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Impact of climate change on bear-movement regarding berry foraging

Feedback on spatio-temporal data analyses

Erwin Pier

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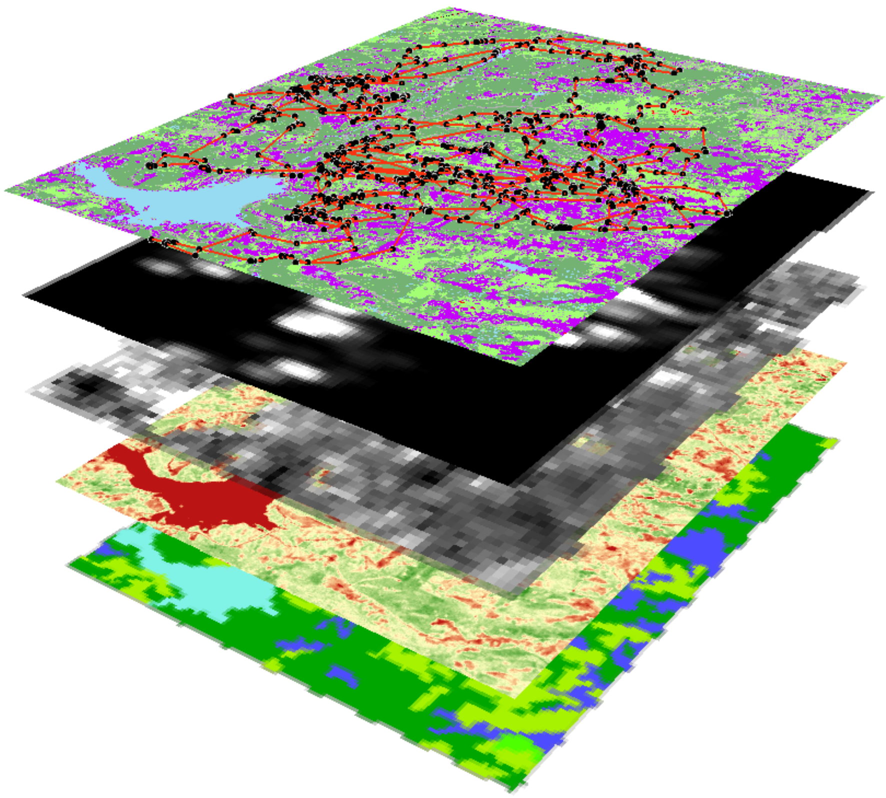

Impact of climate change on bear-movement regarding berry foraging

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Mother’s little Olle

Mother’s little Olle, walked in the woods.
Rosy cheeks, a sunny look.
And little lips blue of berries.
If only I didn’t have to walk here alone!
Brummelibrum, who lumbers there?

The bushes are creaking, a dog surely it is.
Shaggy is the fur. But Olle is happy.
O, a friend. That is good. Good Day!
He cuddles the bear with hands so small.
Offers him the basket! Look, have a taste!
Teddy devours almost all that there is.
Listen, I think you like berries!

Mother now discovered them, she lets out a cry.
The bear ran away, now the game is over.
Oh, why did you frighten away my friend?
Please little mother, ask him to come again!

Alice Tegnér 1895
Swedish children's song
based on true story from the Dalarna region.

Foreword

At the start of my thesis I wanted to focus purely on GIS analyses, which I always liked. However, during the first weeks it came to my mind that I also learned a lot about remote sensing during the study. It would be a shame if I would not use this knowledge. Therefore, after another meeting with Ron we decided to do a thesis which includes both worlds. The bear data as the GIS world and the berry distribution and plant phenology would cover the remote sensing part.

During my thesis when I told people what my research was about, the common reaction was like: brown bears eat fish, I have seen that on the television. This is true for some brown bear populations, but that it is not the case for the bear population in Sweden. The bears in Sweden rely mostly on other food sources.

This report is the result of a half year work. During this period I have had the usual ups and downs, but the endless enthusiasm of Ron van Lammeren and support of family and friends kept me going. Therefore I want to thank Ron van Lammeren for this enthusiasm about the project and support. Also from the WUR I want to thank Harm Bartholomeus for his input and feedback on this report. From the University of Life Science, Department of Ecology and Natural Resource Management in Norway I want to thank Andreas Zedrosser for his input and feedback. Last, but not least I want to thank the Scandinavian Brown Bear Research Project for the possibility of making use of the bear track data. Without this data it would not have been possible to perform this research.

Abstract

Little is known about the berry abundance influencing the brown bear (*Ursus Arctos*) distribution in central Sweden. It is not yet known what happens when this main food source (berries) during the hyperphagia will become less abundant as normal, which may happen due to a changing climate. The berries are estimated to contribute for about 45% of annual energy intake. On average the berry season lasts from mid-July till the end of October. The bear data of only August is used to find correlations between berry abundance and bear behaviour. The MODIS composite NDVI imagery is used to find evidence for global warming by extracting plant phenology parameters with Timesat. The results are compared over a period of 8 years (2003-2010). The suggested increase in growing season length (indication of global warming) was not found in the study area. There are however other spatial trends found in the study area, e.g. a negative correlation between elevation with the growing season length. To find out whether the berry abundance has an influence on the bear behaviour it is necessary to know where these berries are located. After some methods to improve the image quality (i.e. gap filled and pan-sharpened Landsat 7 imagery) it was tried to find these berry locations. The resolution of the imagery is however too coarse (15m) and it is spectrally not detailed enough to distinguish berries from other vegetation. This is partially the result of the growing conditions of the berry shrubs (partial shadow of trees). In this research 6 brown bears are tracked for 6 years (2004-2009). The locations are used to find correlations between bear behaviour (travelled distance, home range size, land use selection and bear-human interactions) during the berry season and the berry yields provided by the Swedish University of Agricultural Sciences (SLU). The bears show ambiguous behaviour and therefore it can be concluded that not only the berries influence the bear behaviour. This can be underpinned by the fact that the phenology parameter values (e.g. length of season and max NDVI) at berry locations show ambiguous results with the bear density. The bears are also influenced by their reproductive status and dominance relationships. Previous studies suggested difference in bear behaviour regarding reproductive status. Therefore it is recommended to make a longer time series and add these missing bear behaviour parameters.

Keywords
Brown bear | Ursus Arctos | Behaviour | Plant phenology | Berry | NDVI | SBBRP

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Acronym list

BB	Correlation with blueberry yield
BB/LB	Correlation with the averaged blueberry and lingonberry yields
DEM	Digital Elevation Model
DP	Darkest Pixel Correction
GPS	Global Positioning System
IHS	Intensity Hue Saturation Pan-sharpening method
LB	Correlation with lingonberry yield
NDVI	Normalized Difference Vegetation Index
PCM	Principal Component Pan-sharpening Method
SBBRP	Scandinavian Brown Bear Research Project
SAM	Spectral Angle Mapper
SLC	Scan Line Corrector
SLU	Swedish University of Agricultural Sciences
SMHI	Swedish Meteorological and Hydrological Institute

1 Introduction

This chapter provides the introduction and background information on my research topic about the impact of climate change on bear-movement regarding berry foraging. This chapter also covers the objectives and research questions. The final section shows how the following chapters elaborate upon the research questions in favour of the overall research objective.

1.1 Context

Due to persecution for centuries the brown bear (*Ursus arctos*) gradually disappeared from much of Western Europe (Zedrosser et al. 2011). The hunting lasted till the end of the 1800s and beginning of the 1900s. At the time a critically low amount of brown bears remained in Sweden and Norway which resulted in a law which forbids to hunt brown bears (SBBRP 2011). In 1943 conservative hunting was reinstated in Sweden, which did not have downsides only. The distribution of brown bears has increased significantly since then (Curry-Lindahl 1972, Sæther et al. 1998, Kindberg et al. 2011). Besides, the Scandinavian brown bear population is regarded as the most productive worldwide (Zedrosser et al. 2000), with an approximate growth rate of an estimated 4.5% per year (Kindberg et al. 2011, SBBRP 2011). The total amount of brown bears in Sweden is estimated around 3221 in 2008 (SBBRP 2011). The brown bear belongs to the group of large carnivores which are very difficult to inventory. They occur in relatively low densities, also in the major bear areas. Furthermore, brown bears avoid as much as possible people and buildings (Gittleman et al. 2001, SBBRP 2011).

Nowadays the brown bear is a protected species and several European countries established programs to protect the European brown bear from total extinction. One of these projects is the Scandinavian Brown Bear Research Project (SBBRP). The SBBRP is active since 1984 and tries to get a better understanding of the ecology of the Scandinavian brown bears in Norway and Sweden. Besides, it provides information to the public, which helps the conservation management of the brown bears (SBBRP 2011). The SBBRP focuses mainly on brown bears in two specific regions. The southern study area is in the counties of Dalarna and Gavleborg in Sweden and Hedmark in Norway, the northern study area is located in the Swedish Norrbotten County (SBBRP 2011).

1.2 Background

Since the 1960s radio-collars have been used to study terrestrial wildlife (Craighead 1982, Craighead et al. 1995). Many of these collars are replaced by the in popularity increasing GPS collars. Researchers prefer GPS collars over radio-collars due to higher spatial and temporal resolution data (Hebblewhite et al. 2010). The SBBRP also used to monitor the bear movement with radio-collars, but since 2003 GPS movement monitoring began to get more detailed movement information (SBBRP 2011). Since GPS is used the temporal scale of the measurements has increased enormously.

Figure 1: Brown bear attracted to berries © Staffan Widstrand

Brown bears are omnivores which mean that they eat actually everything. However studies have shown that there is not much difference in the diet of brown bears over the years (Persson et al. 2001). The main food resources for the brown bears are berries, moose and ants, with estimated annual energy intakes of 44-46%, 14-30% and 14-22%, respectively (Dahle et al. 1998, Persson et al. 2001). Hence it can be concluded that berries are a very important food supply for brown bears (Figure 1). Most of the berries are eaten during the berry season which lasts from mid-July till the end of October (Nilsen 2002). Especially during this period of the year it is important for brown bears to have a steady food supply. During this period they need to gain weight for the hibernation, which lasts from November to April (Swenson et al. 2000). Before the hibernation the food intake more than doubles (hyperphagia), and their body weight increases 30-35% (Hissa et al. 1998). Welch et al. (1997) suggested that bears that live in captivity can eat up to one third of their own body weight daily in fresh fruits. Nevertheless brown bears do not only eat berries, even when it is seasonally abundant. Berries are high on sugars, but low on certain other nutrients, which can lead to an increase in metabolism.

According to Jonkel et al. (1971) a relationship between berry abundance and reproductive success of North American black bears (*Ursus americanus*) exists. Therefore berries seem to be very important for survival of the species.

Many studies, described previously, have given an insight in the diet of brown bears. It is however not yet known what happens if the main food source will become less abundant as normal, which may happen due to a changing climate. Do brown bears stay in the same area to find other food sources, or do they go to other areas and find the main food source there? Brown bears are opportunistic feeders, and they adapt well to new food sources (Swenson et al. 2000). A low variation in food intake suggests however that they go to different berry areas when a food source becomes less abundant as normal.

Over the last decade, the Normalized Difference Vegetation Index (NDVI) has proven extremely useful in animal ecology (Pettorelli et al. 2011). Green leaves have high visible light absorption together with high near-infrared reflectance, resulting in positive NDVI values. Bare soil, cloud, snow, and concrete have NDVI values close to zero, while water has negative NDVI values (Neigh et al. 2008).

Studies have shown a relationship between NDVI and species abundance, which does not only include herbivores. NDVI is correlated with the primary productivity of vegetation (Pettorelli et al. 2005, Oindo 2007), and the primary productivity of an area influences its entire food web (McNaughton et al. 1989). A strong relation was found between the migrant wildebeest population size and the NDVI imagery (NOAA-AVHRR) during the migratory period (Ottichilo 2000). Therefore, it is often assumed that NDVI correlates with seasonal average energy availability, for example, in herbivores (Andersen et al. 2004, Garel et al. 2006), and carnivores (Herfindal et al. 2005, Nilsen et al. 2005). Many of these NDVI related movement studies are conducted in Africa, where the intra-annual fluctuation in NDVI is much bigger than in Sweden. Besides, the wildebeest in Africa do migrate, in contrast to the brown bear. Most of the mentioned studies analysed intra-annual phenomena (cyclical variation) and not differences over multiple years (trend variation).

A study by Hansen et al. (1999) has shown that the northern high latitudes have warmed up by 0.8^{o}C since the early 1970s. The increase in temperature can be correlated with an increase in NDVI and growing season length (Zhou et al. 2001). Due to these changes it is possible that the food sources shift, which can result in migration of brown bears to different areas. This might result in more bear-human interactions. In areas with free ranging cattle, or other human interests problems can occur. Preliminary results suggest however that the brown bears avoid human interactions (Swenson et al. 1996). Despite the avoidance, the emotion of fear is a widespread phenomenon in relation to large carnivores (Kanzaki et al. 1996, Roskaft et al. 2003).

NDVI and animal movement studies have not yet been conducted with this detailed data made available by the SBBRP. Before the GPS technology it was impossible to conduct a full scale migration study (Hebblewhite 2010).

1.3 Objective

Not much is known about the influence of berry abundance on the movement of brown bears during the berry season. Therefore the aim of this research is to find out whether there is a correlation between the NDVI and bear movement data during the berry foraging season. Due to recent studies described above it can be hypothesized that the NDVI, and therefore the abundance of berries, are correlated to the movement of brown bears. The challenge of this study is to find these trends and correlations in the limited time period (2004-2009) due to the availability of data.

The objective can be met in two ways. The first one is to find areas where bear behaviour changes over time, and try to explain this changing behaviour with the NDVI data. The other and chosen route of this study to meet the objective is to find areas where the NDVI is changing over time and find out whether the bear behaviour has changed in those areas. If everything is correct then the results of both ways should give the same results.

1.4 Research questions

The next research questions are answered in this exploratory thesis study.

1. Can NDVI trends be derived from satellite imagery in northern high latitudes in evergreen forest?
2. Is it possible to extract berry sites from satellite imagery?
3. Can brown bear behaviour be explained by berry availability?
4. Is there a correlation between bear-human interaction and berry abundance?

1.5 Thesis structure

This report starts with a small introduction about the study area in 2.1. It continues with an explanation about the data used and some of its properties (2.2). A small introduction about the berry species occurring in the study area is located in 2.3. The berry yields recorded over the last 6 years are also discussed here. In 2.4 the pre-processing steps of several data sets are listed. For each of the research questions the necessary processing steps are also listed. The 3rd chapter shows the results for each of the research questions and includes discussion. The conclusion and recommendations are located in the final chapter (4) of this report.

2 Methodology

In this chapter the study area is elaborately described and used datasets are further explained. Also the processing steps (methods) used to solve the research questions are treated in this chapter.

2.1 Study area

The study area is located in the counties of Dalarna and Gävleborg in south-central Sweden (Figure 2a). This research focuses on a subarea of the southern study area of the SBBRP. Within this area there is a high density of brown bears (Haberkorn 2011). The study area has many lakes and peat bogs, but the area is mostly covered with shrubs and boreal forest (Table 2). Figure 2b, 2c gives an impression of the study area. The dominating tree species are Scots pine (*Pinus sylvestris*) or Norway spruce (*Picea abies*), but also Lodgepole pine (*Pinus contorta*), birches (*Betula spp.*) and European aspen (*Populus tremula*) are present in the study area (Moe et al. 2007). Dwarf shrubs and mosses dominate in the field layer, while individual herbs, including berry shrubs, are scattered. A rolling landscape with elevations ranging from 125 m is present in the south-eastern part which increases to about 600 m in the western part. A few major roads cross the study area, in addition there is also an extensive small (logging) road network present in the area. In addition there are also several small villages present in the southern part of the area and some hamlets are scattered over the study area. The study area is highly affected by logging. Within the period 2000-2006 almost 200 km^2 of forest is felled (Corine 2000-2006 change analysis). These areas are mostly replanted.

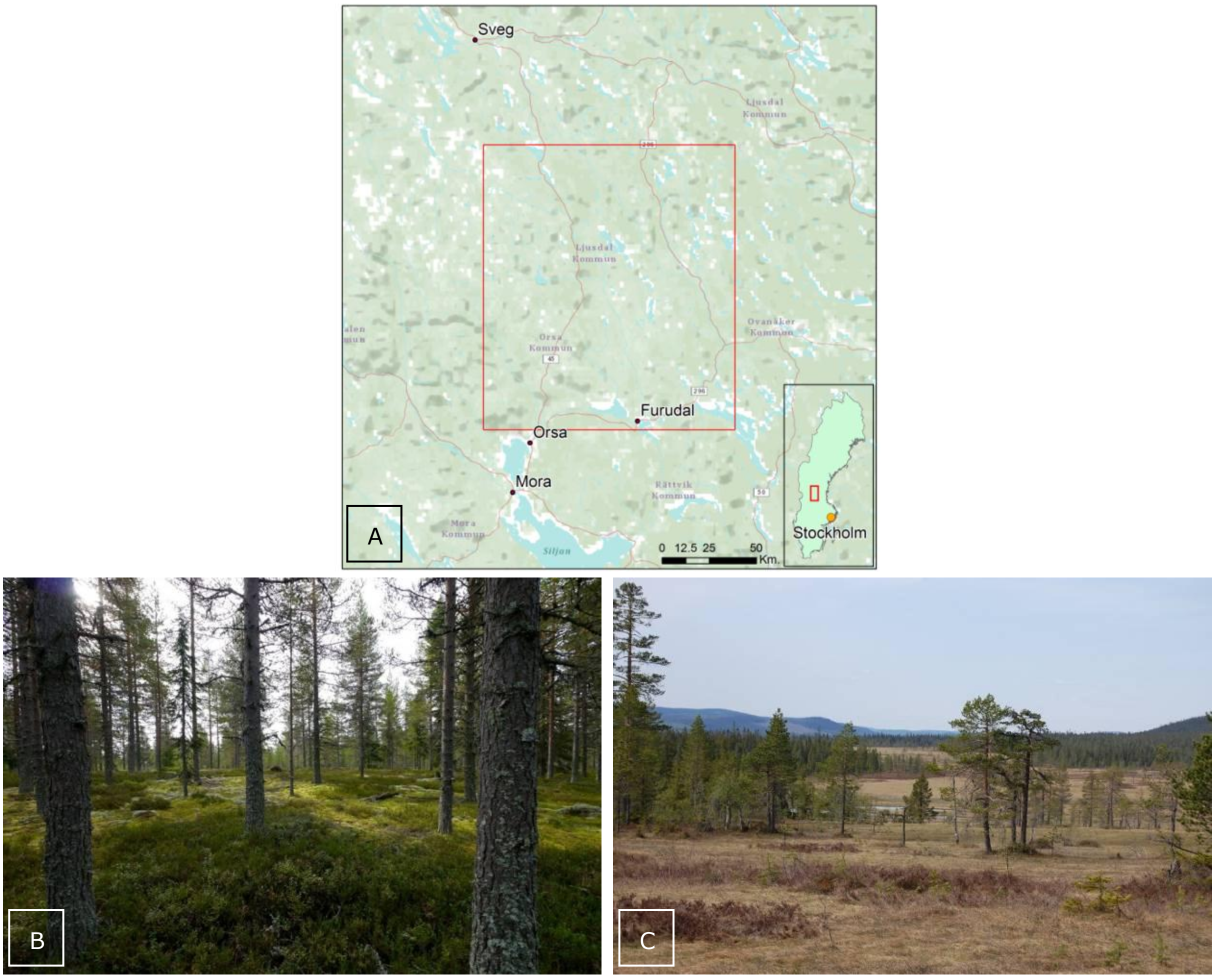

Figure 2: On top (A) the location of the study area in red. On the bottom left (B) pine trees with herbs/shrubs understory (Corine class: Coniferous forest). On the bottom right (C) open fields due to forestry (Corine class: Transitional woodland-shrub). © Panoramio.

2.2 Data

In this paragraph an explanation of all the different data sources used in this research.

2.2.1 Bear positions

The bear position data acquired by the SBBRP is used to monitor the movement of the brown bears. The position data of 91 individual brown bears is acquired in 2008 (SBBRP 2011). The position determent by GPS-collars has an indicated accuracy of 10-15 meters (Schulte 2011), with a logging frequency ranging from 1 up to 30 minutes. Low GPS accuracy and false position fixes can result in a lower logging frequency, due position quality control during pre-processing.

For each year only the positions which are captured during the middle of the berry season (August) are used in any of the analyses. The start and end of the berry season can fluctuate. Therefore only the recorded positions of August are used to be certain that only the berry season is investigated. Possible false or low quality measurements can be detected and removed during the pre-processing of the positions. The pre-processing is more elaborately described further on in this report. At the start of this research 4 individual bears were analysed. However due to a short tracing period of 4 years (2006-2009) 2 more bears were added to the analysis to lengthen the time series (Table 1). The 6 selected bears are all females. Females stay in a smaller area over the years than males, which make longer distances to find females (SBBRP 2011). The behaviour of bears depends on many factors, habitat quality and whether they have cubs, are some examples (Parks Canada 2011). The selected bears have the longest individual tracking period. Due to the relative, in comparison with previous studies, high logging frequency it is possible to 'see' the actual movement behaviour of the bears.

During the hyperphagia bears can be active foraging for 20-23 hours a day (Parks Canada 2011). Therefore all the positions throughout the day are used in this research. The bears prefer different habitat type during resting periods (Moe et al. 2007). This assumed have little influence on the final results due to the fact that the bears are active for almost all day.

Table 1: Characteristics of the selected bears.

ID number	Name	Gender	Tracked since	Data availability	Weight[1]	Cubs
W0004	Öda	Female	1994	2004,2006-2008	95	2005, 2007
W0212	Salma	Female	2001	2005-2008	110	2008[2]
W0411	Kassika	Female	2003	2006-2009	90	2007[2]
W0422	Jämta	Female	2003	2006-2009	82	2009[2]
W0626	Koski	Female	1999	2006-2009	90	2008
W9403	Grivla	Female	1993	2006-2009	87	2004[2], 2005, 2008

(1) Latest available data in kilograms, acquisition dates differ.
(2) Cubs lost during the mating season, which occurs from mid-May to early July (Curry-Lindahl 1972).

The study is focussed on the 2004-2009 period, over the years the logging frequency and total amount of followed brown bears has increased, as can be seen in Figure 3. According to Haberkorn (2011) the logging frequency increased from 34.9 minutes in 2006 to 12.8 minutes in the 2009. The increased logging frequency and the increased number of tracked bears resulted in a huge increase in data volume over the years. For this research it is important to use data which has an equal logging frequency for an time series as long as possible. This is also one of the reasons why these 6 bears are used in the analysis.

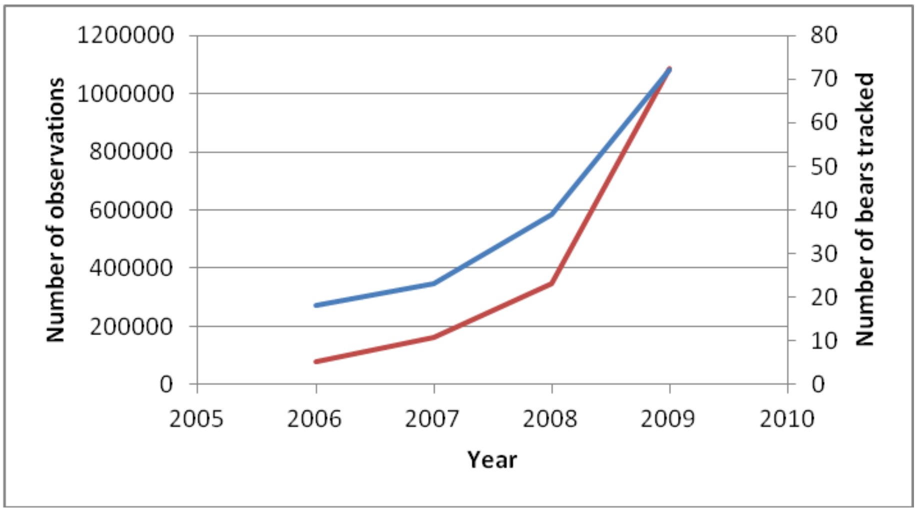

Figure 3: The blue line shows the number of bears tracked and the red line number of observations per year.

To be able to compare the bears over the years it is necessary to correct for the increased logging frequency. An equal logging frequency is necessary due to the fact that bear densities are calculated further on in this research. The densities would give biased results if there was not corrected for an increasing logging frequency. The logging frequency is corrected by merging the highest logging frequencies till they add-up to 30 minutes, which is the most common logging frequency over all the years. In addition the speed and distances are calculated, hence it is possible to detect and remove outliers in the GPS data. After the data filtering the bears have all a usable average logging frequency of about 30 minutes. All the pre-processing steps are visualised in Appendix I.

2.2.2 NDVI

For the vegetation and global warming analyses the NDVI index is used. The NDVI index is calculated with the red and near infrared bands of remotely sensed imagery. Equation 1 gives the formula. NDVI strongly reduces the impact of varying illumination conditions and shadowing effects caused by variations in solar and viewing angle (Kimwa et al. 1984).

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

In which the *NIR* is the Near Infrared band, and *R* is the Red band of the input image.

An inventory is made to find all the suitable remote sensing satellites sources. For this project it is required that the satellite should at least have a red and a near-infrared band to be able to derive the NDVI. It is also preferred that the imagery is freely available. Besides, the spatial resolution is very important because the bear track data has a high spatial detail due to the high logging frequency. In addition it is important that there are images available for the entire time series (2003-2010), and a low revisiting time is important. If there is a short interval between the images then it is more likely that there are cloud free images available. Many high spatial resolution satellites like SPOT for example has a low revisiting time due to a programmable sensor, which can be aimed at a certain location. This is however not possible for the past, therefore it is likely that large parts of the study area do have a partially or no image cover for all of the years. The IRS-P6 Resourcesat-1, Landsat, MERIS and MODIS satellites do have a full image cover for all of the years. Of these satellites the Landsat seems to be the most suitable for the project. The images have a relatively high spatial resolution (30m) with a low revisiting time (16 days), it has a long time series, and its freely available. MODIS also seems to be suitable for this project because it has a very low revisiting time and a long enough time series, and its freely available. The MODIS pixel size is 250 meters with a revisiting time of less than a day.

Landsat

The NDVI index can be calculated with the red and near infrared bands of the Landsat satellite. Due to a failing Scan Line Corrector (SLC) since May 31 2003 the Landsat 7 images are not usable for a time series analysis, because large data gaps at the edges of the images occur, which results in a data loss of 22%. Some techniques are available to partially correct this error (Scaramuzza 2004). Fully correcting for this error is however not possible. The Landsat 7 imagery is however used to create a berry distribution map. Landsat 4-5 (TM) images are used to create a NDVI time series. Herold et al. (2008) stated that Landsat images are suitable for inter-annual analysis. The images have a spatial resolution of 30 meters, and a revisiting time of 16 days. The amount of data available can be less due to cloud cover. Almost all images of the area in August do have a certain quantities of cloud cover.

The downloadable Landsat images[1] are processed by the United States Geological Survey (USGS) and are corrected for the terrain (Level 1T). It provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy. Before the data can be used to make a time series an atmospheric correction needs to be performed, because the atmospheric conditions varies over the time.

MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) has several products freely available online[2]. One of the products is the NDVI 16 day composite, which is used in this study. This means that a NDVI image is available for every 16 days. The image is a composition of multiple images. The NDVI value which has the highest quality of all the images acquired, within the 16 day period, is used to compose the composite image. Due to the best pixel selection the influence of cloud cover is much less than it is for the Landsat images. Due to the short revisiting time of 2 times a day it is possible to generate almost always cloud-free images (Kutser et al. 2007).

2.2.3 Aster GDEM

To be able to explain some of the spatial trends occurring in the study area the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) is used. The GDEM has a spatial resolution of 30 meters[3] and it is freely available. In October 2011 a new dataset has published: Aster GDEM V2. The second version has an improved coverage, and better water masking. The second, and latest, version is used in this research.

2.2.4 Land cover datasets

To explain the bear behaviour the Corine 2006[4] land use dataset is used. Corine is a Europe covering land use dataset which contains 44 land use classes (16 within the study area, Table 2Table 2). The dataset is derived from SPOT-4 and IRS P6 imagery, with a total production time of 1.5 years. To classify an area 2 remotely sensed images is used with a time interval of about 1 year, to improve photo interpretation. The Corine 2000 land cover dataset is also used as basis for the 2006 version (European Environment Agency 2011). The spatial resolution of the Corine dataset is 100 meters, and it is the

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[1] Landsat data are downloaded from http://glovis.usgs.gov,also the latest not yet pre-processed images can be requested there for processing.

[2] MODIS data are downloaded from: ftp://e4ftl01.cr.usgs.gov/MOLT/

[3] http://www.gdem.aster.ersdac.or.jp/index.jsp

[4] The Corine dataset is available at: http://www.eea.europa.eu/

dataset with highest spatial resolution freely available. Therefore it is very much of use in a remote area like the study area in this research. Due to forestry changes may occur over time, but the Corine 2006 falls right in the middle of the study period (2004-2009). Therefore it can be concluded that it is the best up-to-date dataset freely available.

The Federal Agency for Nature Conservation in Bonn Germany has produced a Map of Natural Vegetation of Europe at a scale of 1:2,500,000. This map gives a rough idea which land cover types are present in the area. It also provides a list of ground cover species occurring in the area. This map is generated in 2004.

2.2.5 Human influence data

For the human influence analysis data from the Open Source Map (OSM) is used. This is a more detailed dataset than the data which can be obtained from the national geo-portal of Sweden[5]. The OSM roads, railroads, and places (villages/hamlets) are used in this study. The OSM is established and updated by volunteers. Therefore it is unknown whether the datasets are complete and the spatial quality is unknown. The quality and completeness of the datasets is therefore checked before the data is used.

Table 2: Land cover types in the study area, the total area is 10876.6 km^2

Corine land cover type	Percentage of total area (%)
Urban area	0.13
Airports	0.03
Sport and leisure facilities	0.03
Non-irrigated arable land	0.12
Pastures	0.04
Complex cultivation patterns	0.16
Partially agriculture	0.22
Broad-leaved forest	0.02
Coniferous forest	63.56
Mixed forest	0.73
Transitional woodland-shrub	22.89
Burnt areas	0.02
Inland marshes	0.05
Peat bogs	6.72
Water courses	0.02
Water bodies	5.28

5 Website: http://www.geodata.se/GeodataExplorer/index.jsp

2.3 Berry phenology

This paragraph describes the main characteristics of the selected berry species and berry yields as provided by the Swedish University of Agricultural Sciences (SLU).

2.3.1 Main characteristics

The blueberry (*Vaccinium myrtillus)* and lingonberry (*Vaccinium vitis-ideae*) (Figure 4**,** Figure 5) are analysed to test the hypothesised correlation with the bear density. Especially these 2 berry species are selected because they occur in the entire study area according to the European Vegetation Map. In addition there is also yield information available of these 2 berry species. The analysed berry species are also the berry species which are mostly preferred by the bears (SBBRP 2011).

Figure 4: On the left lingonberry bushes, on the right a blueberry bush.
© Panoramio and Ola Langvall (SLU)

Artic flavours (2011) suggests that the best growing conditions for berries fluctuates for each species, but most berry species like direct or indirect sunlight. Besides, a different moisture level and temperature is preferred by the different berry species (The virtual climatic laboratory 2011).

According to Kardell (1979) the Swedish forests produce an estimate of 500 million tons of berries a year. The blueberries and lingonberries are found in nearly all the forests, and are probably among the country's most common plants. Blueberries cover 17% (3.9 million ha) and lingonberries 5% (1.2 million ha) of the country's productive forest land (Kardell 1979). Lingonberries differ from blueberries because they usually have rather higher fertility than blueberries in clear-cut areas and in young forests (Kardell 1979, Reynolds-Hogland et al. 2006). The production of berries of both of the species is low in very young clear-cuts (Freedman et al. 1981, Reynolds-Hogland et al. 2006). In full sunlight locations (very young clear-cuts) the berry species are mostly out-competed by heather. In the shaded areas the berry species successfully competes heather (Ritchie 1956, Hester et al. 1991a,b).

The lingonberry is classified as a dwarf shrub which can reach a height of 30cm. The shrub grows mainly in the spring where after the white flowers emerge during the summer. The berries are ripe between August and October (Nilsen 2002, Eisenreich et al. 2004). The lingonberry thrives best in the Scottish pine forests and in very good soil. The age of the forest does almost not influence the lingonberry occurrence. The lingonberry occurrence varies from 5% in young forests till 7% in older forests (Kardell 1979). A decrease in occurrence and productivity in clear-cuts was however found by Nilsen et al. (2005). The difference can be explained by the fact that the

Figure 5: Blueberries on the left and lingonberries on the right.
© Staffan Widstrand

study area of Nilsen was located in Canada whilst Kardell's study area was located in Sweden. Therefore it is assumed that the results of Kardell are the most representative for this study.

The blueberry is classified as a deciduous dwarf shrub which can grow up till 50cm tall. The height of the plants is however depended on the altitude the plant grows. The higher the altitude the less tall the plants get due to lower temperatures, stronger winds and greater exposure (Parlane et al. 2006). The flowers occur in May/June, about eight weeks later the berries are ripe, which is between July and September (Nilsen 2002, Eisenreich et al. 2004, SLU 2006). According to Atlegrim et al. (1996) blueberries thrive best in forest of Norway spruce, with an average soil. The bushes are most frequent in semi-open forests, and are less common in very open or dense forests (Atlegrim et al. 1996). Blueberries commonly grows together with the lingonberries and heather (*Calluna vulgaris*). At young clear-cut locations and in young forests about 5% of the ground is covered with blueberry bushes. The coverage increases when the forest gets older, the increase continues until the stand is 80-100 years old. An average 20-25% of the forest ground in old coniferous stands is covered with blueberry bushes (Kardell 1979).

The weather is one of the most important factors influencing the berry yields. Bad weather during the flowering period can influence the berry yields, due to frost flowers can be damaged and other bad weather like strong winds can reduce the ability of insects to fertilize the flowers (SLU 2006). Therefore is the weather one of the most important factors for having a good berry year. These weather conditions can vary on a short distance, therefore the berry production can also vary within the study area.

The berry yields (see 2.3.2) are correlated with the minimum temperatures recorded by the Swedish Meteorological and Hydrological Institute (SMHI) of a ground station located in Malung[6]. During the first months of the year the minimum temperature shows unambiguous negative correlations. This indicates that there are more berries when the minimum temperature is less. During the rest of the year the correlations are positive. Other available meteorological data like, precipitation and snow cover does not show significant correlations.

2.3.2 Available yield data

The SLU keeps track of the blueberry and lingonberry yields since 2003 (Figure 6). In this figure are the berry yields of the 2 main berry species depicted. The measurements are conducted by the Swedish National Forest Inventory and experimental farms at the SLU unit of Forest field research. During the summer the SLU makes a berry yield prediction based on the number of flowers occurring. After the berry season the predictions are being verified by comparing them with the actual yields. These actual yields are also published. The actual yields are used to create a better prediction next year. The yield predictions of the blue- and lingonberry are made for 3 different regions in Sweden, north, middle, and south. The study area is situated in the middle region. Large variations in berry yields within a region can occur due to the small amount of regions, and the weather dependency. Within Sweden there is also a high variation in time when berries are ripen. According to the Swedish nature calendar[7] the difference between north and south can be as much as a month, the southern berries ripen first. From Figure 6 can be concluded that the lingonberry plants do produce more berries than blueberries.

A not significant correlation between the 2 berry species yields (R = 0.16, N = 8) confirms that the berry species have different optimal growing conditions. Therefore it is possible that one berry species flourish whilst the other crop fails. According to Nilsen (2002) brown bears in Sweden do prefer the blueberries over the lingonberries, which act more like a buffer when the blueberry crop fails. The crowberry (*Empetrum nigrum*) is the least important berry species regarding bear preferences. The crowberry does also occur in the study area. The crowberry thrives also best in the forests, however it also occurs in peat

[6] http://data.smhi.se/met/climate/time_series/3hours/
[7] http://www.blommar.nu/

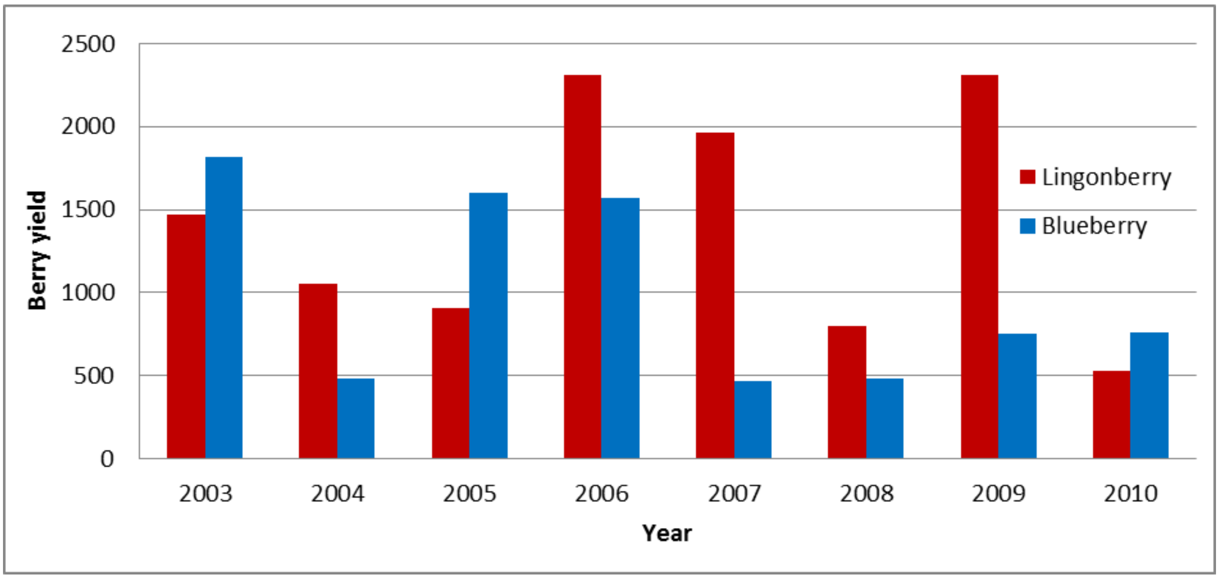

Figure 6: Berry yields of the middle region of Sweden provided by the SLU. On the vertical axis a unit less number which has been calculated, so it was possible to compare the two berry species with each other.

lands (SBBRP 2011). The blueberries contribute for 80% of the total berry intake (Persson et al. 2001). Due to these berry species preferences the different yields can also be used as one class.

The SBBRP also recorded some locations of berry shrubs within the study area and included the following information. The date of acquiring the position, the position itself, and the berry abundance ranging from 0 to 4, which reflects none to high level of berry yields respectively. The exact amount e.g., weight, or number of berries is not recorded. In addition the date when a bear visited the area is recorded. The locations include blue-, lingon-, and crowberry plants. In the data these different species is not differentiated.

2.4 Processing

In the next sub-paragraphs the working process is elaborately described for each of the research questions. In Figure 7 the main processing steps are visualised which are needed to answer the research questions.

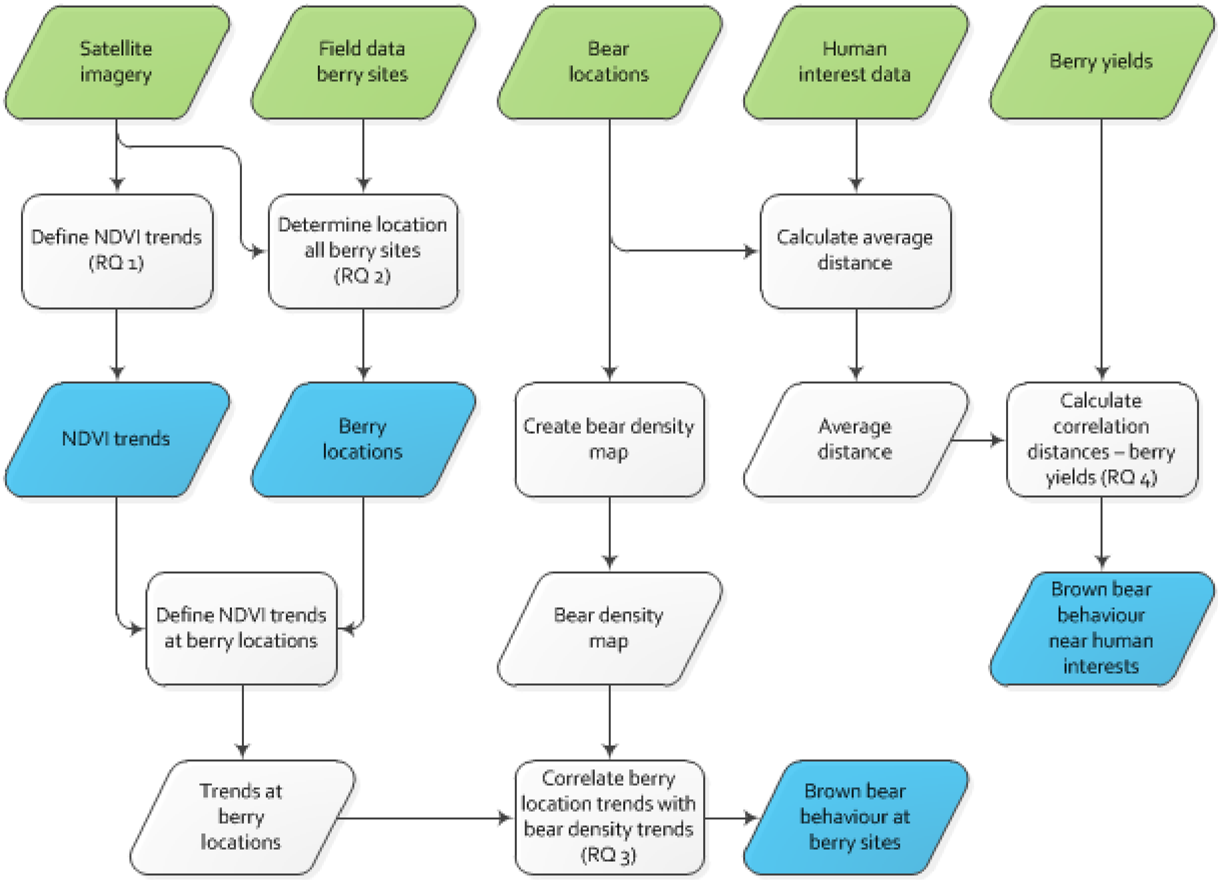

Figure 7: Main processing steps needed to answer the research questions.

2.4.1 NDVI trends

In Appendix II the entire process needed to answer the first research question is visualised.

Landsat

To extract the NDVI trends Landsat imagery from August within the period 2003-2009 are downloaded. The downloaded images are pre-processed firstly and afterwards processed to NDVI maps. During the pre-processing every image is corrected for fluctuating atmospheric conditions by performing a Darkest Pixel (DP) correction. Where after all the images can be treated equally and therefore cloud, shadow, and water masks can be created. These masks are created with ArcGIS as well as with Erdas. The masked areas are removed from the input image where after the NDVI can be calculated. A more detailed description of the Landsat pre-processing steps is available in Appendix III.

Almost every downloaded Landsat image did have some cloud cover. In 2004 and 2008 there was too much cloud cover, so none of the images are usable. For the other images it was possible to make cloud and (cloud)shadow masks to delete these parts from the image. At first it was suggested to fill these parts with data of a previous image or an image from an adjacent satellite row. However when different images from different dates are combined it is no longer possible to find out what caused a possible difference in NDVI. The difference can be the result of a decrease in vegetation, different weather conditions, or decrease in vegetation due to a time shift thus the end of season already started. The map in Appendix IV shows the cumulative result of cloud cover in the study area. It can be seen that there is a maximum of 6 images in total over 8 years, which means that 2 years are missing (2004, 2008). In large parts of the study area the maximum number of images available are lower than 6 images. Due to the low availability of images it becomes very difficult to make a good time series. Hence it would not be possible to find any trends in NDVI. Therefore it was concluded that Landsat was not suitable for creating a time series for this project.

MODIS

The MODIS images downloaded do not have to be corrected for cloud cover, because the composition algorithm relies on observations over a 16-day period to generate a composited image.

The MODIS vegetation index algorithm operates on a per-pixel basis. Due to sensor orbit overlap and multiple observations in a single day, a maximum of 32 observations over a 16-day cycle may be collected (Huete et al. 2002). However, due to cloud cover and actual sensor spatial coverage, this number ranges between 0 and 32. Once all 16 days of observations are collected, the data is filtered based on quality, cloud, and viewing geometry. Only the high quality, cloud-free, filtered data are retained for compositing (Huete et al. 2002). Cloud-contaminated pixels and extreme off-nadir sensor view angles are considered lower quality while cloud-free and nadir-view pixels with minimal residual atmospheric aerosols represent the best quality pixels (van Leeuwen et al. 1999).

The MODIS composite images make it possible to perform a more extended NDVI trend analysis. This is possible due to the fact that there are images available throughout the year. Therefore it is also possible to find out whether for example the start of the growing season has an influence on berry abundance and bear distribution. It is assumed that much more factors preceding the berry ripening have an influence on the berry yields, and not only the NDVI in August.

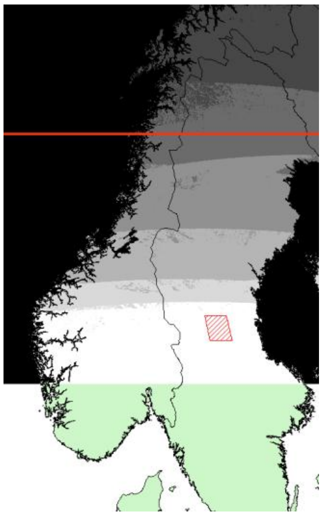

Figure 8: MODIS data gaps, the darker the colour the less data is available. With a minimum and maximum of 16 and 23 respectively. The red line is the arctic circle.

The study area is located less than 5 degrees below the polar circle, therefore there is data available of all year round. During the winter no data is available higher than the polar circle due to the fact that the sun is below the horizon the entire day. Therefore it is impossible in those regions to use optical remote sensing. In Figure 8 these data gaps are visualised, the least data is available during the end of December and beginning of January. At the transitions the data quality is lower than average, this is the results of a lower amount of available satellite data. The minimum available data is 16 images per year, located in the upper north part of Sweden. In the southern part of Sweden, which includes the study area, there are the maximum of 23 images per year available.

With Timesat it is possible to extract plant phenology parameters from the MODIS NDVI composition imagery. By making use of fitted functions the noise and uncertainties are reduced, therefore it leads to more stable measures (Eklundh et al. 2009). The phenology parameters are extracted on a per-pixel basis. The output is a raster for each of the parameters and for each year separately. The following parameters are inferred (see also Figure 9).

1. Time of the start of the season.
2. Time of the end of the season.
3. Length of the season; time from the start to the end of the season.
4. Base level; the average of the seasons left and right minimum values.

5. Time of the middle of the season; the mean value of the time that the left edge has increased to the 80 % level and the right edge has decreased to the 80 % level.
6. Largest data value; at which time the maximum value is found in the fitted function.
7. Seasonal amplitude; difference between the maximum value and the base level.
8. Rate of increase at the beginning of the season (left derivative); calculated as the ratio of the difference between the left 20 % and 80 % levels and the corresponding time difference.
9. Rate of decrease at the end of the season (right derivative); calculated as the absolute value of the ratio of the difference between the right 20 % and 80 % levels and the corresponding time difference.
10. Large seasonal integral; integral of the function describing the season from the season start to the season end.
11. Small seasonal integral; integral of the difference between the function describing the season and the base level from season start to season end.

The large and small integral represent the seasonal vegetation production (Enkhzaya et al. 2011). Therefore these parameters can be used to see whether there are any changes in berry production in the study area. A more elaborate description of Timesat and the performed processing steps are available in Appendix V.

Timesat is able to extract plant phenology parameters over the years for almost all pixels. For 6.75% of the pixels it was not possible to extract the plant phenology parameters. Most of these pixels are clustered and are located in forested areas. A possibility is that these pixels do not show any seasonality due to evergreen forest.

Due to the higher resolution of 30 meters the Landsat satellites have a longer revisiting time. And if the cloud cover is taken into consideration much less images are available for each year then for the MODIS data. The MODIS NDVI composite product consists, with some exceptions, of 23 NDVI images per year. In contradiction to MODIS Landsat has about 5-10 usable images available per year, which still have a certain amount of cloud cover. Due to this significant lower amount of images and the changing distributions of images over the years it is not possible to extract seasonal parameters from Landsat imagery. To extract the seasonality data a large amount of images is needed. Therefore this would not

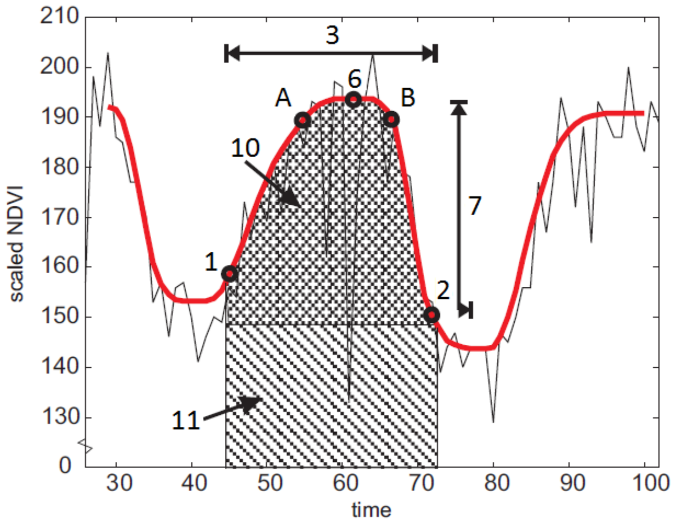

Figure 9: Points 1 and 2 mark the start and end of season. Line 3 represents the length of growing season. Point 6 marks the largest data value. Line 7 represents the amplitude of the season. 10 and 11 are integrals showing the cumulative effect of vegetation during the season. Points A and B represent the 80% levels of the largest data value. Image based on Eklundh et al. 2009

be possible with any other high resolution satellite. Differences between a processed Landsat NDVI image and a MODIS NDVI map is discussed in Appendix VI.

Now the phenology parameters can be derived it is possible to find out whether any spatial and/or temporal trends are occurring in the study area. The spatial trends can indicate that vegetation is influenced by spatial factors. The differences can indicate changes in production of the vegetation and therefore differences in berry yields across the study area. Temporal changes can indicate a changing climate.

Spatial trends

To find out whether there are any spatial trends occurring in the area 2 analyses are performed. The first analysis performed is to check whether the latitude influences the temporal aspect of the growing season. The spatial trend is investigated for the start, end, and length of season. The average parameter value is calculated per kilometre. Therefore the influence of height differences and the distribution of the land use classes has no or less influence on the final result.

The DEM is used to find correlations between the phenological parameters and the altitude. To exclude random events the mean plant phenology parameter value is calculated, all the observations of 8 years are averaged. For each of the parameter it is checked whether any spatial patterns cloud be found by correlating the mean value with the DEM, and several DEM derived products like slope and slope direction. These derived products are created with spatial analyst extension of ArcGIS.

Temporal trends

In addition to spatial trends also temporal trends are deduced. The temporal trend for each of the plant phenology parameter is determined for each pixel separately. The trend is determined by calculating the slope and correlation regarding the derived phenology parameter values throughout the years.
It is important to find out whether any trends are occurring in the area because this can have an influence on the berry availability over time. Which can as hypothesised influence the bear distribution. The derived phenology trends can be the result of global warming. The trend slope and the correlation coefficient (R) of the trend is determined[8]. The correlation coefficient is a number between -1 and 1, that measures the strength of a linear relationship between 2 continuous variables. Whether the correlation coefficient is significant depends on the sample size. Snedecor (1989) provided a table which provides a threshold when a correlation is significantly different from zero. By having 8 years (MODIS) the R^2 needs to be larger than 0.50. For the 6 years of bear positions the R^2 needs to be larger than 0.66 to be significantly different from zero ($P < 0.05$). For some of the analysis the R is used, because it is then possible to determine whether the correlation is positive or negative, which is important for some analyses. If the R is used, then it needs to be larger than 0.71 and 0.81, respectively to be significantly different from zero. The significance level ($P < 0.05$) is also used in other climate trend studies (Fraser et al. 2011). The significance level for bear analyses in other studies varies between 0.05 (McLellan et al. 1988, Kasworm et al. 1990, Rode et al. 2006) and 0.1 (Mattson et al. 1987, Mace et al. 1996), in this study the significance level 0.05 is maintained.

To find out whether a separate land use class is affected by global warming each of the deduced plant phenology parameter results are combined with the Corine land use dataset in ArcGIS. Therefore it is possible to calculate the average plant phenology value for each of the land use classes separately. This allows trend finding, per land use class, and per plant phenology parameter. The calculated average per land use class is also correlated with the berry yields provided by the SLU. The resulting correlations should be the highest for forested land use classes, because most berries do occur in forested areas.

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[8] www.webmaths.co.uk/S1/CORRELATION.ppt

2.4.2 Spatial distribution of berries

After extracting the phenology trends in the study area it is needed to know where the berries occur. This is necessary because it is needed to know what the NDVI, and therefore berry production, does at these locations throughout the years. These results are further used in the following research question to find out whether these differences have an influence on the bear behaviour. The berry yield information provided by the SLU is not spatially detailed enough to be used for analyses with the bear density map. In this part of the report several methods are suggested which should make it possible to create a spatially more detailed berry distribution map. The entire process is also visualised in Appendix VII.

Land use

The first option to create a more spatially detailed berry distribution map is to consult literature about berry occurrence in several land use classes. Kardell (1979) suggested that there is a correlation between berry shrubs occurrence and land use classes. In the boreal forest of Sweden 17% of the ground cover are blueberry shrubs. For the lingonberry this is 5% (Kardell 1979). If other studies which also included other land use classes would be available, then it would be possible to create a more detailed berry distribution map.

Forestry information

Another possibility is to consult forestry data. Literature shows that there is a correlation between forestry and blueberry and lingonberry occurrence. Showing that the berry species are highly affected by clear-cutting (Atlegrim et al. 1996, Nielsen et al. 2004). After clear-cutting a forest stand the berry yields are lower than in the not cleared reference forest. The study of Atlegrim et al. (1996) showed that 80% of the blueberry and 10% of the lingonberry yields disappears during the first years after clear-cutting. During the first period after the clear-cut the berry occurrence is also lower. When the age of the clear-cut increases the berry occurrence firstly increases, but gradually decreases over time (Kardell 1979). Both of the berry species show the same tendencies. During the first years a decrease in coverage is visible which is followed by an increase after 5 years. When the stand reaches an age of 120 years the coverage decreases slowly. Most of the Swedish forest stands are being clear-cut at an age of 120 years (Kardell 1979).

Remotely sensed imagery

Most detailed method covered in this study is to make use satellite imagery like Landsat 7. Despite it was previously mentioned Landsat 7 imagery could not be used it is possible to create a single map. This map is based on multiple images from the same period over several years, despite the failing SLC. NASA developed a tool[9] which is able to correct for this SLC problem by adding information from adjacent scenes of the same period. With the panchromatic band it is possible to increase the spatial detail of a Landsat image. The resolution of the panchromatic band is 15 meters. Due to pan-sharpening techniques it is possible to sharpen the other Landsat bands with the spatially more detailed panchromatic band. In Erdas the Intensity Hue Saturation (IHS) and Principal Component pan-sharpening method (PCM) techniques are tested. According to Wittman et al. (2008) the IHS method performs best spatially, and according to the Erdas help file the PCM method performs best in retaining the radio-metrical properties of the input file.

In Appendix VIII a more extensive description is available of the processing steps undertaken to create the pan-sharpened image.

With the berry ground truth data provided by the SBBRP it is possible to do a classification based on the locations where berries are found. The question is however whether the spatial and spectral information

[9] http://www.4shared.com/zip/ZGKTBEID/frame_and_fill_win32.html

of the Landsat imagery is sufficient. Other studies, like Rao (2007) have shown that it is possible to extract berry sites from satellite imagery. These studies applied their methods at berry orchards and not in 'the wild'. According to Rao (2007) the Vaccinium species (blueberry/lingonberry) cannot be statistically separated from some mosses (*Sphagnum/Pleurozium/Polytrichum*) which do also occur in the study area. The difficulties with separating the berries from other vegetation has very much to do with the growing conditions of the berry plants. The berries grow very close to the ground and in the vicinity of other shrubs, tall grasses and mosses like *Sphagnum*. Besides, they grow in partially open forests because the plants need partial shadow of the pine trees and are therefore hard to distinguish in satellite imagery.

The pan-sharpened image is classified with a selection of the berry locations as training dataset. Of all the berry positions recorded by the SBBRP a random selection of 600 points is made to create a training dataset[10]. According to Swain et al. (1978) as many as 100 samples per input band should suffice. Six bands of Landsat are used in the supervised classification, therefore 600 sample locations are selected, which is 16% of all the samples available. The original band number six of Landsat is not used in the classification. It is assumed that the spatial resolution of 60 metres is too low to contribute to the classification. The spectral signatures of the selected points are added to the signature editor in Erdas. The Spectral Angle Mapper (SAM) algorithm is afterwards used to classify the image. The algorithm derives the angle between a reference spectrum and the image spectrum of each pixel. The SAM algorithm permits comparison of the spectral similarity of two spectra. The output values ranges from 0 to pi/2. Where low values represent a small spectral difference between the spectrum of the sample with the image spectrum. The SAM algorithm is used because it performs well in homogeneous areas (University of Texas 1999).

2.4.3 Bear movement in relation to berry distribution

To find out whether the berry yields and berry locations, obtained in the previous part, have any influence on the bear behaviour the following analyses are performed. The entire process to answer the 3rd research question is visualised in Appendix IX.

Track length

The distance travelled by the bears during the berry season might be influenced by the berry yields. It is hypothesised that the track length decreases when the berry yields increases. Due to the fact that they have to search less for food. The GPS collars record beside the GPS position also the time of the recording. Therefore it is known in which order the points are recorded. With this information it is possible to connect all the points by a polyline, regarding the time the point was recorded. This results is a track the bear travelled. A track is created for each individual bear and for each year separately. Therefore it is possible to compare the distances travelled over time, and correlate these distances with the berry yields provided by the SLU.

Home range size

If the track length is influenced by the berry yields it is likely that also the home range size is influenced. It is hypothesised that the home range size decreases when the amount of berries available increases. Due to the fact that they have to search less for food. The home range is defined as the area in which an individual animal normally lives. Brown bears are not territorial, but establish home ranges that vary in size depending on the individual bear, habitat quality, and reproductive status (Dahle et al. 2003, Parks Canada 2011). Home ranges may overlap and are usually not aggressively defended (Parks Canada 2011). To test whether the berry yields have any influence on the home range size of the bears the next analyses are performed.

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[10] Random selection script: http://arcscripts.esri.com/details.asp?dbid=15441

With the convex hull analysis in ArcGIS it is possible to create a polygon which encloses a selection of points. This analysis can be performed for the data for each individual bear and each year separately. The home range size is represented by the area of the generated polygons. All the generated polygon sizes can be compared with each other and correlated with the berry yields to find out whether there are any correlations.

Despite the fact that the convex hull analysis is used in previous research (Cranston 2004, Steyaert 2009) the analysis is very sensitive for outlying GPS points. Another, more detailed, method to find out whether the bears travel characteristics have changed over time is proposed in this research. By buffering the bear tracks in ArcGIS it is possible to extract the areas that the bears have been too. This is performed with the raster Clip function on the Corine dataset. A bear track buffer is used because it is unknown where the bear went between 2 recorded positions. The buffer size is set to 850 meters. The distance is the average distance travelled (233 m) plus twice the standard deviation (309 m). The average distance and standard deviation are derived from the distances that the bears have travelled in a single time interval of 30 minutes. All the selected bears are used to calculate these statistics. The buffer size is validated in areas where data is required with a shorter interval (Figure 10). The image shows that the buffer size is big enough. The size of the resulting buffer polygon can be calculated for each bear and each year separately. The resulting buffer areas are also correlated with the berry yields.

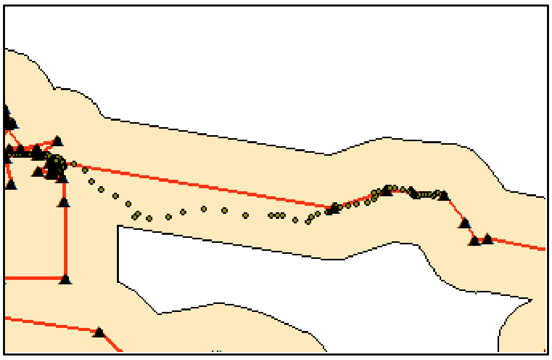

Figure 10: Buffer validation. All the shorter interval positions are within the buffer polygon, created with the generalised path (red line).

Habitat selection

As mentioned previously in this report, a relationship between berry occurrence and the land use type is present. In this research an analysis is conducted to find out whether the berry yields have an influence on the home range selection of the brown bears.

The home range polygons (convex hull and buffer results) for each bear are used to clip the Corine dataset, therefore the areas which have an overlap (Corine + polygon) remain. By performing a summary statistics the total number of cells having a similar cell value are being calculated, which results in a table containing the number of times a cell value is occurring in the dataset. These numbers can be compared with the results of other years and with other bears. Before the results from different years are compared with each other the results are corrected for the size of the home range. Because, when the home range polygon is bigger in size it is logical that then all (or some) of the land use classes are more visited by a bear. To be able to compare the results of different years the results need to be corrected for the varying home range size. By generating a correction factor with the total numbers of cells visited by the bear the land use statistics can be compared with each other. The correction factor is calculated with Equation 2.

$$Correction\ factor\ (i) = \frac{TotalNrCells}{NrCells(i)} \tag{2}$$

In the equation the correction factor for year *i* is calculated. The number of cells visited by the bear in year *i* is divided by the total number of cells visited by the bear regarding all the years. All the cell statistics results of year *i* are multiplied with this correction factor. After the correction the statistics from the different years can be compared with each other, and correlated with the berry yields.

The gap issue from previous analyses is solved with the buffer analysis, but there still is a density issue. The issue is that the overlapping areas are treated as one. The overlapping features are merged into the same single feature, due to limitations of ArcGIS. Therefore the density of the bears is not taken into account. Both of the performed analyses (convex hull and buffer) are coping with this issue.

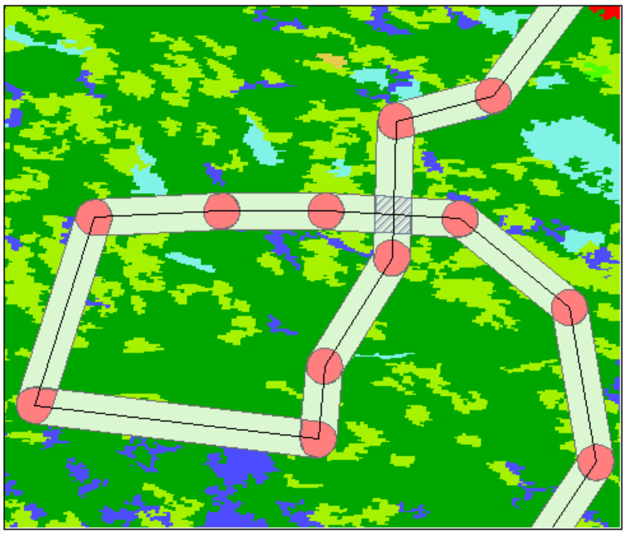

Figure 11: Buffer clean-up. All the red areas have a false overlap between buffered track features, and are deleted. The hashed area should be counted double and therefore the overlap is not deleted.

All the bears have a heterogeneous distribution, therefore the resulting land use statistics of the previous analysis are biased. This can be resolved by performing a more advanced buffer analysis. To solve this issue the bear tracks needs to be split at each vertex, and buffered afterwards, resulting in separate features. These features do however overlap with the next adjacent features. These areas (Figure 11) need to be removed from the data, but the other overlapping areas are still needed. By performing an analysis, visualised in Appendix IX, the overlapping areas with the adjacent features are deleted from the file, but the other overlapping areas are untouched. The tool loops through all the features. A feature and the following feature is selected. The overlapping area is extracted with the clip tool. The result is deleted from the first selected feature, where after the cleaned feature is added to a dataset containing all the cleaned features. The tool continues with the following feature until all features are processed.

The results of the analysis could give a better representation of the real life situation hence it takes the bear density into account. To extract the land use statistics the Corine dataset needs to be clipped for every feature in the dataset separately, otherwise the overlapping parts are still handled as one, and not separately. The separate clips are again merged into one dataset. After all the features are processed the same summary statistics, as previously, can be performed with the Corine land use dataset. After the home range size correction, as mentioned previously (Equation 2), the data of the different years can be correlated with the berry yields.

Bear density

After the berry locations are determined it is possible to extract the phenology parameters at these inferred berry locations. Where after the correlation can be calculated between the bear density and phenology parameter values at the berry locations. Therefore it is possible to determine whether the berry locations and yields have any influence on the bear behaviour during the berry season.

To be able to find out whether there are any changes in bear occurrence the bear density is determined. The density is determined for each bear and each year separately. The density is determined with the kernel density tool in ArcGIS. A search distance of 850m (= mean travelled distance + 2 * standard deviation) is used to create the density maps. The function calculates the density regarding all the observations which are in the search radius. The density value is highest at the location of the observation and decreases with increasing distance from the point. The density reaches zero at the search radius distance from the point.

With these generated density maps it is possible to correlate the bear density at the berry locations with the seasonal parameter result at the same berry location. The large and small integral represent seasonal vegetation production (Enkhzaya et al. 2011). Therefore it is assumed that it also represents the berry abundance at that specific location.

Another analysis is performed to find out whether it is possible to predict the bear density in the area with the deduced plant phenology parameters. To be able to do this a regression analysis is performed for every of the plant phenology parameters. Of every recorded bear position the plant phenology parameter value is extracted. Of all the parameter values the frequency is calculated. By performing a regression analysis on the results a most preferred value is determined. The locations of the years 2006-2008 (of 4 bears) are used to perform a regression analysis. By combining all the regression formulas of every parameter it is possible to generate a bear density map. The prediction model is tested with the data of 2009.

2.4.4 Impact of berry availability on bear-human interaction

According to Swenson et al. (1996) there is a relationship between human interests and bear densities. In Figure 12 the human interest objects are overlaid with the bear density. The suggested relationship seems to be present in the data. Whether the berry yields influence the bear density near human interests is however not yet known. The actual influence is determined by calculating the average distance to the human interest objects. The average of all these distances is calculated and correlated to the berry yields to find out whether they influence each other. The entire process is visualised in Appendix X.

Data

All the data used in this analysis is from the OSM. Before the analyses can be performed the completeness of the dataset has to be checked and if necessary features have to be added to the dataset. The OSM is the most detailed dataset freely available.

With the Corine dataset, Landsat imagery and Google Maps the locations and the completeness of the dataset is visually checked. From which can be concluded that all the villages and localities were already included in the dataset. Also the location of the points seems to be valid.

Also all the main roads are already available in the dataset. There are however many more smaller roads present in the study area. These are manually added to the dataset. In addition the main logging roads are added to the dataset, if not present in the dataset already. Main logging roads are defined as roads which lead to at least 3 logging sites, and do not lead to villages, hamlets, or localities. The ESRI base map of the world is used to add these roads to the dataset. The data provided includes information from Tele Atlas of 2010 at a scale up to 1:18.000[11].

In addition 2 railway lines cross the study area, one in the western part and one in the southern part. The railway data from the OSM seems to be complete and the spatial quality also seems to be sufficient. The southern railway line is no longer in use and is therefore removed from the dataset[12]. The western railway line is part of the Inlandsbanen, which runs from Mora (south of Orsa) to Gällivare which is located above the polar circle. Only during the 3 summer months passenger trains make use of the railroad track[13]. During these months 2 passenger trains a day make use of this stretch of railroad. In addition there are freight trains making use of the railroad. The frequency of these trains is however unknown. Due to the low usage of the railroad it is possible that the bears are less influenced by the railroads.

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11 http://resources.arcgis.com/content/community-maps/world-topographic-map

12 http://sv.wikipedia.org/wiki/Alfta

13 http://www.inlandsbanan.se/

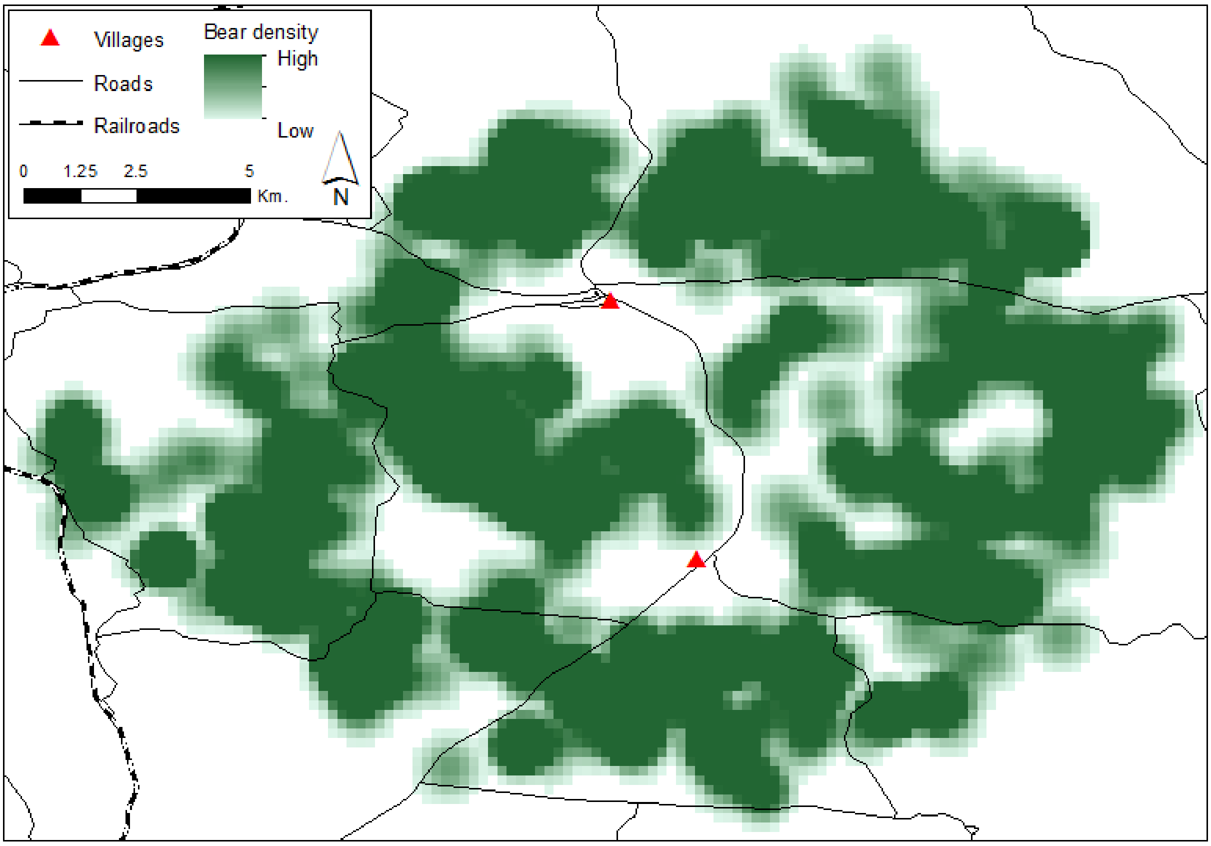

Figure 12: Bear density of bear W9403 in 2006 and human interest data.

3 Results and discussion

In this chapter the results of each of the research questions are listed. These results are also discussed in this chapter.

3.1 NDVI trends

The NDVI trends are determined in 2 different ways, spatially and temporally.

Spatial trends

The spatial trends occurring in the study area can suggest that vegetation is influenced by other spatial factors. The differences can indicate changes in production of the vegetation and therefore differences in berry yields across the study area. A spatial trend is found between the timings of the growing season and the latitude. The length of the growing season gets shorter when reaching higher latitudes (Figure 13). This is the result of an earlier occurring end of season and a delayed start of the season. This can be explained by the fact that higher latitudes cope with lower temperatures and less incoming radiation from the sun. The decrease is present in all of the main land use classes in the study area.

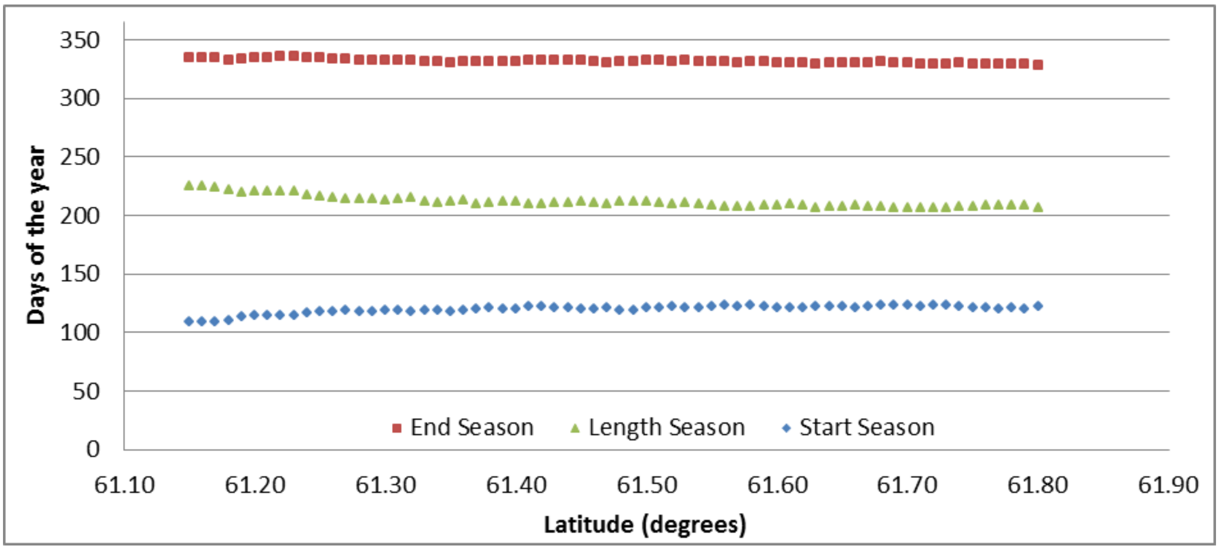

Figure 13: Seasonal parameters correlated with latitude.

With a maximum distance of 70 kilometres the changes in the timings of the season are assumed to be linear. However it should be taken into consideration that when the scope is enlarged, these changes are no longer linear. The equation of the linear regression line ($y = -22.574x + 1599.6$) proves that the trend cannot be linear. Otherwise the length of the season would endure for about 1600 days a year at the equator. The length of the season decreases with 22 days per degree north, which is about 111 kilometres. All 3 plant phenology parameters show a significant trend with a correlation for end, length and start of season, 0.78, 0.77, 0.63 respectively.

The length of season is positively correlated with the large integral phenology parameter, which indicates the seasonal vegetation production (Enkhzaya et al. 2011). Therefore it can be concluded that the food availability decreases when the latitude increases.

The length of season with the latitude is not the only spatial trend found in the study area. Also the elevation has an influence on the length of the growing season. Especially the timings of the season, i.e. start, end and length of season show a correlation with the elevation. The length of the growing season is correlated the strongest with the elevation. With a R of -0.6 (N = 396 189) the length of the growing season is significantly negative correlated with the elevation. This can be explained by the fact that higher elevations cope with lower temperatures, stronger winds and lower air pressure. Despite that the total height difference in the study area is less than 600 meters, there is still a correlation present. In

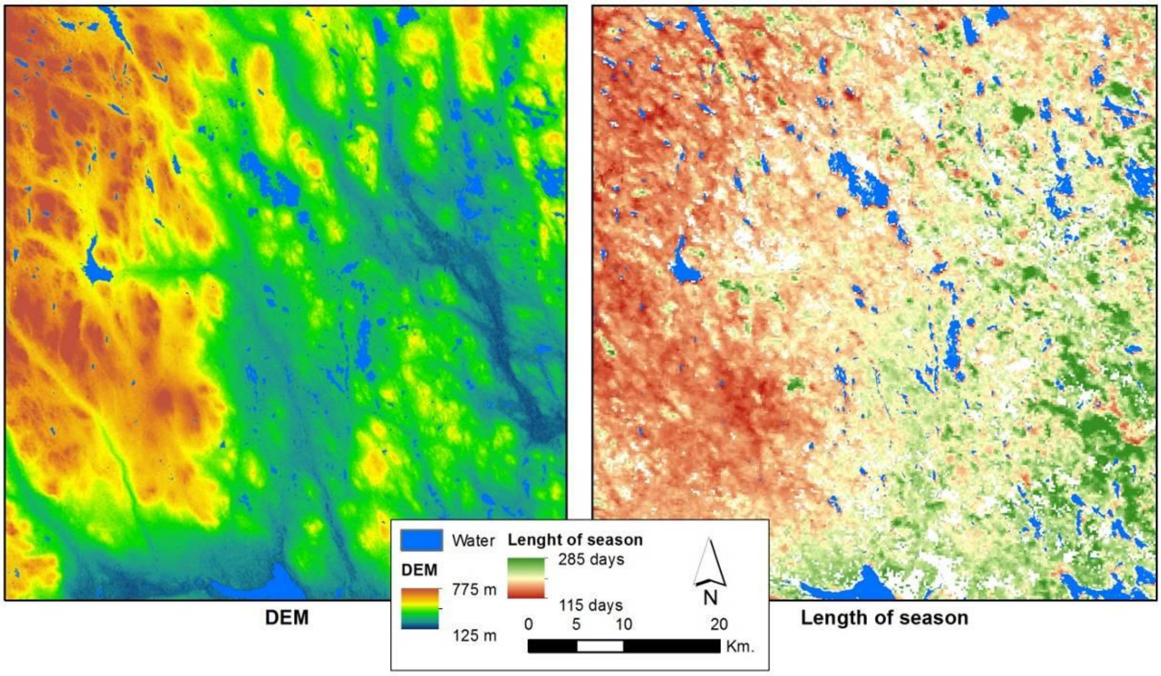

Figure 14: Comparison DEM - length of season

Figure 14 the correlation between the DEM and length of growing season is visualised. In this figure some exceptions in length of season are visible. These areas are mainly influenced by forestry. If a forest plot is clear-cut within the study period the vegetation type changes and therefore also the length of the growing season. The shortest length of season areas in the eastern part of the study area are due to agricultural activities (harvesting earlier in the season). The longest season lengths also located in the eastern part can be the result of absence of human activities.

Temporal trends

Besides the occurring spatial trends, also other temporal trends are occurring in the study area. The NDVI curves of all the years are visualised in Figure 15. In this figure no overall temporal trends can be distinguished. The maximum NDVI is almost equal over all the years and it almost always occurs at the same time of year. In the first months of the year the NDVI is quite stable and low due to guaranteed snow cover. When the snow disappears in the spring the NDVI increases rapidly. This can be explained due to the fact that some of the vegetation beneath the snow is still green (evergreen forest) and still contains a reasonable amount of chlorophyll. The slope of NDVI and timing of the start of season varies, but no significant trend can be distinguished (Table 3). The start of season does show a trend, but not significantly. The start of season starts later every year, except for 2006 and 2007. In 2006 the start of season date is very and in 2007 it is early, otherwise it would be a significant trend. The NDVI value at the end of each year fluctuates due to the presence or absence of snow, which is one of the mayor factors influencing the NDVI value in the end of the year.

The averaged large integal and length of season parameter are showing a significant temporal trend (Table 3). Some of the other parameters do show a significant trend if 2003 is ignored. Figure 16 visualises the assumed trend of the amplitude and large integral. However, the amplitude value

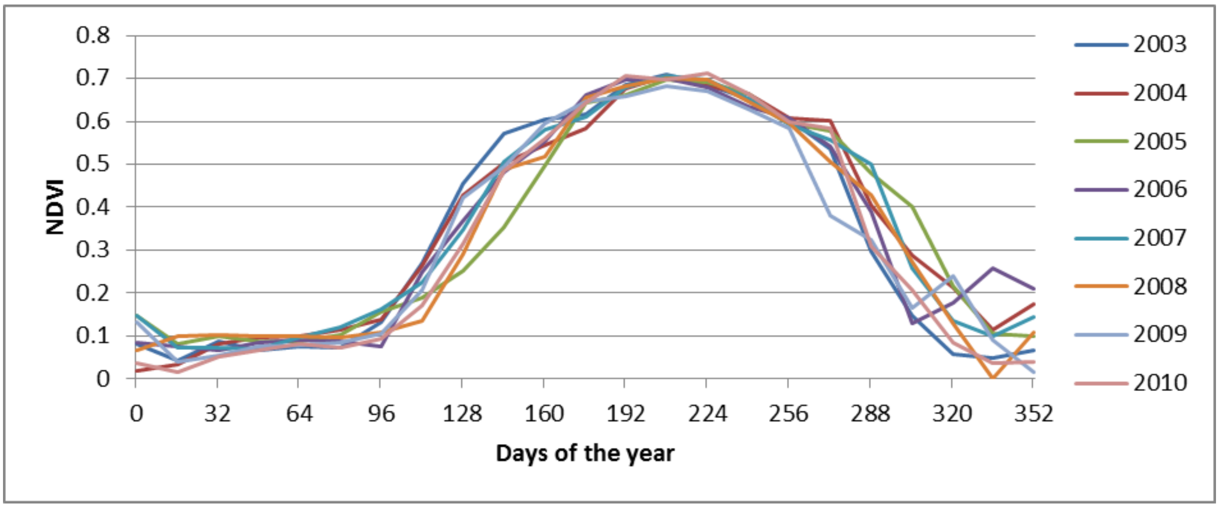

Figure 15: NDVI trend throughout the years.

calculated for 2003 is not an outlier, it only deviates from the trend. If the value of 2003 is ignored than the correlation of the trend is 0.94, which is significant.

Significant temporal trends are mainly found in areas influenced by forestry. These areas are young clear-cuts and greening up of older clear-cuts. These areas can easily be distinguished in the phenology parameter data. In addition the burned areas can be easily distinguished from non-burned areas due to large decrease in vegetation cover and therefore a large decrease in the large integral parameter value.

An increasing growing season length found by Zhou et al. (2001) and Myneni et al. (1997) is not found in the data. Zhou et al. (2001) suggested that the increasing temperatures of the high northern latitudes can be correlated with an increase of NDVI and growing season length. This can however not be verified by the results of this study, the results actually show a decrease. Myneni et al. (1997) found an increase in NDVI over the years 1982-1990 in northern high latitudes (40°-70°). This can however not be supported with the results obtained in the study area. Besides, the climate data from the SMHI does not show an increasing temperature during the 2002-2010 period. Therefore it is not possible to underpin that climate change (increasing temperature) has an influence on the vegetation in the area.

Table 3: Percentage of study area showing a temporal trend ($P < 0.05$) for each phenology parameter.

Phenology parameter	Positive trend (%)	Negative trend (%)	No trend (%)	Average trend study area (R^2, N = 8)
Amplitude	9.7	0.7	89.7	0.32
Base value	1.1	22.2	76.8	0.43
End season	0.1	0.9	99.0	0.04
Large integral	0.4	16.2	83.4	0.69
Left derivative	11.0	0.1	88.9	0.45
Length season	0.0	7.2	92.8	0.59
Maximum season	3.8	9.9	86.2	0.24
Middle of season	2.0	1.5	96.5	0.02
Right derivative	6.7	0.0	93.3	0.12
Small integral	3.4	1.9	94.7	0.09
Start season	5.4	0.1	94.6	0.18

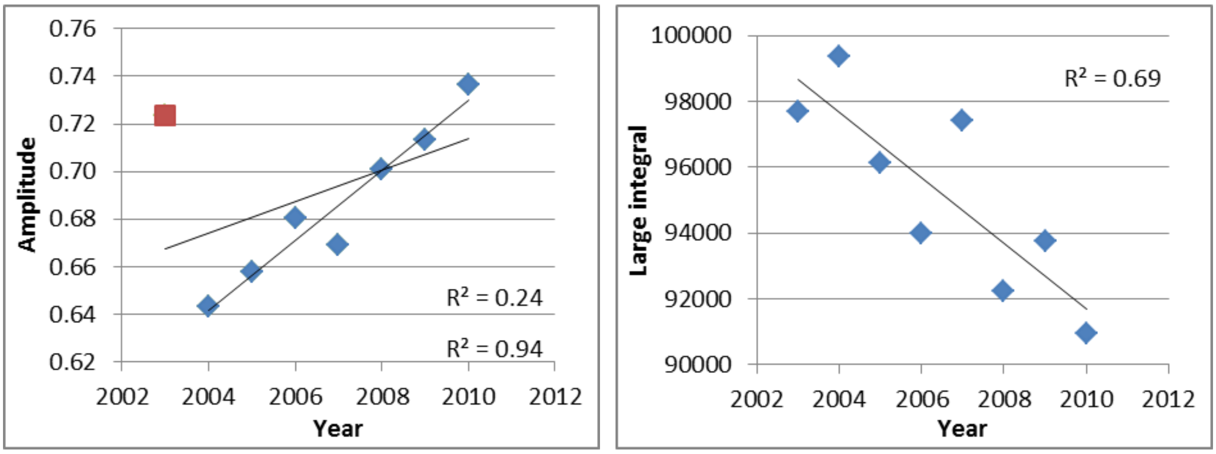

Figure 16: Average trends occurring in the study area. On the left the trend of the amplitude, when the first year (2003) is ignored the trend correlation is 0.94, otherwise it is 0.24. On the right the significant trend of the large integral.

If a longer time-series is used then it is more likely to find evidence for global warming. A time series of at least 15-20 years is probably needed to find any evidence for global warming.

The averaged phenology parameters per land use are also calculated, the results are located in Table 4. In the table the results of the blueberry correlations are listed for each land use and phenology parameter separately. The only significant correlations found are the Max NDVI with the human interacted land uses. The land use classes are: agricultural / nature, non-irrigated arable land, pastures and peat bogs. The latter one is not influenced by humans. Besides, all the Max NDVI correlations are positive, which indicates a higher berry yield when the max NDVI increases. A higher NDVI is, according to Pettorelli et al. (2005) and Oindo (2007), correlated with an increasing primary productivity. All the correlations of the left and right derivative are negative which indicates higher yields when the slopes at the start and end of the season are less steep. Which indicates that a graduate start of season is positive for higher yields in the fall.

Table 4: Blueberry yields correlated with phenology parameters for each land use class separately.

Blueberry	Ampli-tude	Base NDVI	End Season	Left deriv.	Large integral	Length season	Max NDVI	Middle season	Right deriv.	Small integral	Start season
Broad-leaved forest	0.14	0.04	-0.49	-0.09	0.02	-0.07	0.39	-0.06	-0.26	0.01	-0.16
Burnt areas	0.03	0.20	0.35	-0.68	0.21	0.38	0.30	0.04	-0.41	0.00	0.03
Complex cultivation patterns	0.14	0.05	0.00	-0.42	-0.28	-0.46	0.66	0.50	-0.16	-0.22	0.33
Coniferous forest	-0.01	0.16	0.24	-0.51	0.24	0.27	0.57	-0.22	-0.44	-0.01	0.01
Inland marshes	-0.02	0.11	0.20	-0.39	0.35	0.48	0.39	-0.43	-0.25	0.17	-0.30
Agriculture / nature	0.16	0.06	0.35	-0.43	-0.06	-0.02	0.90	0.44	-0.29	-0.10	0.58
Mixed forest	0.08	0.05	0.22	-0.47	0.05	0.04	0.61	-0.04	-0.39	-0.03	0.27
Non-irrigated arable land	0.34	0.00	0.37	-0.39	0.40	-0.07	0.81	0.58	-0.11	0.14	0.30
Pastures	0.10	0.12	-0.13	-0.44	-0.09	-0.23	0.81	0.15	-0.28	-0.20	0.12
Peat bogs	0.19	0.13	0.20	-0.45	0.19	0.15	0.74	-0.23	-0.39	0.14	0.04
Transitional woodland-shrub	0.09	0.03	0.24	-0.47	0.13	0.22	0.41	-0.21	-0.38	0.10	0.03

Also the lingonberry yields are correlated with the phenology parameters for each land use class separately (Table 5). The resulting correlations show very different results then listed in the previous table. The burned areas show the highest significant positive correlations (end and length of season) with the lingonberry yields. The burned areas are however very small (1 km^2) and therefore the results can be influenced by mixed pixels. If only the tree cover is burned down it is possible that the lingonberries became visible from the satellite point of view. However, this should also give a higher blueberry correlation results due to the ratio blue- and lingonberry occurrence in the Swedish forests. The correlations with the blueberry yield are however not significant. Due to the fact that only small forest fires occur in the area it is assumed that it is easy for plants to return to the area. In this case the difference in fertility and therefore occurrence can explain the difference between the blueberry and ligonberry correlations. The fertility of lingonberries is higher in recent clear-cuts (Kardell 1979, Reynolds-Hogland et al. 2006) than blueberries in similar conditions.

The right derivative correlations are all negative again, of which some are significant. All the end of season correlations are positive, despite for the pastures. This can be the result of harvesting by farmers earlier in the season. The results show that if the middle of the season is earlier in the year the berry yields increase. This is the case for every land use class.

Table 5: Lingonberry yields correlated with phenology parameters for each land use class separately.

Lingonberry	Ampli-tude	Base NDVI	End Season	Left deriv.	Large integral	Length season	Max NDVI	Middle season	Right deriv.	Small integral	Start season
Broad-leaved forest	-0.67	0.47	0.37	0.60	0.00	0.02	-0.45	-0.80	-0.71	0.51	0.15
Burnt areas	0.15	-0.08	0.79	0.22	0.68	0.91	0.18	-0.30	-0.64	0.54	0.02
Complex cultivation patterns	-0.06	-0.01	0.49	0.51	-0.26	-0.17	-0.25	-0.53	-0.62	0.57	0.41
Coniferous forest	-0.26	0.15	0.64	0.23	0.24	0.49	-0.40	-0.46	-0.60	0.54	0.27
Inland marshes	-0.05	-0.08	0.59	0.23	0.24	0.55	-0.48	-0.37	-0.50	0.50	0.06
Agriculture / nature	-0.07	0.02	0.48	0.48	0.15	0.34	-0.08	-0.66	-0.65	0.52	0.36
Mixed forest	-0.25	0.17	0.59	0.46	0.32	0.49	-0.32	-0.55	-0.60	0.54	0.33
Non-irrigated arable land	0.07	-0.03	0.40	0.55	-0.25	-0.26	0.13	-0.59	-0.65	0.54	0.40
Pastures	0.03	-0.04	-0.02	0.30	-0.48	-0.49	-0.05	-0.65	-0.82	0.56	0.43
Peat bogs	-0.19	0.13	0.63	-0.07	0.37	0.58	-0.20	-0.42	-0.63	0.50	-0.04
Transitional woodland-shrub	-0.26	0.15	0.63	0.18	0.33	0.55	-0.44	-0.57	-0.66	0.51	0.14

The correlation results of the averaged blue- and lingonberry yields are listed in Table 6. The resulting correlations show again different results then listed in the previous 2 tables. The burned areas is the only land use class which has a significant positive correlation. Besides, the right derivative is the only phenology parameter which is consistently negative for all the different berry yields and for every of the land use classes.

The suggested correlation between forested land use classes and the berry yields is not present. Despite that most of the berries occur in these areas. Because this is not the case it can be concluded that the berries cannot be differentiated with phenological parameters extracted from MODIS data only.

A sensitivity test is conducted to find out the role of the spatial resolution of the Corine 100m dataset. The previous analyses are also performed with the 250m Corine dataset. The results show, despite some small differences, a significant correlation for every of the land use classes. The correlation factor is a bit smaller for the least common land use classes. Besides, these land use classes consists of small patches which have a lower overall correlation result. Despite this all the correlations are above 0.97, which is significant. Therefore it can be concluded that the bigger cell size does not affect the results of the analysis. This can be explained by the fact that the MODIS data has a coarse resolution of 250m. If the

Corine dataset would have a higher resolution than the resolution of MODIS then the differences would increase, and the correlations would decrease.

Table 6: Averaged blue- and lingonberry yields correlated with phenology parameters for each land use class.

Blueberry / Lingonberry	Ampli-tude	Base NDVI	End Season	Left deriv.	Large integral	Length season	Max NDVI	Middle season	Right deriv.	Small integral	Start season
Broad-leaved forest	-0.31	0.32	-0.12	0.30	0.02	-0.04	0.00	-0.52	-0.61	-0.28	-0.02
Burnt areas	0.11	0.09	0.73	-0.34	0.57	0.82	0.32	-0.15	-0.68	0.29	0.04
Complex cultivation patterns	0.06	0.03	0.30	0.02	-0.35	-0.43	0.31	0.02	-0.49	-0.26	0.49
Coniferous forest	-0.17	0.20	0.56	-0.22	0.32	0.49	0.15	-0.43	-0.67	-0.03	0.17
Inland marshes	-0.04	0.03	0.50	-0.13	0.39	0.67	-0.02	-0.52	-0.48	0.31	-0.17
Agriculture / nature	0.07	0.06	0.54	-0.01	0.05	0.19	0.58	-0.10	-0.60	-0.07	0.63
Mixed forest	-0.09	0.13	0.51	-0.05	0.23	0.33	0.22	-0.37	-0.63	-0.04	0.39
Non-irrigated arable land	0.28	-0.02	0.50	0.07	0.12	-0.21	0.65	0.05	-0.47	0.04	0.45
Pastures	0.09	0.06	-0.10	-0.12	-0.36	-0.46	0.53	-0.30	-0.70	-0.34	0.35
Peat bogs	0.02	0.17	0.52	-0.36	0.36	0.46	0.40	-0.42	-0.66	0.34	0.00
Transitional woodland-shrub	-0.09	0.11	0.55	-0.21	0.29	0.49	0.02	-0.49	-0.66	0.13	0.10

It can be concluded that the MODIS 16 day, 23 images a year, composites are temporally detailed enough to extract temporal trends. The images are also spatially detailed enough to extract the trends at for example the clear-cutted areas. The composite images are however not detailed enough to distinguish the rich berry sites like forests.

3.2 Spatial distribution of berry species

After the performed temporal and spatial trend analysis it is needed to know where the berries occur to find out whether any trends are occurring at these berry locations.

Literature is used to create a berry distribution map based on the land use classes present in the study area. There is however no information available for every land use class. Besides, based on NDVI and land use maps the area is very homogeneous. Therefore there are large areas which have the same berry occurrence. Due to research conducted by Kardell (1979) it is known that berry occurrence changes when a forest stand has been clear-cut. Hence the forests in the area are highly managed and therefore a lot of clear-cutting occurs. According to the Corine datasets of 2000-2006 6% of the study area did change within these 6 years. Most of the change is the result of forestry (land use change: coniferous forest to transitional woodland-shrub). Therefore much more difference in berry occurrence is present in the area than is shown by the result of this literature research.

The forestry company Orsa Besparingsskog, which is active in the study area, keeps track of the age of the forest stands. It was however not possible to obtain this data within the time schedule of this research. Therefore it was not possible to create a more detailed map with forest stand age data.

With the large integral plant phenology parameter it is possible to extract the recent cleat-cut sites. These inferred sites are verified with Landsat imagery. Therefore it is possible to quantify the forestry activity in the area. These results show 8% deforestation over 8 years, which means that 1% of the area is clear-cut by the forestry company every year. This number is in agreement with the land cover change results of the analysis with the Corine data. The large integral parameter shows an increasing trend at older logging sites. Therefore it might be possible to determine the age of these older logging sites. Due to literature research it might be possible to determine the berry occurrences at these locations. However also other local characteristics, e.g. elevation, soil characteristics, are influencing the berry occurrence. Due to the coarse spatial resolution of the MODIS data a different and more detailed method is preferred.

According to Raatikainen et al. (1983) the dominant tree species is a more important factor than the land cover type in explaining the blueberry yield. However there was also no spatially detailed information about the dominant tree species available.

3.2.1 Gap fill results

The most detailed method covered in this research is a supervised classification of the Landsat 7 imagery. However before the imagery can be processed the gaps in the original Landsat 7 image need to be filled up with data from adjacent Landsat 7 images from the same period. The original, and result of the analysis is shown in Figure 17. The gap size in the study area in the original image is 369 380 cells, which is 7.2% of all cells. After the gap fill analysis the number of cells without information decreased to 43 849 cells, which is 0.9% of the total amount of cells. The percentage of missing data in the original image is significantly lower than the 22% literature suggested (Scaramuzza 2004). The main reason for this difference is the satellite orbit. The centre of the satellites orbit crosses the middle of the study area, and near the centre of the orbit no data is lost. Therefore the percentage of empty cells is much lower as can be seen in Figure 17. The filled gaps are not distinguishable from the original data, therefore it can be concluded that the histogram matching has worked properly. The NASA tool was not able to fill all the empty cells, at these locations no data was available in all 3 images. The missing pixels are mostly located near the edges of the study area where almost none of the bears occur. By adding more images these gaps can be filled.

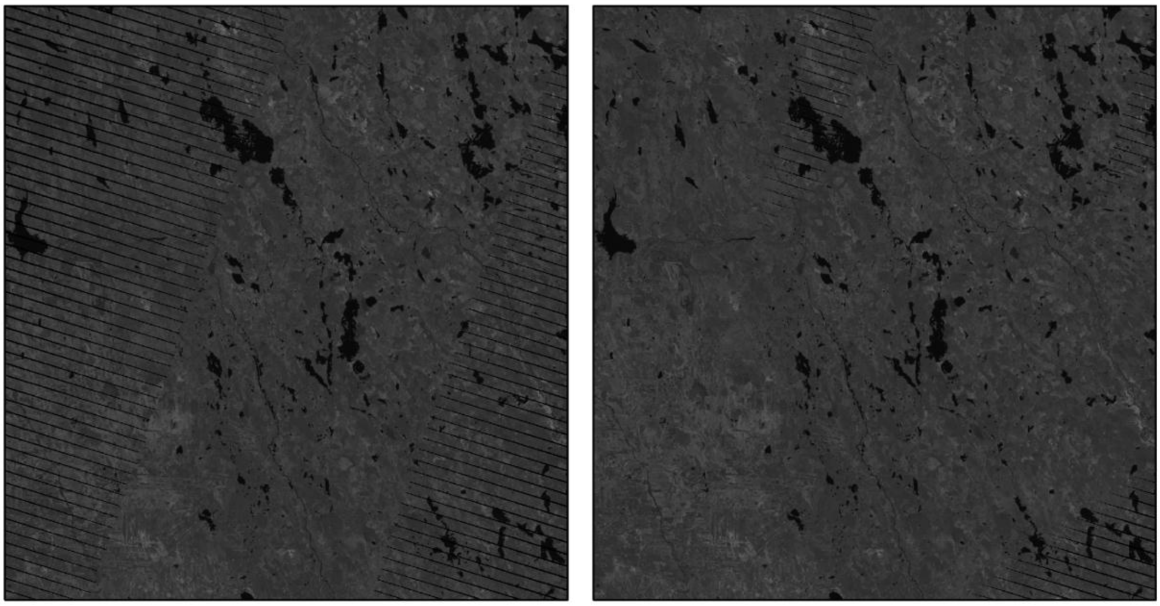

Figure 17: On the left the original image, on the left the filled image. The number of stripes has decreased significantly.

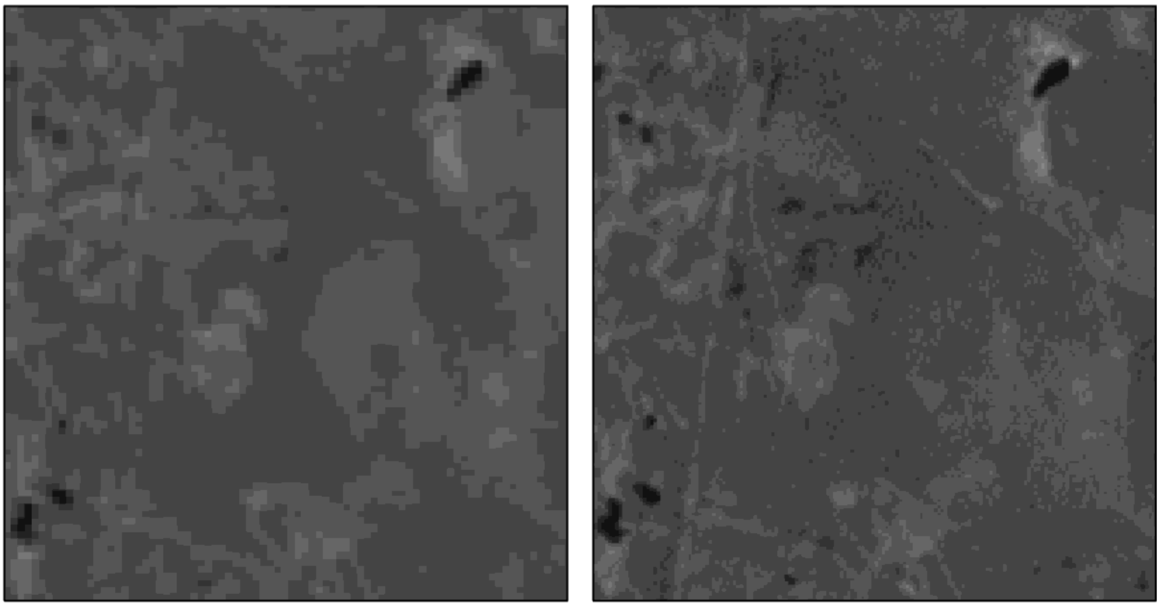

Figure 18: On the right the original filled image, on the left the filled IHS pan-sharpened image.

3.2.2 Pan-sharpening results

The panchromatic band is also filled with information from images of adjacent rows. As previously mentioned the NASA gap fill program is not able to perform this task. Therefore it is performed in Erdas

Imagine. The results of the filled parts can be identified by the a small colour difference. These areas might be assigned to a different class during the classification. After the gaps are filled the bands are pan-sharpened with the filled panchromatic band, which resulted in a spatial resolution of 15 meters, instead of 30 meters (Figure 18). As can be seen in the figure the image is much sharper and also more spectral detail is added. Small differences within the forests are now possible to be distinguished. These differences can be the result of artefacts.

The feature space plot of the pan-sharpening shows some strange artefacts (Figure 19). In the figure the values of band 1 are compared with the values of band 2. The colour indicates the number of pixels which have the same value. On the right the feature space plot of the pan-sharpened image of the same bands. Due to the trade-off between spatial detail and spectral detail mentioned by Wittman et al. (2008) the feature space plot shows some artefacts. All the feature space plot band combinations show the same kind of artefacts. Therefore it is hard to generate a valid classification with the pan-sharpened image. Due to the artefacts the IHS pan-sharpening method gives suitable results for visualising purposes, but not for more enhanced spectral analyses.

The resulting PCM image also shows some imperfections. Some striping is visible due to the not perfect gap filling of the panchromatic band. The PCM pan-sharpened result is used to classify the berry sites, because it is better in retaining the spectral information of the input file.

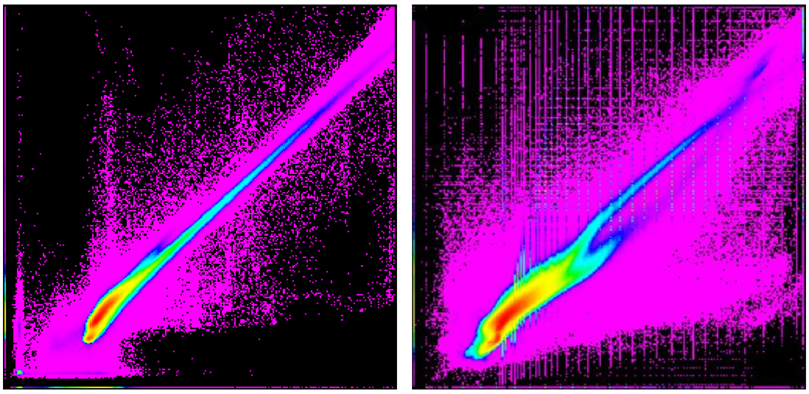

Figure 19: Feature space plots of original image (left) and the pan-sharpened image (right).

3.2.3 *The classification results*

The PCM results are used to classify the image with the SAM method. As training data a random selection of 600 (16%) of the positions are used. The average angle value for the to be classified berry locations is 0.054. Of all berry locations (3762) 68.2% locations (2564) have a smaller angle than the mean.

If all the areas with a shorter distance than the mean are classified as berries then almost the entire area contains berries. As can be seen in the resulting classified image (Figure 20) some striping is visible due to the imperfections in the filled panchromatic band. A strong correlation is found between the classified berry sites and land use class according to the Corine dataset. Most of the forested areas are classified as berry sites, this can be the result of the location of the sampling locations. According to Kardell (1979) the boreal forest ground cover in Sweden is covered for about 17% of blueberry shrubs. For the lingonberry this is 5%. Of the crowberry no quantitative information is available. The classification results show however a much higher amount of berries in forested areas. 77% of all the as berry classified areas are situated in forests, 17% in shrub land, and 3% in peat bogs. The remaining 3% is located in the other land use classes. The 3% in peat bogs are probably crowberries, because the other berry species do not grow in peat bogs (SBBRP 2011). If also the size of the land use class is taken into account then all the forest classes have relatively the highest occurrence of berries.

Studies which succeeded in distinguishing berry sites from the surrounding vegetation used more spatially detailed satellite imagery like the 1 meter multi-spectral NAIP imagery and 2.15 meter Quickbird. These used imagery has much more detail than the Landsat pan-sharpen imagery used in this research. According to Panda et al. (2010) Landsat imagery with a 30 meter resolution seems to be too coarse to be able to extract blueberry sites. Due to the berry location sampling strategy (which are almost all in the forest) the classification results can be biased. Of all the berry sampling locations 63%, 30%, and 3% of them are located in deciduous forest, shrub land, and peat bogs, respectively. These numbers correspond well with the quantities of the classified berry areas. Despite this the Landsat imagery is not spatially and spectrally detailed enough. The results are also influenced by the growing conditions of the berry plants. The plants grow in partial shadow underneath the trees.

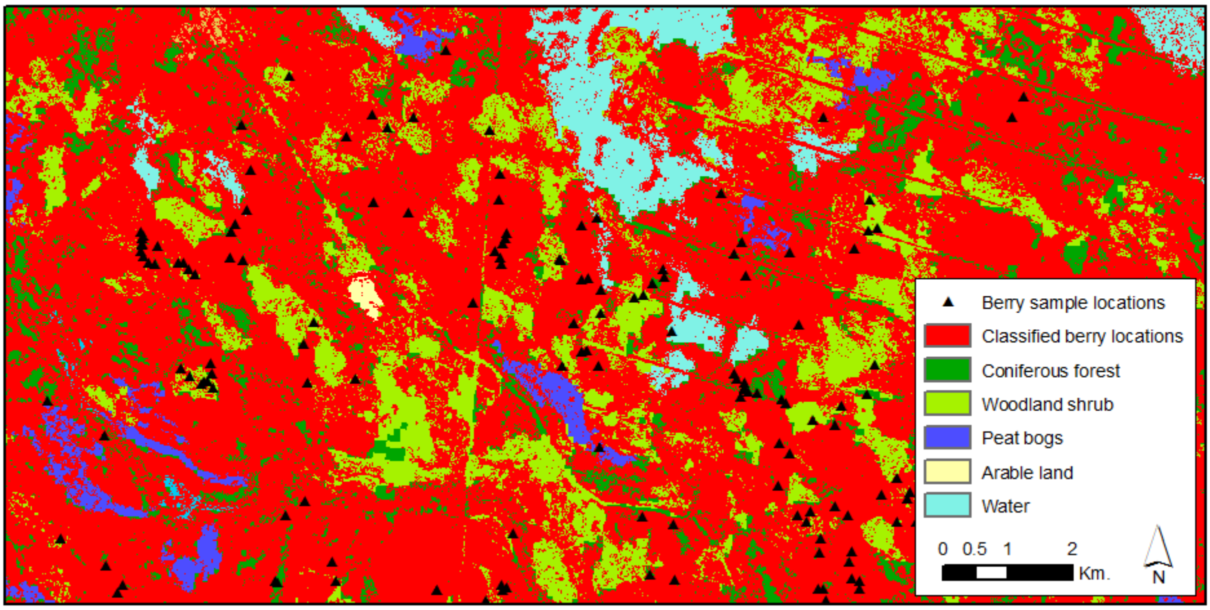

Figure 20: Classification result

3.3 Bear movement in relation to berry availability

Now it is known where the berries occur. It is needed to correlate different bear behaviour parameter results with the berry yields to find out whether the bears are influenced by the berry abundance.

3.3.1 Bear track length analysis

Firstly the influence of berry yields on the bear track length is analysed. The results of the analysis are listed in Table 7. All the distances are normalised with the average distance travelled for all bears and all years combined. Therefore it is easier to find similarities in behaviour between the different bears.

Table 7: Track length results, 1 = 287 kilometre.

Bear ID	2004	2005	2006	2007	2008	2009	BB(1)	LB(2)	BB/LB(3)
W0004	1.00	-	0.73	0.75	1.15	-	-0.58	-0.98	-0.83
W0212	-	0.73	0.93	0.99	0.75	-	-0.22	0.92	0.39
W0411	-	-	1.00	1.00	1.17	1.05	-0.51	-0.90	-0.80
W0422	-	-	1.14	0.92	1.18	0.85	0.33	-0.58	-0.14
W0626	-	-	1.15	1.20	1.36	0.88	-0.22	-0.78	-0.56
W9403	-	-	1.04	0.83	1.14	1.06	0.21	-0.41	-0.11
Average	1.00	0.73	1.00	0.95	1.12	0.96	-0.62	0.06	-0.38

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

On average the distance travelled decreases when the amount of berries available increases. However on an individual level the bears show ambiguous behaviour. Some of the correlations are positive for one bear whilst the correlation of another bear is negative. Also when the tracking period is equal. Bear W0004 and bear W0422 should give the same results because they share about the same area. This is however not the case, which might be explained by the fact that the period the bears are tracked is not similar and bear W0004 did have cubs in 2007. According to the Parks Canada (2011) and the SBBRP (2011) the ambiguous results can also be the result of different factors e.g. dominance relationships W0004 is mother of W0422 almost share the same area, and reproductive status. The average track length correlation with the blueberry yields is much stronger than the correlation with lingonberries. This can be explained by the fact that the bears do prefer blueberries over lingonberries.

In further analyses the averages of all bears are used, due to the fact that the selected bears show ambiguous behaviour. Besides, the spatial resolution of the berry yields is too coarse to study the behaviour of individual bears.

3.3.2 Bear home ranges

Secondly the influence of berry yields on the home range size of a bear is investigated. The average home range area results of the convex hull analysis is located in Table 8. The results of the convex hull analysis show on average a decreasing home range size when the berry yields increase. However, the correlation is not significant. The home range size of the buffered tracks are on average smaller in size. This has much to do with the fact that the buffered polygons can have gaps, whilst the convex hull polygons cannot. Despite this the results do show almost the same trends. Which results in almost equal correlations, and are therefore not significant. In Appendix XI all the results of all the bears are listed.

Again, the average home range size correlation with the blueberry yields is much stronger than the correlation with lingonberries. Which can be explained by the fact that the bears do prefer blueberries over lingonberries.

The buffer distance used in this research (850m) should be made variable, as can be seen in Figure 10. The optimal buffer distance can be modeled by investigating more areas where a lower than average logging frequency is used. In Python it is then possible to calculate the travelled distance and the associated buffer distance. The result gives a better representation of the real uncertainties in positioning.

Table 8: Home range size results

Method	2004	2005	2006	2007	2008	2009	BB[(1)]	LB[(2)]	BB/LB[(3)]
Convex hull, 1 = 120 km^2	2.28	0.38	1.23	0.84	0.89	0.91	-0.39	-0.05	-0.30
Buffer tracks, 1 = 98 km^2	1.66	0.51	1.18	0.86	0.97	0.95	-0.40	0.03	-0.25

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

3.3.3 Habitat selection

It is now known that the berry yields have some, but not significant, influence on the bear travelled distance and home range size. It is needed to find out whether the bears select a different land use class when the berry yields are changing. In Table 9 the for the home range difference size corrected land use statistics are listed. The quantities for every year represent the average corrected land use preference of all bears.

Despite literature suggested that the brown bears avoid human interactions as much as possible the brown bears visited urban areas. This can be traced back to one individual bear, W0212. Only in 2007 the bear actually entered the village. The other years the bear did not go into a village, but only went close to it. Due to the buffered tracks it suggests that the bear also went into the village. The same applies to the water bodies land use class. Also other land use classes are visited by one bear only. Pastures, complex cultivation patterns, and inland marshes are visited by bears W0422, W0411, and W9403, respectively. Therefore the correlation results for each bear separate are listed in Appendix XII. The land use classes visited by every bear are coniferous forests, mixed forests, peat bogs, and water bodies. The only significant correlation between the land use and berry yields is found with the transitional woodland-shrub. These areas are less visited when the blueberry yield increases. Also the correlation with lingonberry is negative, however not significant. The correlation between transitional woodland-shrub and blueberry yields are also negative for every bear separately. All the other correlations show ambiguous results, but it can be hypothesised that the bears visited the coniferous forests more when blueberry yields increase. One bear (W9403) shows a very weak negative correlation with the coniferous forests. All the others show a quite strong, but still not significant, positive correlation. The coniferous forests are also the areas where the occurrence of blueberries is the highest. The analysis is also performed with the convex hull and buffered tracks home range polygons. These results show the same tendencies, and therefore are the correlations also almost equal.

It can be concluded that if there are less (blue)berries available the bears select the transitional woodland-shrub areas more often. This can be the result the availability of different food sources in these areas. The other main food sources besides berries are ungulates, insects, forbs and grasses (Dahle et al. 1998). Several of these food items occur in regenerating forests such as numerous species of ants (Rolstad et al. 1998, Rolstad et al. 2000), more diverse and abundant herbaceous materials (Apps et al. 2004, Nielsen et al. 2004), and promote grasses, herbs and crowberries (Rolstad et al. 2000). In addition moose forage preferably in regenerating forest stands and clear-cuts (Edenius et al. 2002, Cassing et al. 2006). The regenerating clear-cuts in the study area are classified as transitional woodland-shrub.

Table 9: Land use preference correlated with berry yields

Land use	2004	2005	2006	2007	2008	2009	BB(1)	LB(2)	BB/LB(3)
Urban area	0	1924	695	515	980	0	0.02	-0.72	-0.40
Pastures	0	0	0	0	0	7	-0.09	0.43	0.19
Complex cultivation patterns	0	0	195	0	185	524	0.14	0.30	0.25
Partially agriculture	0	0	35	0	202	1600	-0.13	0.33	0.12
Coniferous forest	511600	680076	600184	564872	574155	604837	0.68	0.60	0.73
Mixed forest	4921	21378	13104	5129	14447	15020	0.31	-0.14	0.09
Transitional woodland-shrub	324563	97654	203856	231248	227508	219532	-0.98	-0.55	-0.87
Inland marshes	0	0	0	0	0	276	-0.09	0.43	0.19
Peat bogs	36861	59306	53083	67754	52730	25562	-0.11	-0.28	-0.22
Water bodies	1112	18719	7905	9539	8851	11699	-0.46	0.28	-0.10

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

3.3.4 Bear density

From the previous part it can be concluded that the bears do select different home ranges when the berry yields in- or decrease. In this part it is investigated whether the plant phenology parameters values at berry locations have any influence on the bear behaviour.

The correlation of the seasonal parameter and bear density for each bear at the recorded SBBRP berry locations is listed in Table 10. The large and small integral represent the seasonal vegetation production (Enkhzaya et al. 2011). Only the large integral shows a significant correlation, together with the length of season and end of season. All the significant correlations ($P < 0.05$) are negative, which indicates a lower large integral with an increasing bear density at berry locations. The end of season starts earlier in a year and the length of season is shorter when the bear density increases. It is plausible that the berry yields at these locations is actually higher. If the tree cover is less abundant then it is possible that the berry shrubs produce more berries due to the increased sunlight. With the Leaf Area Index (LAI) time series it is possible to detect whether the amount of leafs in- or decreases over time. With this extra information it is possible to detect whether the tree leaf cover abundance has any influence on the berry production.

All the results of all the bears separate are listed in Appendix XIII.

The used method has a drawback, which is that it is not capable to find out when the bears visited the SBBRP berry sites. By proposing a different analysis it might be possible to find out whether there are any correlations in visiting time of the berry sites. To do this a buffer needs to be generated around the berry sites. The buffer size can be set at the standard deviation error of the device which it was obtained with. Then the tracks can be intersected with the buffered polygons. The remaining polylines indicate a visit of a bear. It is highly unlikely that the bears have travelled in a straight line between the 2 bear positions. Therefore it should be taken into consideration that the not all of the resulting visits are actually visited. Besides, some of the actual visits are, for the same reason, not registered.

Table 10: Correlation results bear density and plant phenology parameter at berry locations

Phenology parameter	Correlation (R)
Amplitude	0.27
Base	-0.17
End season	-0.73
Large integral	-0.88
Left derivative	-0.36
Length season	-0.82
Max NDVI	-0.36
Middle of season	-0.09
Right derivative	0.50
Small integral	-0.64
Start season	-0.15

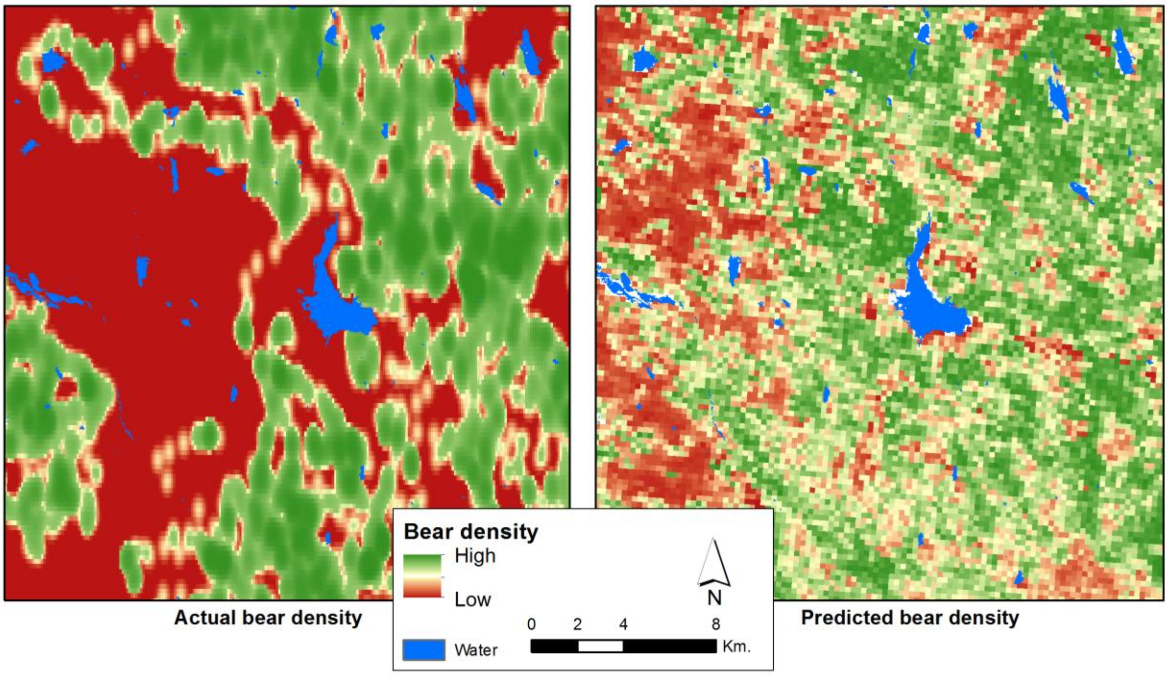

Figure 21: Predicted bear density results

The bear density prediction map (Figure 21) is correlated with the actual bear density of all the bears in 2009. The result shows a weak correlation (R = 0.02 and N = 42 963) between the bear density of 2009 and the predicted bear density. It should be taken into consideration that the most preferable plant phenology parameter value is also the most occurring value in the area. Therefore it can be concluded that the vegetation in the study area is too homogeneous to create usable results. Besides, all the parameters are treated equally, but it is possible that some of them have a higher influence on the bear distribution. The low correlation can also be the result of a limited amount of tracked bears. It is plausible that untracked bears do occur in the areas which have a high prediction. However when only the prediction and the density of a bear is used within its home range the correlation does not improve. Therefore it can be concluded that it is hard to predict the bear movement with the derived NDVI products only, more factors play a role in the bear distribution.

Other studies like Nellemann et al. (2007) and Martin et al. (2010) used other parameters to explain the bear behaviour. The best results are obtained with the ruggedness, slope and elevation of the terrain as well as the distance to regenerating forests, elevation, distance to houses, distance to low traffic roads, human disturbance level. Therefore it is recommended to make use of more non-vegetation parameters

3.4 Impact of berry availability on bear-human interaction

Now it is known that the bear distribution is not influenced by vegetation (phenology parameters) alone, but also by human influences. Therefore it is needed to look at whether the berry yields have any influence on the average distance bears keep to human interest objects.

Due to the extensive road network, there is always a road nearby the bears habitat area. In total almost 1200 kilometres of road in the area is mapped, this includes the main logging roads. Only the roads in the vicinity of the bear tracks are added, so the entire road network in the study area is much more extensive. The places (villages, hamlets and localities) are checked whether these are complete and fully covering the area. Most of the localities and hamlets in the area do have less than a dozen houses in their neighbourhood. The villages are bigger. 35 hamlets and localities, and 3 villages are present in the study area. The villages are however more situated at the edge of the study area where less or no bears occur. The hamlets and localities are more scattered over the study area. In total there is for about 150 kilometres of railroad in the study area. Of which 65 kilometres is out of use. The abandoned railway line is ignored in the analysis. The 85 kilometres of railroad, which is in use, is located in the western part of the study area. Most of the bears are, on average, more than 10 kilometres away from any railroad. Therefore it is assumed that the railroad does not have any influence on these bear locations.

None of the resulting correlations are significant as can be seen in Table 11. There is not one year specific responsible for the not significant correlations. This is the case for every human interest object. There is a possibility that the average distance for the railroads is too big to influence the bears. Even when the results of the closest individual bears are taken into account (Appendix XIV) then the behaviour is ambiguous. However, the roads, which have the highest density in the study area, do also have ambiguous results for each bears separately.

McLellan et al. (1988) suggested that avoidance of roads was independent of traffic volume. However Mace et al. (1996) found a decreased selection of road buffers when traffic volume increases. By differentiating traffic volumes it is possible to find out what the influence of traffic volume is on the bear behaviour. This is also unknown for villages and hamlets. Besides, other studies did not calculate the average distance to the roads, but predicted the bear density near roads by locating random point within the home range area of a bear (McLellan et al. 1988, Kasworm et al. 1990). The number of random points can then be compared with the actual observations. The number of points are counted for multiple distance classes, ranging from 0 meter to 1 kilometre (Mattson et al. 1987, McLellan et al. 1988). Therefore it is possible to find out whether till what extent the roads (and other objects) have an influence on the bear behaviour. McLellan et al. (1988) also found a relationship between the reproductive status, and age of the bears and the average distance to roads. When female bears have cubs they stay significantly closer to the roads than when they are with yearlings or when they are alone. Less variation was found within the age-sex classes by McLellan et al. (1988). Mattson et al. (1987) and Nellemann et al. (2007) suggested that adult male bears keep longer distances from human settlements. In this research all the observations are used without taking a maximum distance to the objects into account. The results of Mattson et al. (1987) suggest that the bears tended to avoid an area averaging 3 km along roads during fall. Nellemann et al. (2007) suggested that the difference in habitat use is present till a range of 10 kilometres. Therefore it is not necessary to set a maximum distance to human interest objects. Due to the dense road network in the study area almost all the recorded bear positions are within the 4 kilometre range of roads. This is however not the case for the villages and railroads present in the area. Besides, it is suggested that bears avoid disturbed areas during the hours of higher human activity (Martin et al. 2010).

Table 11: Average distance to human interest correlations with the berry species.

Human interest	2004	2005	2006	2007	2008	2009	BB(1)	LB(2)	BB/LB(3)
Roads, 1 = 878m	0.77	1.18	0.96	1.10	0.90	1.09	0.44	0.27	0.47
Railroads, 1 = 8260m	0.60	1.42	0.89	0.99	1.01	1.15	0.49	-0.04	0.30
Villages, 1 = 4383m	0.82	0.87	0.99	1.13	0.96	0.95	-0.20	0.57	0.22

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

4 Conclusion and recommendations

In this final chapter the conclusions which could be made from the results are listed here. In addition the recommendations for further research is located in this chapter.

4.1 Conclusion

Research question 1

The Landsat imagery used in this study cannot be used for a time series analysis. This has to do with the significant amount of cloud cover present in the study area throughout all the years. The MODIS composite NDVI images are less influenced by the clouds due to the composition algorithm. Therefore good quality images are available throughout the year. The timings of the season show significant spatial trends with the latitude. The higher the latitude the shorter the season gets, mainly due to a later in the year occurring start of season and earlier in the year occurring end of the season. In addition a significant correlation was found between the elevation and the length of growing season. Temporal trends are also found in the data, mainly in cleared forested areas. However, no evidence is found for global warming which should, according to previously mentioned literature, result in an increasing season length. The time series used in this study is relatively short, and it can be concluded that it is too short to detect trends. Overall it can be concluded that the MODIS 16 day, 23 images a year, composites are temporally detailed enough to extract temporal trends. Also the methods implemented in this study to find spatial and temporal trends are suitable for trend studies.

Research question 2

The gap filled and pan-sharpened Landsat 7 imagery is not able to distinguish berries from forests. The spectral signatures of berries and other vegetation are very similar. The Landsat 7 imagery is not spectrally detailed enough to distinguish berry vegetation from other vegetation. Besides, the berries grow underneath the trees in partially shaded areas. The Landsat 7 imagery is not spatially detailed enough to look through these gaps between the trees. In addition the methods used fill the gaps in images perform sufficiently for viewing purpose. However striping is visible when the gap filled and pan-sharpened images are classified. The main reason for this is that the mosaic tool in Erdas does not produce faultless results. In other research hyperspectral data was successfully used to differentiate berry plants from other vegetation. This research was however conducted at berry orchards and not in the wild. The growing conditions of the berry plants, in partial shade of the trees, make it impossible to deduce the berry locations with remotely sensed imagery. Therefore other non-remotely sensed methods should be investigated to get a better understanding of the berry distribution and phenology.

Research question 3

It was hypothesised, and found in the data, that the track length (distance travelled) of brown bears decreases on average when the berry yields increase. Also the correlations between the home range size and berry yields show a positive correlation. The resulting correlations are however not significant. The new suggested home range size calculation method results differs from the old method calculation results, however the correlations with the berry yields are almost equal. Besides, the investigated bears react differently to each of the berry species yields, this differs for every individual bear. The habitat selection results show that the bears do select different land use classes when berry yields change. When the berry yields increase the bears avoid transitional woodland-shrub and are more attracted to the coniferous forests, in which the most berries occur. In the transitional woodland-shrubs other important food items occur, like ants, moose, and herbaceous plants. These results are almost equal for every individual bear. The proposed method to determine the home range selection does give almost equal results as performed with the old method. Therefore it can be concluded that the old method, which is much less computational intensive, can also be used. The bear density analysis results, at the recorded

SBBRP berry sites, show different behaviour. At these locations the large integral, end of season and length of season do shows a significant correlation with bear density. At these locations it is plausible that the berry yields are actually higher. If the tree cover is less abundant then it is possible that the berry shrubs produce more berries due to the increased sunlight. The bear distribution map generated with the plant phenology parameter does not show a significant correlation with the actual bear distribution. Therefore it can be concluded that it is hard to predict the bear distribution with only plant phenology parameter data in homogeneous areas. This is partially the result of the spatial scale level of the plant phenology parameters, which is not detailed enough. In addition there are more factors influencing the bear distribution, like reproductive status, dominance relationships, and other terrain and human interest derived parameters.

Research question 4

According to literature the bears keep as much distance to human interests as possible. An influence of berries on the average distance bears keep to human interests can however not be statistically underpinned. The bears show different behaviour and they react differently to the different human interest objects. This can be due to the degree of human interest, human activity in the individual bear home range area, the method used, or the amount of data used in the analysis. The method used in this study can give suitable results, but there are more detailed methods available which can give better results. These methods can be implemented in ArcGIS.

It can be concluded that no evidence is found for global warming during the study period in the study area. But it is possible to detect spatial and temporal trends with the used methods. Besides, the berry locations cannot be derived from remotely sensed imagery due to the growing conditions of the berry plants. Therefore other non-remotely sensed methods should be used. In addition it can be concluded that all selected bears show different behaviour, and most of the correlations with the berry yields are not significant. Bears that share the same home range area react differently to changing berry yields. This is cannot be the result of the logging activity in the area. The difference in behaviour is the result of other un-investigated factors influencing the bear distribution like, reproductive status and dominance relationships. Another explanation for the not significant results can be that there are still enough berries available for the brown bear population in a bad berry season. Besides, the results can be biased due to the high logging frequency in the study area, which is not taken into account. Also influencing the final results is the limited availability of the data.

Due to some significant correlations it can be concluded that the bears are influenced by berry abundance, but they are also influenced by other un-investigated factors.

4.2 Recommendations

Due to some limitations of the data and performed analyses the results are mostly not significant. In this part of the report suggestions and improvements to the used methodology how this research can be improved.

The MODIS data is spatially and spectrally detailed enough for a detailed time series analysis. Due to the launch date it is however not possible to extract phenology parameters from before 2001. This results in a maximum time series length of about 10 years. To do a real climate change study a longer time series is needed. Since 1989 the NOAA-AVHRR satellite produces NDVI maps on a 1km scale. Due to the longer time series (22 years) these images can be used for finding evidence for climate change in the study area. NOAA-AVHRR is the only satellite which has such a long time series with a relatively high resolution. In addition the trend studies conducted in this research are limited by the size of the study area. It would be more likely that trends are found when the study area size is increased. The trend study with MODIS or NOAA-AVHRR data is more suitable on a smaller scale. To extract the plant phenology parameters a different method should be implemented, because Timesat is not able to deduce the parameters of such a large area at once. Therefore the images should be divided and processed one by one. In addition the NDVI algorithm used has some issues in rather homogeneously green areas. The small differences which are very important in this study cannot be differentiated with NDVI. By making use of a different vegetation index these small differences might become more clearly visible. The Weighted Difference Vegetation Index (WDVI) should perform better in these conditions due to a correction for the bare soil reflectance. The MODIS and NOAA-AVHRR imagery have the necessary bands available to calculate the WDVI. Despite of these changes Timesat can be used to extract the phenology parameters, except when a smaller scale is u. Otherwise the processing steps are the same as described in this report.

For the second research question there are several options to improve the used method in this research. As mentioned previously, remotely sensed data is not suitable to derive the location of the berry plants. Therefore it is recommended to investigating the possibility to create a berry distribution map with the forest stand age collected by the forestry company. The literature described in this research provides information about the stand age and the berry occurrence. If the age of the forest stands is known a more detailed berry distribution map can be created. If the tree species occurring in the area are also known it is possible to create a berry distribution map for the 2 main berry species. By monitoring the already recorded berry sites of the SBBRP a more detailed temporal pattern can be analysed. When an estimation of number of berries and size of the berries is recorded the total production of the bushes can be calculated and gives a better representation of the total berry yields. If the berry location data also differentiated the berry species then it would be possible to find differences in behaviour regarding the different berry species. The yields at the monitored berry locations can be correlated with the climate data obtained by the SMHI. When a large amount of berry bushes is monitored in the area it is possible to interpolate the berry yields to the locations where there are berries (according to the previously generated berry map) which are not monitored. Additional information is needed to perform the interpolation. The DEM and latitude are probably the most important ones, because they have a significant influence on the plant phenology and therefore berry production. If the berry sites are monitored the NDVI (MODIS) is no longer needed.

Research described in this report has shown that the ambiguous correlation results of the latter 2 research questions can be the result of dominance relationships and reproductive status. To be able to differentiate these differences it is needed to make use of more bears in the analyses. The following reproductive statuses can be used (Haberkorn 2011):

- Sub adult male (age < 5 years)
- Sub adult female (age < 5 years, no litter yet)
- Adult male
- Reproductive female (can be younger than 5 years if she had litter before)
- Female with cubs of the year (number of cubs)
- Female with yearlings (number of yearlings)

The average results can then be used to find differences over time, and to find differences between the bear reproductive status groups. Besides, a longer time series is needed to find significant patterns in the brown bear behaviour. It is likely when a longer time series is investigated that the trends occurring in the study area are no longer linear, therefore also non-linear correlations should be investigated. In addition, the logging frequency of the bear data should be as constant as possible to be able to create the density maps needed to find correlations between the SBBRP berry sites and bear occurrence. Therefore it is still needed to perform the pre-processing steps described in this report. Besides, to give a better representation of the real uncertainties in positioning a variable buffer distance should be used. The optimal buffer distance can be defined by investigating more areas where a higher than average logging frequency is used. In Python it is then possible to calculate the travelled distance for every feature and calculate the associated buffer distance. To get better results for the bear distribution prediction map it is necessary to add more datasets to the prediction method. A better prediction might also be possible with other datasets which are not as homogeneous as the used parameters. By adding the following datasets it is likely that the prediction is improved. The datasets are: ruggedness, slope and elevation of the terrain as well as the distance to regenerating forests, elevation, distance to houses, distance to low traffic roads, and human disturbance level. As previously mentioned the not significant and ambiguous results are most likely the results of dominance relationships and reproductive status. Therefore it is recommendable to make use of this data. Other research described in this report suggests that different bears with different reproductive statuses show different behaviour regarding the distance to the roads. To find these difference regarding berry yields, not the average distance to the human interest objects need to be calculated. The actual usage of multiple distance zones from human objects need to be calculated. With a zone size of 250 meter, ranging from 0-10 km the bear usage can be determined by calculating the number of observations within a zone. These numbers can then be compared over the years, and correlated with the berry yields.

To find more differences, the bear data of not only August should be used, but data of the entire berry season should be used. Then it should be easier to detect changes in start and the end of the berry season. It is also recommendable to divide the study in 2 scale levels. The trend study could be conducted on a smaller scale than the bear data. The trend study can be performed for entire Scandinavia. The bear behaviour study can be conducted on a more detailed (individual) level. During this study one of the bears was shot by hunters in 2009. Therefore the time series could not be extended. It is therefore recommendable that hunters should not kill a bear which is tracked by SBBRP. One other bears GPS collar stopped working during the study period. The GPS collar batteries last for about 7 years (on average 1300 observations a month, 2 months disabled during hibernation)[14]. Other manufacturers might offer collars which have a longer battery lifetime.

In this study some significant results were derived from the data. A longer time series is needed for the climate study as well as the bear behaviour study. If also different scale levels and extra parameters (e.g. reproductive status and dominance relationships) are used it is likely to find more significant correlations.

[14] http://www.vectronic-aerospace.com/files/GPS_PLUS_2010_Collar.pdf

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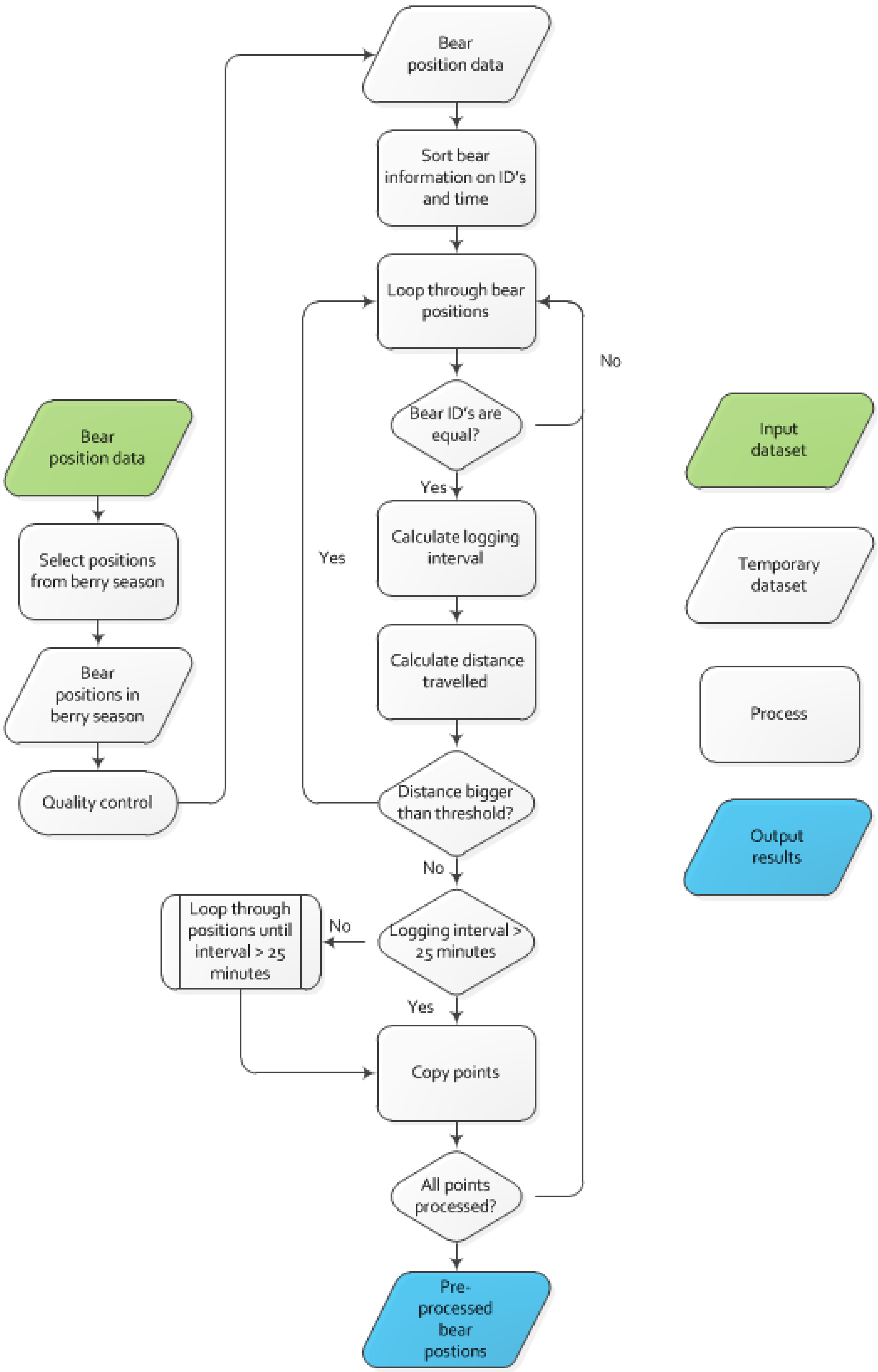
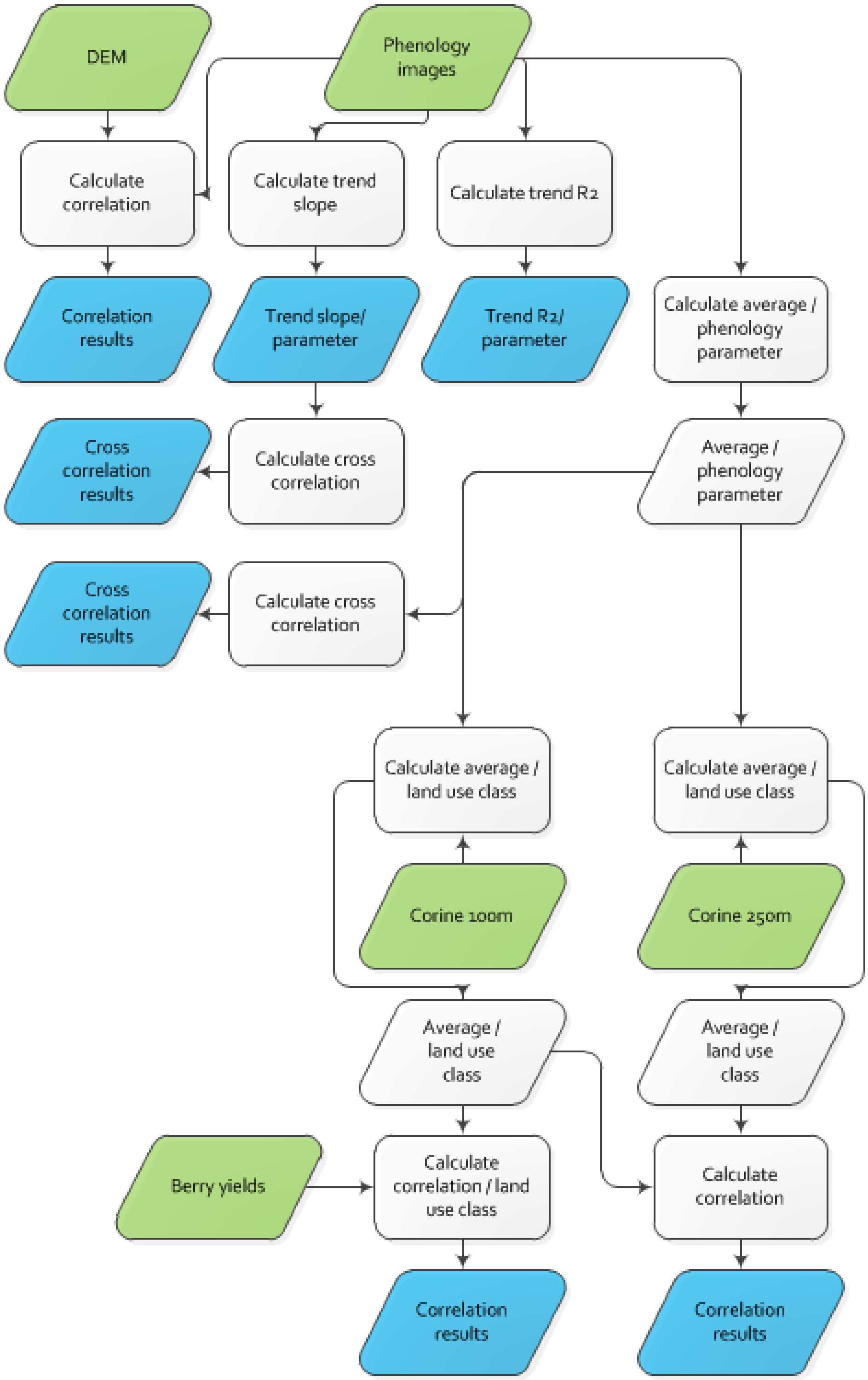
Appendix I Flowchart pre-processing bear data



Appendix II Flowchart RQ1



Appendix III Landsat pre-processing

A satellite sensor does not only measure the electromagnetic radiation from the earth's surface. Some of the brightness is due to the reflectance of the atmosphere (Hadjimitsis et al. 2010). The influence of the atmosphere is not constant over time. Therefore it is not known how much the atmosphere influences the measured radiation at the satellite. So, the objective is to quantify the influence of the atmosphere for every of the images. There are many methods for atmospheric correction which apply to multi-spectral satellite imagery (Hadjimitsis et al. 2004). The Darkest Pixel (DP) atmospheric correction, the most basic, method is applied to the Landsat imagery. The DP correction method has provided reasonable correction in previous studies (Hadjimitsis et al. 2004).

The principle of the DP approach states that most of the signal reaching a satellite sensor from a dark object was contributed by the atmosphere at visible wavelengths. Therefore, the pixels from dark targets are indicators of the amount of upwelling path radiance in this band. The atmospheric path radiance is added to the surface radiance of the dark target, thus giving the target radiance at the sensor. The surface radiance or reflectance of the dark target is assumed zero.

In this study a large water body is used as a dark object. Large water bodies are most suitable because they remain mostly stable over time. With this method the measured reflectance of a dark object is subtracted from the entire image, this is done for every band and image separately. After the darkest pixel correction all the images, which have different recording dates, can be treated equally.

After the DP correction masks can be created in ArcGIS, and Erdas. In ArcGIS the valid value ranges for the following objects are retrieved: shadow, clouds, water. The value ranges are retrieved for every band separately. In the raster calculator all the ranges are used to extract only those areas which are within all the ranges of the bands. These ranges are used to extract the clouds, shadows and water features for every input image file. All the extracted pixels are deleted from the input image.
With ArcGIS it is however not possible to extract haze, mainly because it was difficult to get the best value ranges. With haze still some part of the ground cover is visible, so the value ranges differ over the area.

With Erdas it is possible to classify an image. By making use of several sample clouds, water features and shadow it is possible to perform a supervised classification. A sample is made for all the different cloud types. After the classification the classified image needs to be reclassified to create a mask, which is a raster containing ones and zeros. The unwanted, clouds, shadow and water, classified parts need to be set to 0, all the other parts are set to one. By multiplying the input raster with the mask the unwanted pixels are set to zero.

The results of cloud masking are depicted in Figure 22.

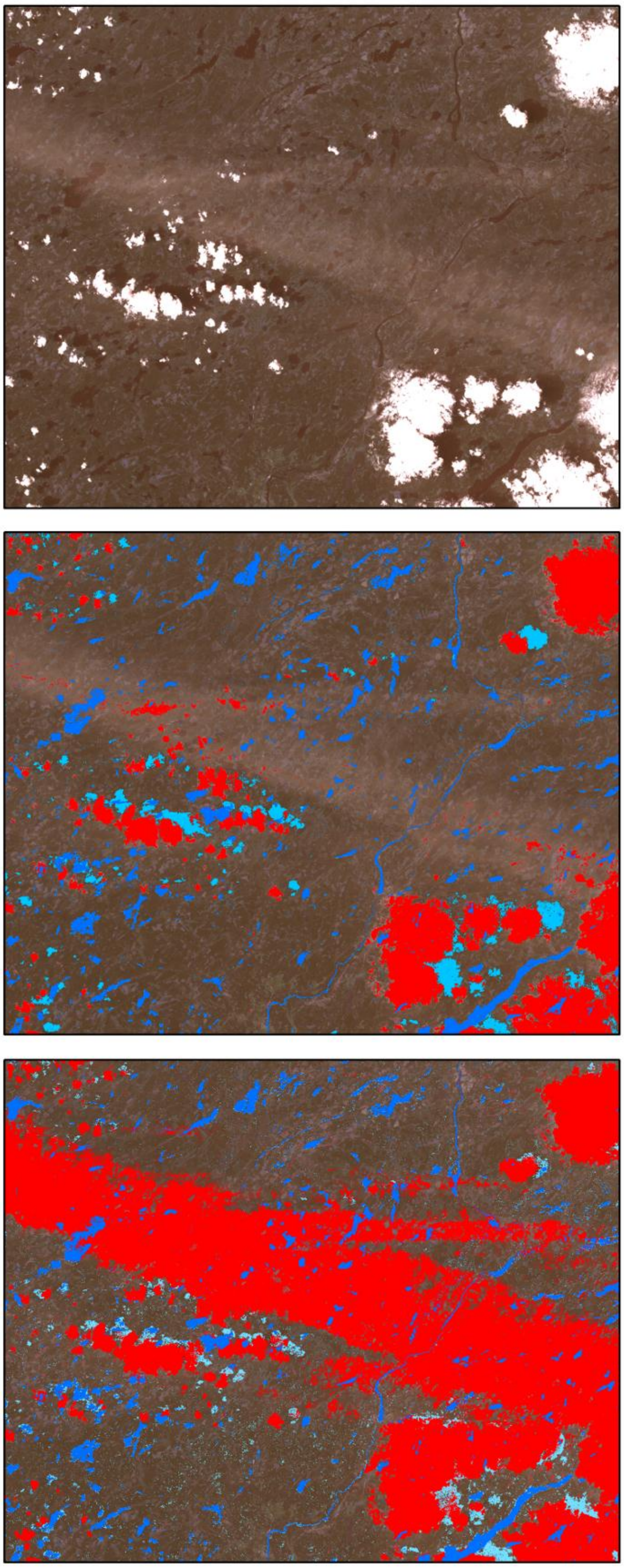
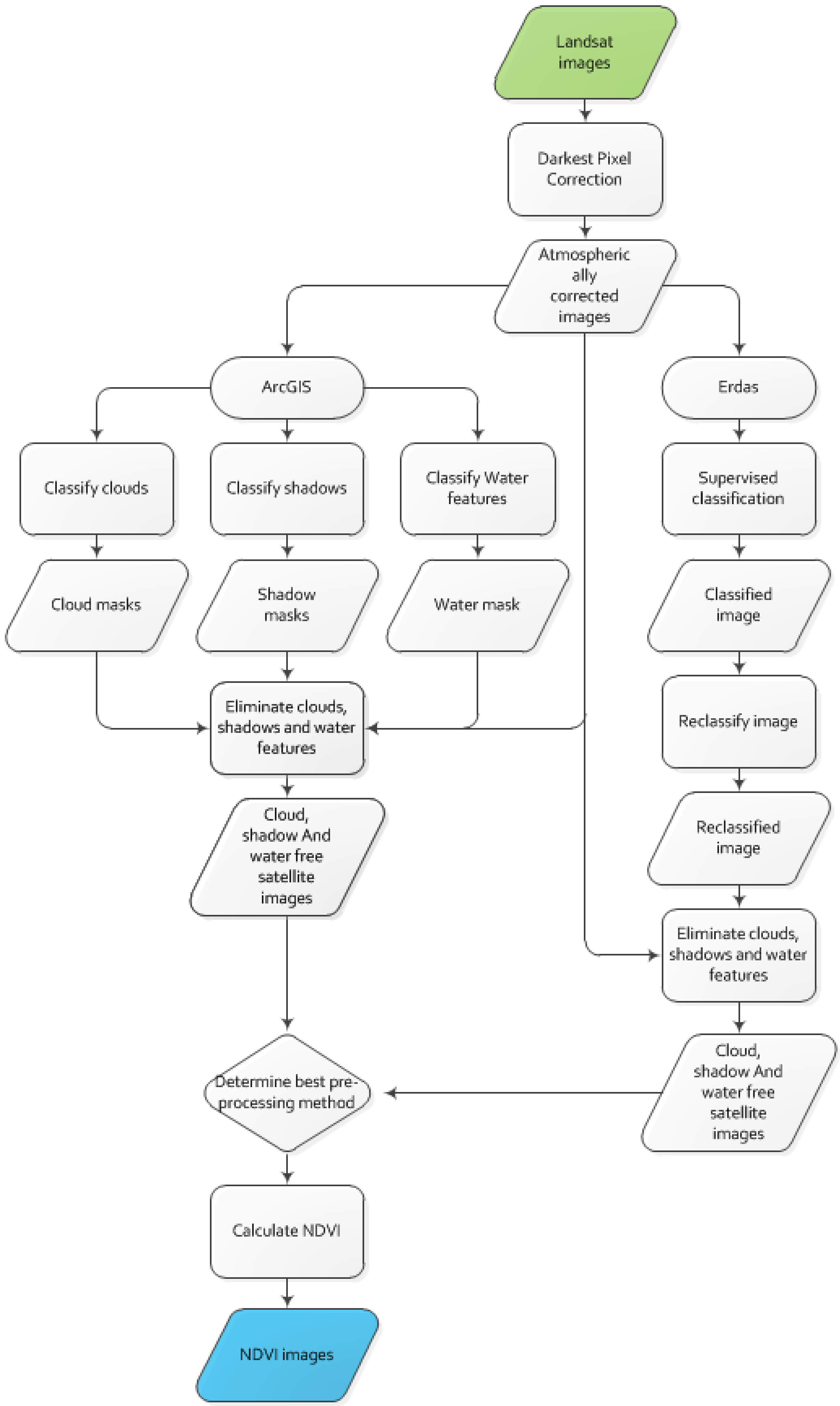
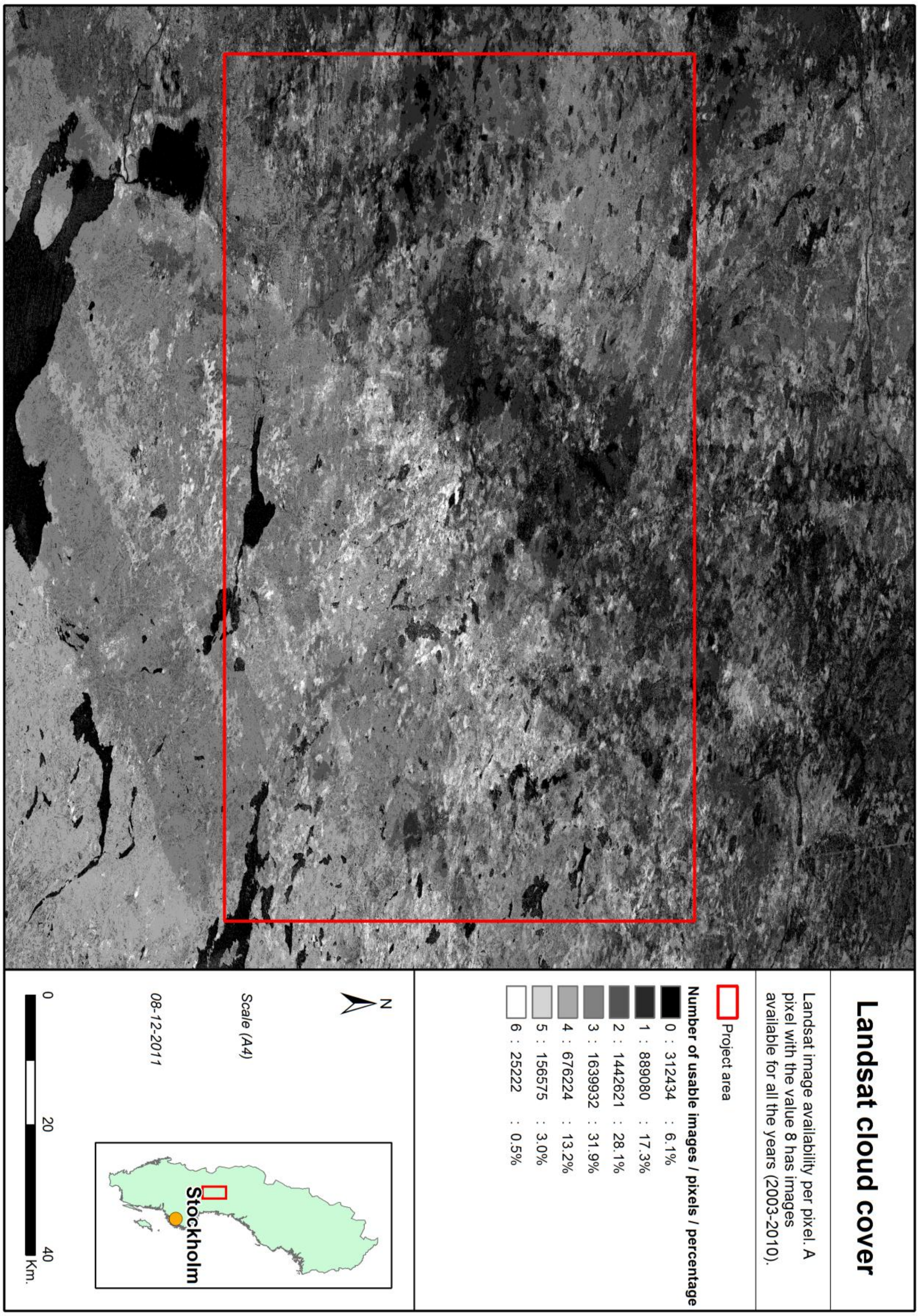


Figure 22: From top to bottom, original input image (2006). In the middle cloud and shadow classification results with ArcGIS. At the bottom classification result created with Erdas.


Landsat images
Darkest Pixel Correction
Atmospherically corrected images
ArcGIS
Erdas
Classify clouds
Classify shadows
Classify Water features
Supervised classification
Cloud masks
Shadow masks
Water mask
Classified image
Reclassify image
Eliminate clouds, shadows and water features
Reclassified image
Cloud, shadow And water free satellite images
Eliminate clouds, shadows and water features
Determine best pre-processing method
Cloud, shadow And water free satellite images
Calculate NDVI
NDVI images

Appendix IV Landsat cloud problem



Appendix V Timesat (pre-)processing

Timesat is a freeware program from the University of Lund in Sweden. The program is able to extract seasonal parameters (plant phenology) from MODIS time series (Jönsson et al. 2002, Jönsson et al. 2004 and Eklundh et al. 2004). The seasonal parameters which are derived with Timesat are:

1. Time of the start of the season.
2. Time of the end of the season.
3. Length of the season; time from the start to the end of the season.
4. Base level; the average of the seasons left and right minimum values.
5. Time of the middle of the season; the mean value of the time that the left edge has increased to the 80 % level and the right edge has decreased to the 80 % level.
6. Largest data value; at which time the maximum value is found in the fitted function.
7. Seasonal amplitude; difference between the maximum value and the base level.
8. Rate of increase at the beginning of the season (left derivative); calculated as the ratio of the difference between the left 20 % and 80 % levels and the corresponding time difference.
9. Rate of decrease at the end of the season (right derivative); calculated as the absolute value of the ratio of the difference between the right 20 % and 80 % levels and the corresponding time difference.
10. Large seasonal integral; integral of the function describing the season from the season start to the season end.
11. Small seasonal integral; integral of the difference between the function describing the season and the base level from season start to season end.

The large and small integral represent the seasonal vegetation production (Enkhzaya et al. 2011). Therefore these parameters can be used to see whether there are any changes in berry production in the study area.

Firstly the images need to be converted to the BIL (Band Interleaved by Line) format before the images can be processed in Timesat. The conversion is performed in ArcGIS. Timesat is able to extract the plant phenology data for the n – 1 center-most seasons (Figure 23). This can be overcome by adding dummy data at the beginning and at the end of the time series. Also the number of images needs to be identical for each year. This means that 2011, which is yet incomplete, cannot be processed.

Plant phenology patterns may be affected by the response of the vegetation to seasonal climatic cycles in irradiance, temperature and rainfall. Plant phenology parameters obtained from satellite derived time-series are often affected by the high degree of noise in the data. Using fitted functions reduces the uncertainties and noise, therefore it leads to more stable measures (Eklundh et al. 2009).

In contrast to functions resulting from Fourier methods, the resulting functions in Timesat able to capture inter-annual changes, i.e. changes in seasonal timing between years. This property makes them suitable for studying vegetation dynamics (Boschetti et al. 2009). Among the available possibilities to smooth the time series by eliminating the false records, which affect NDVI data, a local polynomial function (Savitzky–Golay filter) is used. This algorithm allows data smoothing without forcing a given mathematical function (e.g. Gaussian or logistic curves) to fit the data time series thus reducing artefact creation (Chen et al. 2004).

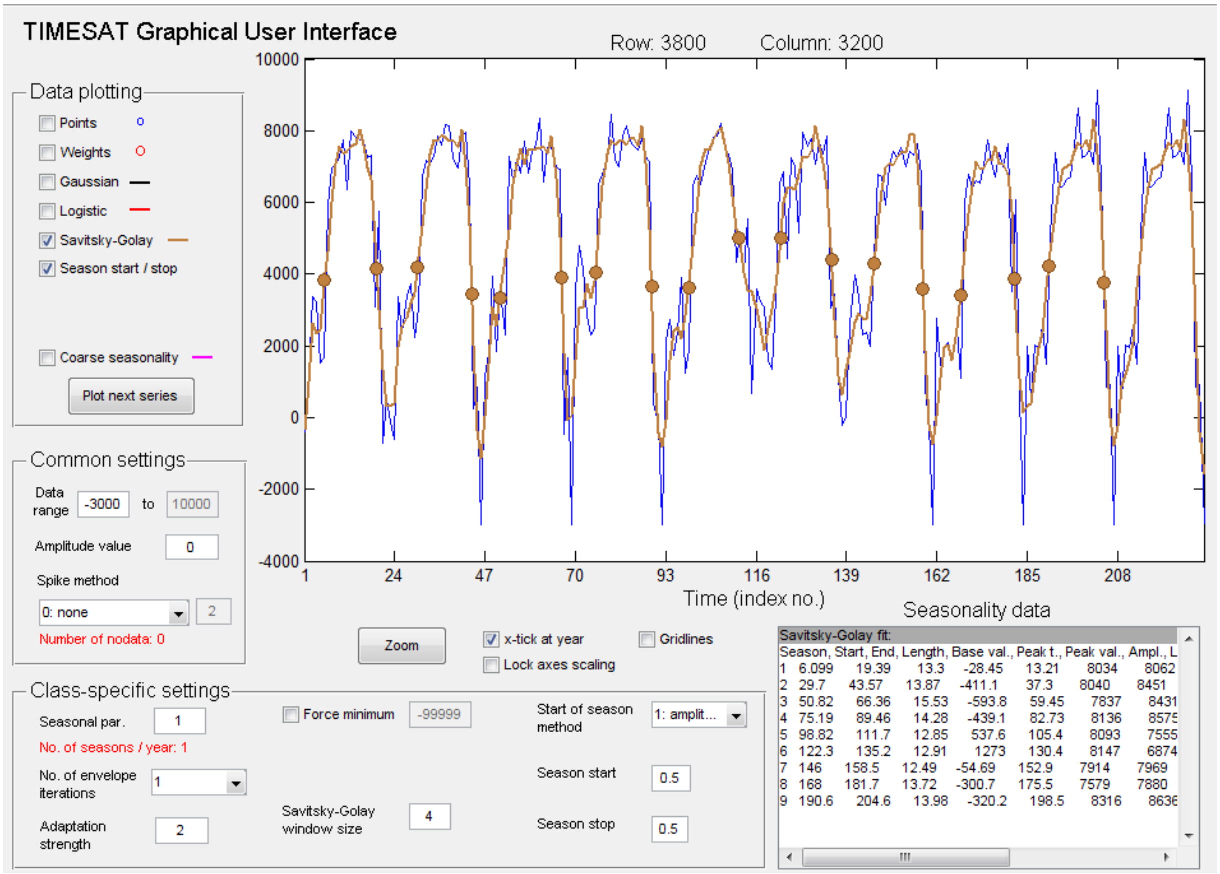
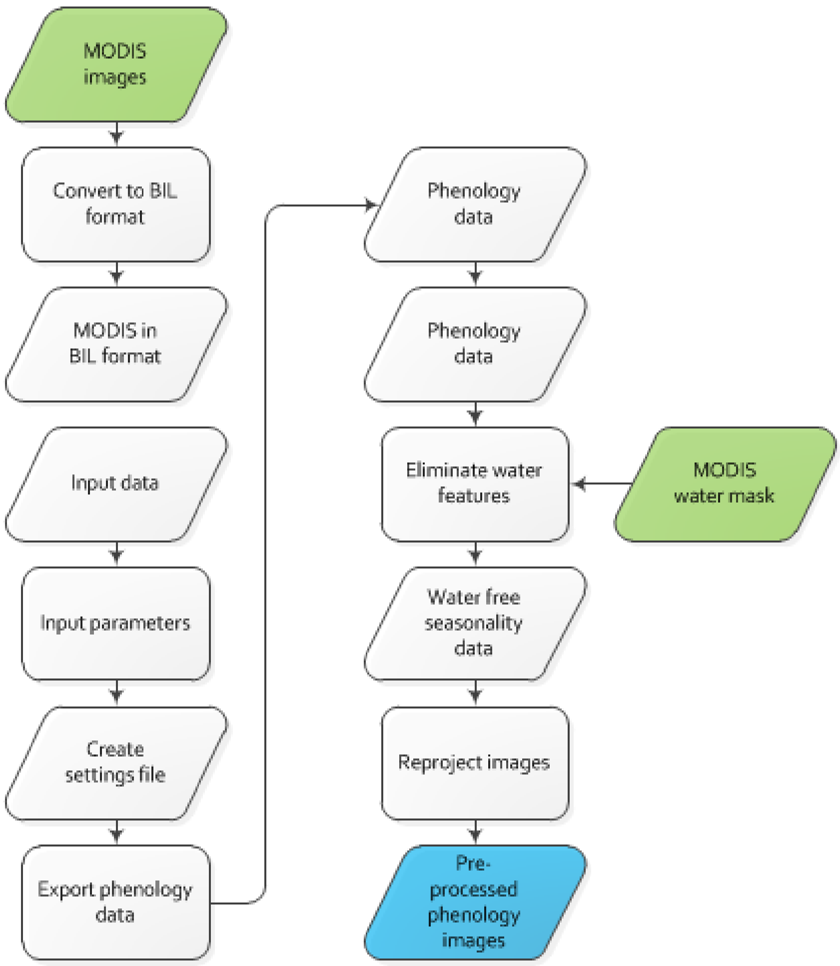


Figure 23: Plant phenology parameters extraction with Timesat, there is a seasonal pattern in NDVI visible. As can be seen the pattern is for one pixel (3200, 3800) only.

Timesat is able to generate the seasonal parameters on a per-pixel basis. After the pre-processing the seasonal parameters are exported to image files. An image is created for each year and for each parameter separately. These images are re-projected to a different coordinate system, so the images can be analysed further. The images are re-projected from the MODIS sinusoidal coordinate system to the European ETRS coordinate system. After the re-projection the images can further be analysed in ArcGIS. Some of the parameters first needed to be reclassified before it was possible to compare the results of the different years with each other. These extra processing steps are necessary for the start of season and the end of season results. Timesat extracts the image number at which the season starts and/or ends. So, in for the fourth season the start of season is not lower than 70. For the second season this is 24. Therefore these numbers are not comparable with each other. The reclassification is actually a subtraction of the product of the number of the season minus one with the number of images a year, Equation 3. After the reclassification of the start and end of season these two dataset can be compared with each other. Also the water features are deleted with a water mask. The used water mask is one of the MODIS products (MOD44W). The mask has the same resolution of the composite images. The mask is used to delete the water features from the plant phenology images.

$$CorrectedRaster = rastervalue - \ SeasonNr * i \qquad (3)$$

In this formula the input raster (start/end season) value is being corrected, so the different output files can be compared with each other. The *SeasonNr* is the number of the season of the input image, *i* is the number of images available per year. For MODIS this number is 23. The product of the season number and the number of images a year is subtracted from the input raster values.


MODIS images
Convert to BIL format
MODIS in BIL format
Input data
Input parameters
Create settings file
Export phenology data
Phenology data
Phenology data
Eliminate water features
MODIS water mask
Water free seasonality data
Reproject images
Pre-processed phenology images

Appendix VI Landsat vs. MODIS

Due to the higher resolution of 30 meters the Landsat satellites have a longer revisiting time. If the cloud cover is taken into consideration then much less images are available for each year than for MODIS data. The MODIS NDVI composite product consists of, with some exceptions, 23 NDVI images per year. Within the study area about 5-10 usable Landsat images are available per year, which still have a certain amount of cloud cover. Due to this significant lower amount of images and the changing distributions of images over the years it is not possible to extract seasonal parameters from Landsat imagery. To extract the plant phenology data a large amount of images is needed. Landsat cannot be used for an intra-annual time series, because Timesat is not able to accurately extract the phenology parameters with 11 MODIS images a year. The number of available images is too low, besides the Landsat data copes with

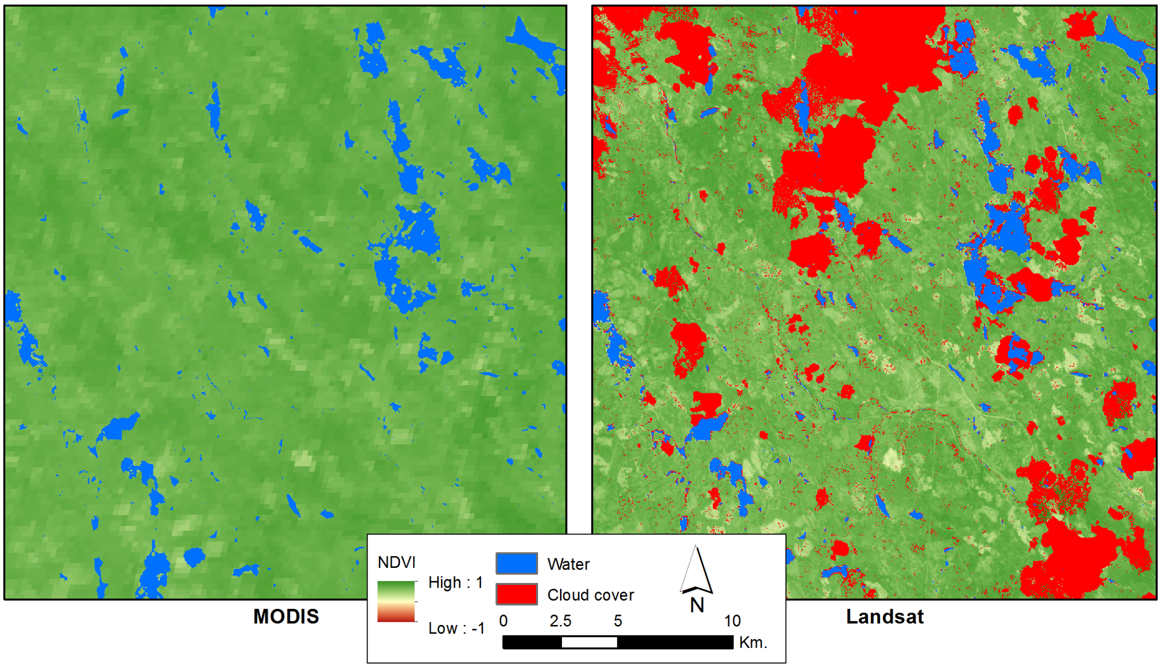
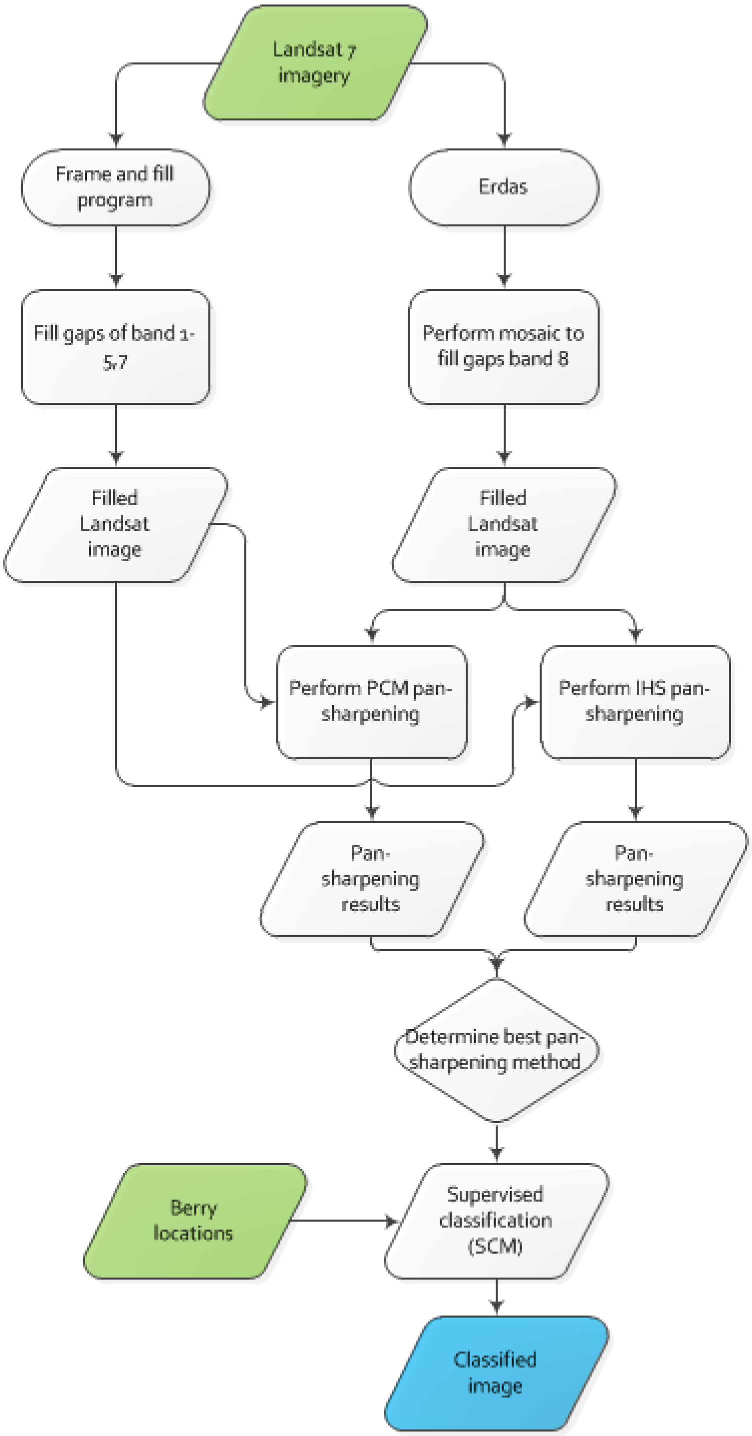


Figure 24: Comparison between MODIS and Landsat.

an, after pre-processing, unequal recording dates. MODIS however has the best data guarantee with the relative highest spatial resolution. In Figure 24 the difference in spatial resolution between Landsat and MODIS becomes more clear. The Landsat image has clearly more detail and it looks sharper than the MODIS image. It is however possible to distinguish the same NDVI patterns in the area. The boundaries of the individual fields are easier to distinguish in the Landsat data, but there still is the problem with the cloud cover.

With a R^2 of 0.42 (N = 410 775) the NDVI of the MODIS shows a significant correlation with the NDVI extracted from Landsat. The NDVI of MODIS is on average higher due to the composition algorithm, it ensures that the best pixels remain. The MODIS NDVI in the study area is always larger than 0, this is not the case for Landsat. It is likely that the differences are the result of the difference in image resolution. The highest NDVI values of MODIS do also occur in the Landsat NDVI, this can be explained by the fact that the NDVI saturates when it reaches 1. The Enhanced Vegetation Index (EVI) is optimised for areas which have a high biomass. Therefore it does not saturates when it reaches 1. This might result in a better distinction of the different forest types and forest health. As can be seen the result show homogeneous areas. The Weighted Difference Vegetation Index (WDVI) performs better in homogeneous areas and can therefore lead to a more detailed result.

Appendix VII Flowchart RQ2



Appendix VIII Landsat gap-fill and pan-sharpening methods

As previously mentioned the Landsat 7 imagery has data gaps due to a failing Scan Line Corrector (SLC). This problem made it impossible to create an inter-annual time series. It is however possible to create a single map based on multiple images from the same period over several years.

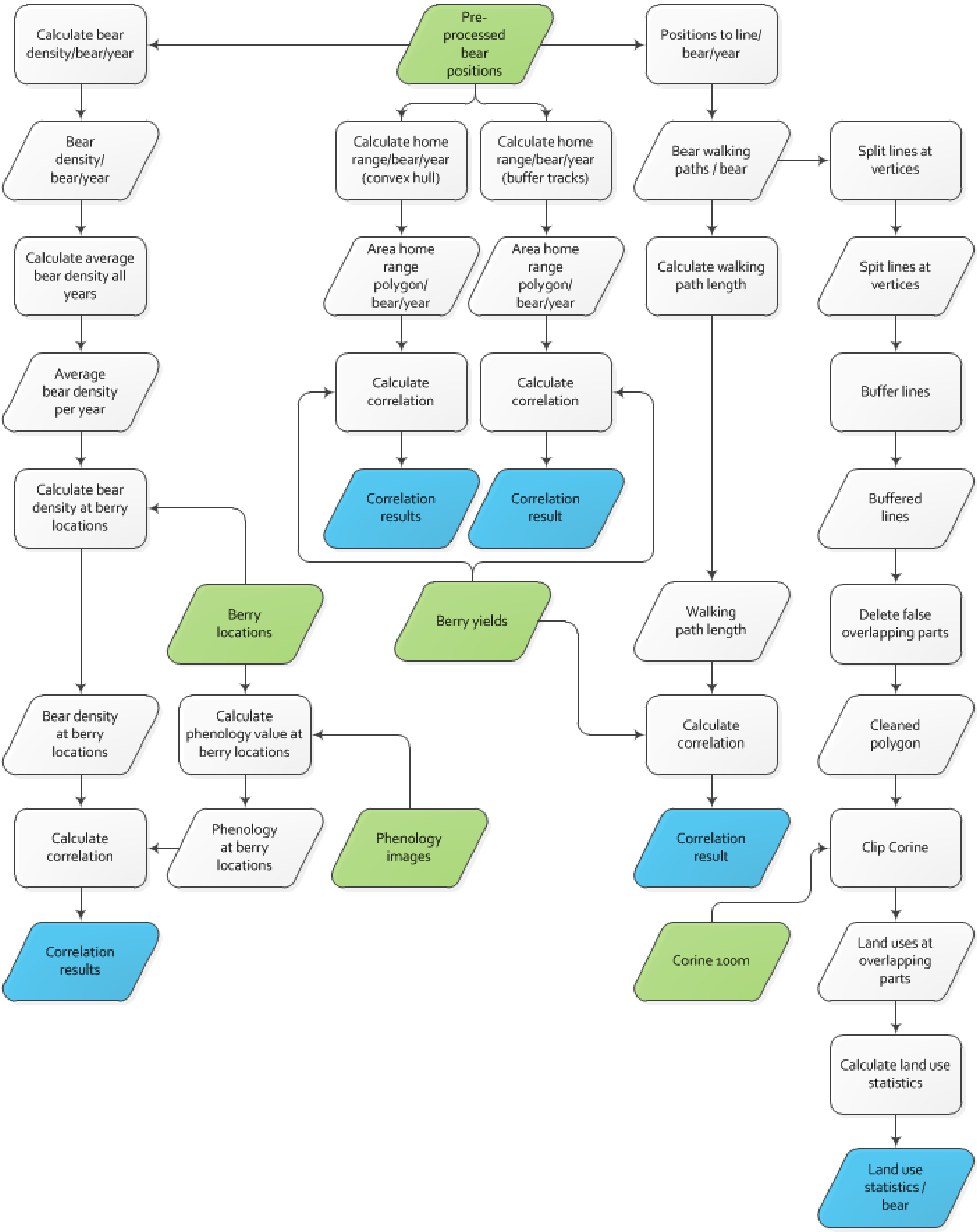
NASA developed a tool which is able to correct for this SLC problem by adding information from adjacent scenes of the same period. The program can do this for all the bands except for the panchromatic band. Beside gap filling with information from adjacent rows the program also performs histogram matching. The first step of the program is to align multiple Landsat 7 scenes to a common frame. This provides equal number of lines and line length of all the input images. The second step is to fill all the no-data gaps with information of the adjacent rows. The imagery used are all from the same period over different years, the images are mostly cloud-free.

The panchromatic band can be used to increase the spatial resolution. The resulting pan-sharpened image has a spatial resolution of 15 meters. The gap filling program is not able to fill the gaps in the panchromatic band, therefore this needs to be done manually. The gaps also needs to be filled with information from adjacent rows. The analysis is performed with the mosaic tool images with histogram matching enabled Erdas Imagine.

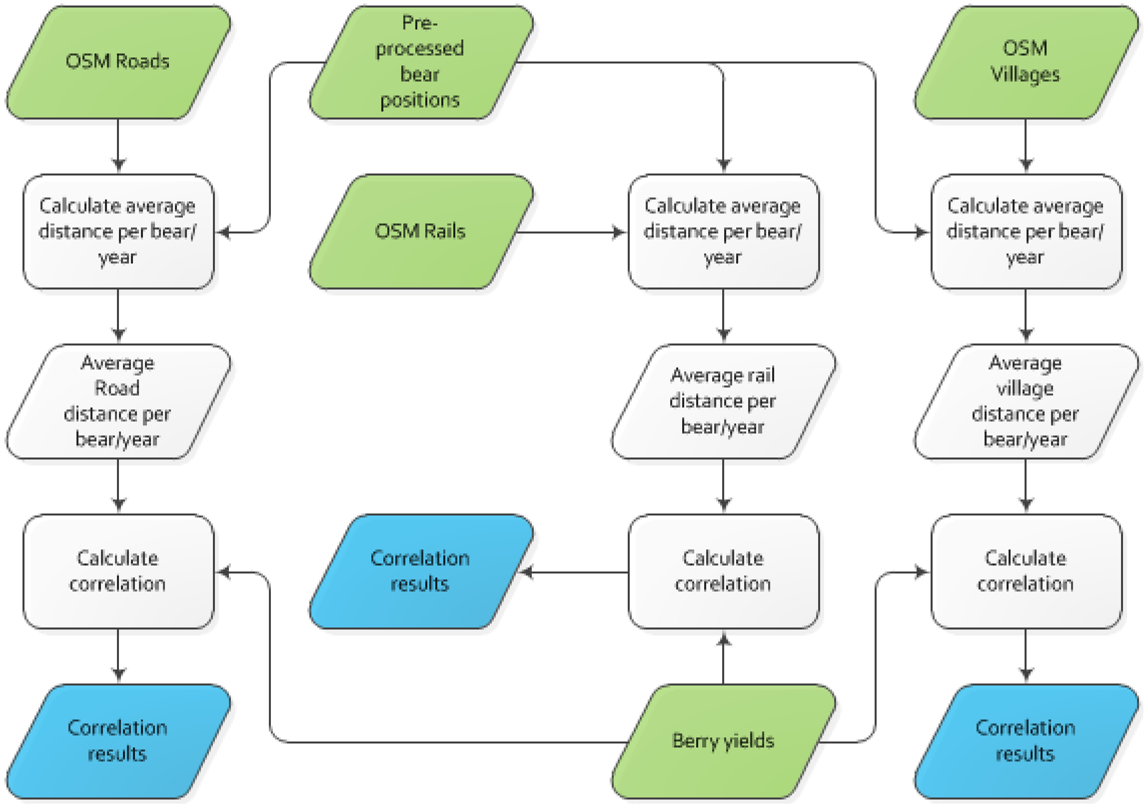
The gap filled panchromatic band is used to perform pan-sharpening. Many different methods are available to perform a pan-sharpening. In most cases there is a trade-off between spatial and spectral resolution (Wittman et al. 2008). Two different pan-sharpening methods are used in this research. The intensity hue saturation (IHS) pan-sharpening method, and the Principal Component pan-sharpening method (PCM) are used in this research. The IHS method is the most basic and popular image fusion technique available. The image is firstly transformed to IHS colour space, than the intensity band is switched with the panchromatic band which are then converted back to the RGB colour space. According to Wittman et al. (2008) performs the IHS method best spatially and the VWP method performs best spectrally this method was however not implemented in Erdas. Due to the fact that the VWP methods is not implemented in Erdas, the IHS method is used in this research for the best spatial results.

According to the Erdas help file the Principal Component Method (PCM) the best in retaining the radio-metrical properties of the input file. Therefore this method is also used in this research.

Appendix IX Flowchart RQ3



Appendix X Flowchart RQ4



Appendix XI Home range size

In this appendix the results of the home range size analysis of the individual bears are listed.

Home range size (Convex hull), 1 = 120 kilometre sq.

Bear ID	2004	2005	2006	2007	2008	2009	BB(1)	LB(2)	BB/LB(3)
W0004	2.28	-	1.10	0.91	1.32	-	-0.32	-0.61	-0.50
W0212	-	0.38	1.14	1.25	0.54	-	-0.20	0.93	0.42
W0411	-	-	1.84	0.94	1.04	0.94	0.95	0.33	0.73
W0422	-	-	1.05	0.50	0.43	0.55	0.99	0.58	0.89
W0626	-	-	1.16	0.93	1.12	0.91	0.57	-0.34	0.13
W9403	-	-	1.06	0.51	0.87	1.23	0.50	0.32	0.46
Average	2.28	0.38	1.23	0.84	0.89	0.91	-0.39	-0.05	-0.30

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

Home range size (buffer tracks), 1 = 98 kilometre sq.

Bear ID	2004	2005	2006	2007	2008	2009	BB(1)	LB(2)	BB/LB(3)
W0004	1.66	-	1.09	0.89	1.22	-	-0.25	-0.65	-0.48
W0212	-	0.51	1.19	1.16	0.70	-	-0.15	0.95	0.46
W0411	-	-	1.25	0.90	1.05	1.02	0.91	0.21	0.63
W0422	-	-	1.09	0.61	0.56	0.71	1.00	0.62	0.91
W0626	-	-	1.27	1.03	1.27	0.94	0.41	-0.50	-0.05
W9403	-	-	1.19	0.59	1.00	1.11	0.67	0.16	0.47
Average	1.66	0.51	1.18	0.86	0.97	0.95	-0.40	0.03	-0.25

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

Appendix XII Land use selection regarding berry yields

Land use classes

Land use	Name
2	Urban area
18	Pastures
20	Complex cultivation patterns
21	Partially agriculture
24	Coniferous forest
25	Mixed forest
29	Transitional woodland-shrub
35	Inland marshes
36	Peat bogs
41	Water bodies

Bear W0004

Land use	2004	2006	2007	2008	BB	LB	BB/LB
2	0	0	0	0	-	-	-
18	0	0	0	0	-	-	-
20	0	0	0	0	-	-	-
21	0	0	0	0	-	-	-
24	97855	82777	76558	77428	0.90	0.52	0.80
25	941	191	172	152	0.96	0.42	0.78
29	62080	67767	68092	71630	-0.76	-0.14	-0.51
35	0	0	0	0	-	-	-
36	7050	17404	23312	18904	-0.92	-0.70	-0.92
41	213	0	5	25	0.99	0.48	0.83

Bear W0211

Land use	2005	2006	2007	2008	BB	LB	BB/LB
2	327	616	369	1222	-0.27	0.46	0.10
18	0	0	0	0	-	-	-
20	0	0	0	0	-	-	-
21	0	0	0	0	-	-	-
24	115648	112294	113132	118076	0.46	0.60	0.60
25	3635	2507	1509	3196	0.79	0.95	0.98
29	16606	22512	24385	18749	-0.88	-0.85	-0.98
35	0	0	0	0	-	-	-
36	10085	9210	8712	7029	0.49	-0.03	0.26
41	3183	2345	1377	1213	0.73	0.44	0.66

Bear W0411

Land use	2006	2007	2008	2009	BB	LB	BB/LB
2	0	0	0	0	-	-	-
18	0	0	0	0	-	-	-
20	190	0	174	284	0.35	0.15	0.28
21	0	0	190	858	-0.19	0.23	0.02
24	88931	89247	88477	85585	0.10	-0.29	-0.10
25	5957	860	7694	6978	0.23	-0.29	-0.03
29	25367	28741	24289	28688	-0.29	0.62	0.18
35	0	0	0	0	-	-	-
36	4842	1363	3209	2273	0.84	0.03	0.50
41	4539	9613	5792	5160	-0.63	-0.09	-0.41

Bear W0626

Land use	2006	2007	2008	2009	BB	LB	BB/LB
2	0	0	0	0	-	-	-
18	0	0	0	0	-	-	-
20	0	0	0	0	-	-	-
21	0	0	0	0	-	-	-
24	126818	107476	107057	127196	0.75	0.76	0.86
25	833	1096	1005	275	-0.20	-0.52	-0.40
29	19360	31604	32878	26709	-0.98	-0.71	-0.95
35	0	0	0	0	-	-	-
36	12341	18727	17863	5009	-0.37	-0.62	-0.56
41	418	866	967	582	-0.89	-0.82	-0.97

Bear W0422

Land use	2006	2007	2008	2009	BB	LB	BB/LB
2	0	0	0	0	-	-	-
18	0	0	0	4	-0.09	0.43	0.19
20	0	0	0	0	-	-	-
21	31	0	0	9	1.00	0.59	0.90
24	71800	51705	73636	64278	0.44	-0.36	0.05
25	1647	307	1420	1140	0.63	-0.12	0.29
29	57257	71151	55476	62814	-0.42	0.40	-0.01
35	0	0	0	0	-	-	-
36	1292	8863	1494	3425	-0.52	0.22	-0.17
41	0	0	0	355	-0.09	0.43	0.19

Bear W9403

Land use	2006	2007	2008	2009	BB	LB	BB/LB
2	0	0	0	0	-	-	-
18	0	0	0	0	-	-	-
20	0	0	0	0	-	-	-
21	0	0	0	0	-	-	-
24	113282	112695	116755	111154	-0.22	-0.92	-0.65
25	1326	760	1040	27	0.44	-0.31	0.08
29	14383	22606	17634	22158	-0.74	0.14	-0.34
35	0	0	0	161	-0.09	0.43	0.19
36	10637	3751	3658	5790	1.00	0.60	0.91
41	184	0	725	522	-0.28	-0.61	-0.50

Appendix XIII Correlation results bear density plant phenology parameters

	W0004	W0212	W0411	W0422	W0626	W9403	Average
Amplitude	0.84	-0.39	-1.00	0.28	0.29	-0.21	0.27
Base	-0.50	0.55	0.93	-0.23	-0.78	0.40	-0.17
End season	-0.71	-0.73	0.13	-0.55	-0.48	-0.36	-0.73
Large integral	-0.91	-0.36	0.57	0.13	0.42	0.56	-0.88
Left derivative	0.02	-0.74	-0.74	-0.14	-0.04	0.09	-0.36
Length season	-0.92	-0.61	0.31	-0.07	0.45	0.25	-0.82
Max NDVI	0.17	0.59	0.86	-0.17	-0.58	0.57	-0.36
Middle of season	0.28	0.65	-0.77	0.28	-0.70	-0.87	-0.09
Right derivative	0.69	0.74	-0.34	0.47	0.55	0.34	0.50
Small integral	-0.69	-0.83	-0.27	0.32	0.97	0.32	-0.64
Start season	0.82	-0.55	-0.50	-0.89	-0.88	-0.65	-0.15

Appendix XIV Bear distance human interest

Normalised average bear distance to roads correlated with berry yields, 1 = 878 meter.

Bear ID	2004	2005	2006	2007	2008	2009	BB[(1)]	LB[(2)]	BB/LB[(3)]
W0004	0.77	-	1.22	0.92	0.81	-	0.95	0.88	0.99
W0212	-	1.18	0.91	1.08	0.67	-	0.45	0.17	0.42
W0411	-	-	0.97	1.05	1.41	1.21	-0.64	-0.81	-0.82
W0422	-	-	0.80	0.87	0.60	0.93	0.14	0.89	0.58
W0626	-	-	0.81	1.04	0.90	1.07	-0.68	0.20	-0.27
W9403	-	-	1.03	1.61	1.00	1.13	-0.45	0.23	-0.13
Average	0.77	1.18	0.96	1.10	0.90	1.09	0.44	0.27	0.47

4) Correlation coefficient with blueberry yields
5) Correlation coefficient with lingonberry yields
6) Correlation coefficient with the averaged blueberry and lingonberry yields

Normalised average bear distance to villages correlated with berry yields, 1 = 4383 meter.

Bear ID	2004	2005	2006	2007	2008	2009	BB[(1)]	LB[(2)]	BB/LB[(3)]
W0004	0.82	-	1.12	0.94	0.74	-	0.86	0.96	0.98
W0212	-	0.87	0.96	1.32	0.83	-	-0.43	0.62	0.07
W0411	-	-	1.18	1.70	1.23	1.26	-0.54	0.09	-0.26
W0422	-	-	0.69	0.63	0.77	0.72	-0.11	-0.64	-0.42
W0626	-	-	1.20	1.39	1.53	0.73	-0.27	-0.73	-0.56
W9403	-	-	0.79	0.80	0.65	1.11	0.07	0.71	0.44
Average	0.82	0.87	0.99	1.13	0.96	0.95	-0.20	0.57	0.22

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields

Normalised average bear distance to railroads correlated with berry yields, 1 = 8260 meter

Bear ID	2004	2005	2006	2007	2008	2009	BB[(1)]	LB[(2)]	BB/LB[(3)]
W0004	0.60	-	0.70	0.62	0.62	-	0.98	0.75	0.94
W0212	-	1.42	1.51	1.66	1.57	-	-0.86	0.37	-0.39
W0411	-	-	1.66	1.59	2.02	2.18	-0.31	-0.23	-0.30
W0422	-	-	0.52	0.57	0.62	0.68	-0.62	-0.17	-0.45
W0626	-	-	0.27	0.47	0.34	0.58	-0.52	0.32	-0.11
W9403	-	-	0.68	1.06	0.90	1.17	-0.72	0.09	-0.36
Average	0.60	1.42	0.89	0.99	1.01	1.15	0.49	-0.04	0.30

1) Correlation coefficient with blueberry yields
2) Correlation coefficient with lingonberry yields
3) Correlation coefficient with the averaged blueberry and lingonberry yields