010

215 Amelie Lindgren (2011) The Effect of Natural Disturbances on the Carbon Balance of Boreal Forests.

216 Klara Århem (2011): Environmental consequences of the palm oil industry in Malaysia.

217 Ana Maria Yáñez Serrano (2011) Within-Canopy Sesquiterpene Ozonolysis in Amazonia

218 Edward Kashava Kuliwoye (2011) Flood Hazard Assessment by means of Remote Sensing and Spatial analyses in the Cuvelai Basin Case Study

Ohangwena Region –Northern Namibia
219 Julia Olsson (2011) GIS-baserad metod för etablering av centraliserade biogasanläggningar baserad på husdjursgödsel.
220 Florian Sallaba (2011) The potential of support vector machine classification of land use and land cover using seasonality from MODIS satellite data
221 Salem Beyene Ghezahai (2011) Assessing vegetation changes for parts of the Sudan and Chad during 2000-2010 using time series analysis of MODIS-NDVI
222 Bahzad Khaled (2011) Spatial heterogeneity of soil CO2 efflux at ADVEX site Norunda in Sweden
223 Emmy Axelsson (2011) Spatiotemporal variation of carbon stocks and fluxes at a clear-cut area in central Sweden
224 Eduard Mikayelyan (2011) Developing Android Mobile Map Application with Standard Navigation Tools for Pedestrians
225 Johanna Engström (2011) The effect of Northern Hemisphere teleconnections on the hydropower production in southern Sweden
226 Kosemani Bosede Adenike (2011) Deforestation and carbon stocks in Africa
227 Ouattara Adama (2011) Mauritania and Senegal coastal area urbanization, ground water flood risk in Nouakchott and land use/land cover change in Mbour area
228 Andrea Johansson (2011) Fire in Boreal forests
229 Arna Björk Þorsteinsdóttir (2011) Mapping *Lupinus nootkatensis* in Iceland using SPOT 5 images
230 Cléber Domingos Arruda (2011) Developing a Pedestrian Route Network Service (PRNS)
231 Nitin Chaudhary (2011) Evaluation of RCA & RCA GUESS and estimation of vegetation-climate feedbacks over India for present climate
232 Bjarne Munk Lyshede (2012) Diurnal variations in methane flux in a low-arctic fen in Southwest Greenland
233 Zhendong Wu (2012) Dissolved methane dynamics in a subarctic peatland
234 Lars Johansson (2012) Modelling near ground wind speed in urban environments using high-resolution digital surface models and statistical methods
235 Sanna Dufbäck (2012) Lokal dagvattenhantering med grönytefaktorn
236 Arash Amiri (2012)Automatic Geospatial Web Service Composition for Developing a Routing System
237 Emma Li Johansson (2012) The Melting Himalayas: Examples of Water Harvesting Techniques
238 Adelina Osmani (2012) Forests as carbon sinks - A comparison between the boreal forest and the tropical forest
239 Uta Klönne (2012) Drought in the Sahel – global and local driving forces and their impact on vegetation in the 20th and 21st century
240 Max van Meeningen (2012) Metanutsläpp från det smältande Arktis
241 Joakim Lindberg (2012) Analys av tillväxt för enskilda träd efter gallring i ett blandbestånd av gran och tall, Sverige
242 Caroline Jonsson (2012) The relationship between climate change and grazing by herbivores; their impact on the carbon cycle in Arctic environments
243 Carolina Emanuelsson and Elna Rasmusson (2012) The effects of soil erosion on nutrient content in smallholding tea lands in Matara district, Sri Lanka
244 John Bengtsson and Eric Torkelsson (2012) The Potential Impact of Changing

Vegetation on Thawing Permafrost: Effects of manipulated vegetation on summer ground temperatures and soil moisture in Abisko, Sweden

245 Linnea Jonsson (2012). Impacts of climate change on Pedunculate oak and Phytophthora activity in north and central Europe

246 Ulrika Belsing (2012) Arktis och Antarktis föränderliga havsistäcken

247 Anna Lindstein (2012) Riskområden för erosion och näringsläckage i Segeåns avrinningsområde

248 Bodil Englund (2012) Klimatanpassningsarbete kring stigande havsnivåer i Kalmar läns kustkommuner

249 Alexandra Dicander (2012) GIS-baserad översvämningskartering i Segeåns avrinningsområde

250 Johannes Jonsson (2012) Defining phenology events with digital repeat photography