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Mapping moth induced birch forest damage in northern Sweden, with MODIS satellite data

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Master thesis, 30 credits, in *Physical Geography and Ecosystem Analysis*

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Abstract

Large synchronous outbreaks of herbivory geometrids is regularly occurring at 9-10 years intervals when they reach peak densities in the Fennoscandian birch forest, in the northern part of Scandinavia (Tenow 1972, Bylund 1995). Climate change is likely to increase the frequency, intensity and extent of the outbreak due to increasing temperatures in the area (Callaghan 2010, Heliasz *et al.* 2011, Wolf *et al.* 2008). The consequence is a detrimental effect to the birch forest since the forest might not have enough time to recover between outbreaks, which will potentially decrease the proliferation and distribution of birch forest (Tenow et al. 2001, 2003, Karlsson et al 2004). This will have an ecological cost by making the forest inhabitable and non-resourceful for the animals and people that depend on it (Helle 2001). However, the effects on the Birch forest are not well known, therefore it is important to continue studying the distribution of forest damage, to gain a better understanding of its dynamics and the underlying spatio-temporal factors controlling the synchronous outbreaks.

The most current year of infestation in the study area of the surroundings of lake Torneträsk in northern Sweden was 2012. To map the distribution and dynamics of the geometrids of the birch forest, time series data of MODIS 16-day NDVI composites were analyzed. To facilitate the analysis, a tree cover map with high resolution was created based on Lidar data. The Lidar based forest cover map was created to mask the forest. The topographical distribution of infested forest at four altitudinal intervals with 100 meter equidistance in between was also studied.

A method was developed in this study to separate infested from non-infested forest with a threshold value based on z-score, which was successful at showing the distribution of the geometrid outbreak in 2012. The size of the infested area was 80km^2, equal to 54.3% of the forest in the area. If the forest classified as “likely infested” would have been included, the ratio of infested forest would increase to 64.4%. This is a significant proportion of the forest that will certainly affect the forest in future years. The topographical distribution of the infestation over the study area was relatively evenly distributed, without displaying any range of altitude that was more prone to infestation.

Keywords: Remote sensing, Birch forest, MODIS, time series, geometrids, *Epirrita autumnata*, TIMESAT, topography

Svensk Sammanfattning

Stora synkrona utbrott av björkmätare förekommer vart 9-10 år i de norra delarna av Skandinavien i den Fenoskandiska björkskogen. Björkmätaren konsumerar bladen och kan orsaka stora skador under ett toppår. Man misstänker att klimatförändringarna kommer att öka utbrottens omfattning och intensitet på grund av ökad temperatur i området. Konsekvenserna kan bli förödande för björkskogen, eftersom tiden mellan utbrotten riskerar att bli för korta för skogen att återhämta sig. Det kan resultera i att träden dör och skogen försvinner i de värst drabbade områdena. Om skogen minskar eller försvinner kan det få ekologiska konsekvenser för de djur som är beroende av den och människor som utnyttjar dess resurser.
Hur skogen kommer att påverkas vet man inte säkert, därför är det viktigt att studera utbredningen av skogsskador och på så sätt få bättre kunskap om de underliggande faktorerna som kontrollerar utbrottens dynamik.

Ett utbrott inträffade sommaren 2012 i studieområdet vilket var indelat i 2 olika stora överlappande område; Ett större som täcker området runt sjön Torneträsk i norra Sverige och ett mindre som täcker den västra delen av sjön runt Abisko. För att kartlägga omfattningen av björmatarutbrottet användes tidsserier av MODIS 16-dagars NDVI kompositer som analyserades men en utvecklad förändrings analys för projektet. Som en del i analysen skapades en högupplöst skogsutbredningskarta med Lidar data. Den topografiska utbredningen av utbrotten studerades också genom att dela in området i fyra höjdintervall med 100 meters ekvidistans mellan intervallen.

För att identifiera skadade område utvecklades en metod baserat på standardiserade z-värde och definierade gränsvärde för klassificeringen av skogen. Det angripna området i Torneträsk var 251 km^2 stort, motsvarande 32% av skogen. I studieområdet i Abisko var utbrottet 80km^2 stort, vilket motsvarar 54.3% av skogen i studieområdet. Om skogen klassad som ”troligen angripen” inkluderas i beräkningen, skulle den del av skogen som var angripen ökas ytterligare. Det är en signifikant andel skog som med stor sannolikhet kommer att påverka skogen i flera år. Den topografiska utbredningen av utbrottet i studieområdet var relativt jämnt fördelat, inget höjdintervall visade sig vara extra känsligt för att bli angripen.

Contents

Abbreviations

GIS	- Geographic information system
NIR	- Near infrared
SWIR	- Short wave infrared
EOS	- The Earth observation system
MODIS	- Moderate Resolution Imaging Spectro-Radiometer
NDVI	- Normalized difference vegetation index
LAI	- Leaf area index
fPAR	- Fractional photosynthetic active radiation
Lidar	- Laser Imaging Detection and Ranging
DEM	- Digital elevation model
LP DAAC	- Land processes distributed active archive center

1. Introduction

Geometrid infestations are the largest natural disturbance factor of the birch (*Betula pubescens* ssp. *Czerepanovii)* forest in the Scandinavian mountain ridge in northern Sweden (Tenow 1972). Infestations are natural events that rejuvenate and create succession of a forest. There are two main species of Geometrids (suborder of Lepidoptera; moth and butterflies) that can form dense peak population levels, which cause severe defoliation of the forest by leaf consumption. These two Geometrids are the autumn moth *Epirrita autumnata* and the winter moth *Operophtera brumata.* They have synchronous outbreaks every 9-10 years, which means they reach peak levels simultaneously but at separate locations (Tenow 1972, Bylund 1995).

The forest analyzed in this study is located in the Torneträsk area, in the northern part of Sweden. This area has been the target of large infestations several times before. The summer of 2012 was the lastest infestation and will be analyzed in this study. The 2012 infestation can clearly be observed in Figure 1. The two pictures were taken from the scientific research station in Abisko at almost the same day in different years (2011, 1 August kl 11.55am and 2012, 4 August kl. 11.47am). The left picture taken in 2012 is more brown/grey than the right picture taken in 2011. From the research station much geological, climatological and environmental research is conducted (Polarforsnings seketariatet 2012).The research station also records the increasing temperature from climate change, which may help to understand the infestations.

Climate change is known to affect the region where the birch forest grows. Research data, collected from the Abisko Scientific Research Station, have reported an increasing mean annual temperature since 1913, and it is now above 0 degrees (Callaghan 2010, Heliasz *et al.* 2011). An increasing temperature is thought to increase the frequency and intensity of insect damage on birch forest (Wolf *et al.* 2008). Increasing minimum winter temperatures will have two effects; the survival rate of the birch moth eggs will increase in areas already exposed, and previously winter protected areas will be made more habitable for infestation (Tenow *et al.* 2001). Virtanen *et al.* (1998) made a model to forecast the minimum winter temperature for the northernmost of Finland. They found that the number and size of areas too cold for the survival of geometrid eggs can decrease by one-third until the middle of next century, as a consequence of increasing minimum winter temperatures. Temperature is important for geometrids survival, and ecological consequences will result if the temperature changes from what the forest and insects are adapted to.

The forest is habituated by animals that are dependent on the forest and its heterogeneity. For instance, the area is used as pasture for both wild and semi-domestic reindeer, which utilize the mixture of trees and lichens for food throughout the year (Helle 2001). Additionally, the forest contributes with socio-economic values to the local community, by the tourists and hikers in the area visiting the forest. For the livelihood of the forest animals as well as the people that benefit from the forest, studying the impact infestations have on birch forest vegetation is important.

To analyze vegetation damage caused by infestations, satellite images are an efficient tool to observe vegetation change over large areas. NDVI time series from the MODIS satellite and Lidar data were utilized in this study to provide information about the spatial distribution of the outbreak dynamics of the moths in 2012, and to monitor the consequences of the increased forest damage on the birch forest in the Torneträsk area. This study of a geometrid infestation is of great value because of the potential future impacts. If the outbreaks continue to increase in intensity and frequency, as predicted with climate change, permanent deforestation could occur, resulting in a substantial ecological cost for the animals and individuals that depend on the forest. Monitoring and studying the distribution of infestation will prepare us for future changes and allow us to adapt our sustainable use of the forest.

Figure 1. Picture of Njulla hill taken with a camera taking a few pictures every day automatic camera mounted on the Abisko Scientific Research Station showing the non-infested year 2011 (left) alongside the infested year of 2012 (right).

1.2 Aim

The aim of this study is to map the 2012 spatial distribution of defoliated forest in the Torneträsk area caused by the herbivory birch moth, by analyzing MODIS satellite images and Lidar data. The Lidar data will be used to produce a high resolution forest cover map to perform a detailed analysis. Unfortunately Lidar data is currently not available for the entire study area of Torneträsk. Consequently there are two extents of the study area. The area of main interest is the one of smaller extent defined by the available Lidar data, and it is called the “Abisko study area”. This main area of interest covers the west part of the lake and surrounding mountains, and is shown by the red rectangle in figure 2. The study area with the larger extent, which could not be studied with the detailed Lidar approach is called the “Torneträsk study area”. This larger area covers the whole lake, the mountains around it and expands into Norway. The larger area is represented by the yellow square in Figure 2.

The following sub aims are identified:

- Create an up-to-date, high resolution forest cover map of the Abisko study area and the infestation of this area for 2012.
- Produce an overview map of the infestation that shows the damage distribution for the whole extent of the Torneträsk area.
- Investigate the topographical effects on infestation distribution in the mountainous area

1.3 Study site

The study site is the surrounding area of lake Torneträsk (68°23′42″N, 18°51′17"E), located in the northern part of the geographical province of Lapland, belonging to the eastern part of the Swedish mountain ridge (figure 2).

There are two types of birch trees growing in the Swedish mountains; polycormic and monocormic. The dominant types in the study area, mainly on the south side of the lake, are polycormic birch trees. Polycormic birch trees can be recognized by their shrub-like growth, with basal sprouts growing from a common root system. This is in contrast to the monocormic trees that grow with one main stem and rejuvenate by seeds instead of basal sprouts (Wielgolaski 2001, Tenow *et al*. 2004).

The birch forest of the Torneträsk area grows in the subalpine section and consists of a heterogeneous landscape with mires and heath vegetation in between the birch forest, along with dwarf shrubs, grasses and lichens (Wielgolaski 2001). In areas where the birch trees have died, there is sometimes a succession of other trees and shrubs of *Betula, Alnus* and *Salix* growing (Tenow *et al* 2001). The vertical distribution of birch forest ranges from the lowest point of the lake Torneträsk at 342 m. a.s.l. (meter above sea level) to about 650 m. a.s.l (Tenow *et al.* 2001). The Abisko Scientific Research Station, from where the photo in Figure 1 was taken, is located on the south eastern shore of Torneträsk at 68° 21’N, 18° 49’E.

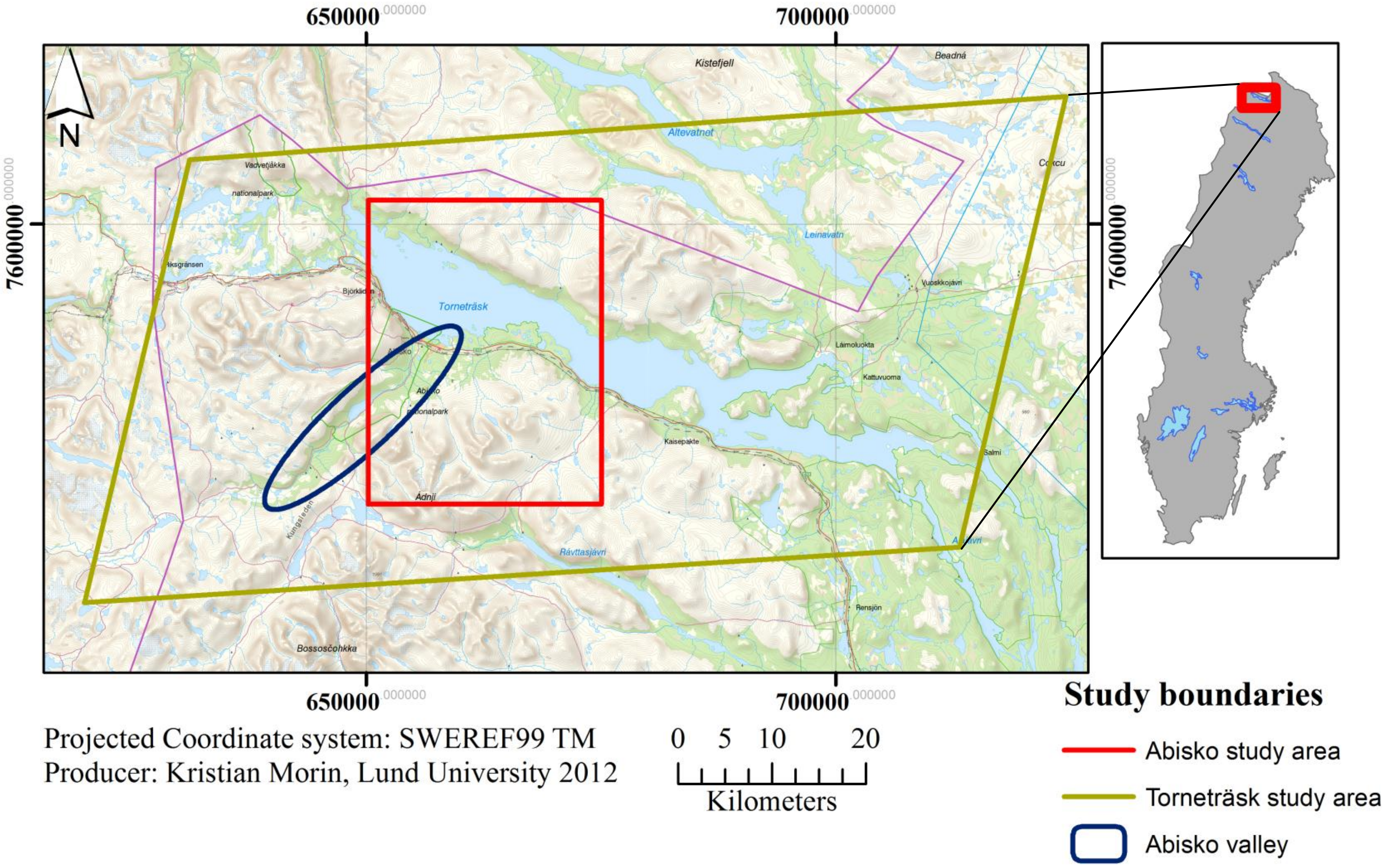


Figure 2. An overview of the study area. The small red rectangle shows the extent of Lidar data and is the main study area, the "Abisko study area". The large yellow rectangle is the Torneträsk study area. (Basemap @ Lantmäteriet, Dnr: i2012/927).

2. Background

In this section of the study the data used and the general concepts of how the analysis was performed will be introduced. An overview of remote sensing will first be given. The MODIS satellite data will be described in more detail, followed by an overview of the vegetation index NDVI. The second part will describe active remote sensing with Lidar, continued with an introduction to the Lidar data utilized in this study. Lastly, the concepts of the change detection techniques will be explained and the program TIMESAT that was used to extract seasonal parameters for the analysis will be described.

2.1 Overview Remote sensing

Remote sensing is the science of observing, collecting and analyzing data of the earth's surface without being in physical contact with it. The information is collected by sensors, which are carried by aircrafts or satellites. Sensors collect information of an object/surface by measuring the electromagnetic energy reflected or emitted from it (Lillesand *et al.* 2008). There are many advantages of working with remote sensing data. Large areas can be covered in a snapshot of time,

without the expensive labor intensive field work that would be required to cover the same area. Remote, inaccessible and inhospitable locations can be investigated (Lillesand *et al.* 2008). Data recorded by a sensor are not subjected to bias as compared to manual interpretation, where experience, knowledge and engagement may vary between different interpreters and influence the result. Remote sensing is also more economical than large scale field studies because investigations can be repeated for a lower cost than fieldwork (Lillesand *et al.* 2008).
Remote sensing is a valuable tool with many benefits, but field work should not be underestimated. Field work can provide more detailed information which cannot be obtained by remote sensing. By combining the benefits of both field work and remote sensing data, more comprehensive studies can be performed with deeper analyses.

Remote sensing instruments measure different parts of the electromagnetic spectrum; the spectrum can roughly be divided into classes based on their properties and wavelengths. These classes are; ultra violet (0.1 – 0.4 µm), visible (0.4 – 0.7 µm), near infrared (NIR) (0.7 - 1.7 µm) shortwave infrared (SWIR) (1.3 - 3 µm) and thermal energy (3 - 14 µm) (Lillesand *et al.* 2008). Sensors are designed to record a spectral bands or channels, which measure specific ranges of wavelengths from different parts of the electromagnetic spectrum, like the red and infrared band. Electromagnetic energy can interact with features by being reflected, transmitted or absorbed. The reflected energy is measured by a sensor and the information is used to analyze these features. There are two main types of sensor systems that record reflected or emitted electromagnetic energy; passive and active sensors (Lillesand *et al.* 2008).

2.2 Passive sensors

Passive sensors record the energy that is radiated from an external energy source, i.e. the sun, which has interacted with surface features on the earth. Use of an external energy source can sometimes be a limitation, because it makes sensors sensitive to the time of day they are operated. These types of sensors are affected by illumination angles, which can result in shadows, shaped from land features. The MODIS sensor on the Terra satellite is used in this study and is an example of a passive sensor (Lillesand *et al.* 2008). Passive sensors are often constructed to be multispectral and capable of measuring reflected electromagnetic energy in several specific wavelength bands. It is the difference in reflection between bands that make remote sensing so useful. The reflectance from different surfaces can be similar for one wavelength band; however, when several bands are used to record the reflected energy from the same surface, the reflectance in some of the bands is likely to will be different. The configuration of spectral reflectance from different objects creates a unique reflectance curve for each feature, also called a spectral signature. By knowing the spectral signature for different objects, the objects can be separated from one another (Lillesand *et al.* 2008). For example, reflectance from soil can be different depending on its composition. Soil moisture, surface roughness and organic content all make varying soil types spectrally separable. Different tree species can by the same principle be separated. However, the spectral signature for vegetation may change over time because of the vegetation change between different seasons, such as budburst and autumn defoliation (Lillesand *et al.* 2008). Spectral signatures can also change during events if exposed to a stress, such as water deficiency or as in the case of this study, defoliation caused by geometrid insects (Neuvonen *et al.* 2001, Lillesand *et al.* 2008). During defoliation events the forest will be interrupted from it natural growth, resulting in a loss of chlorophyll production that will increase the reflectance in the red and blue wavelength bands and decrease the NIR reflectance (figure 3). The influence of these external disturbances to the forest is utilized in this study to separate healthy forest from forests affected by herbivory Geometrids.

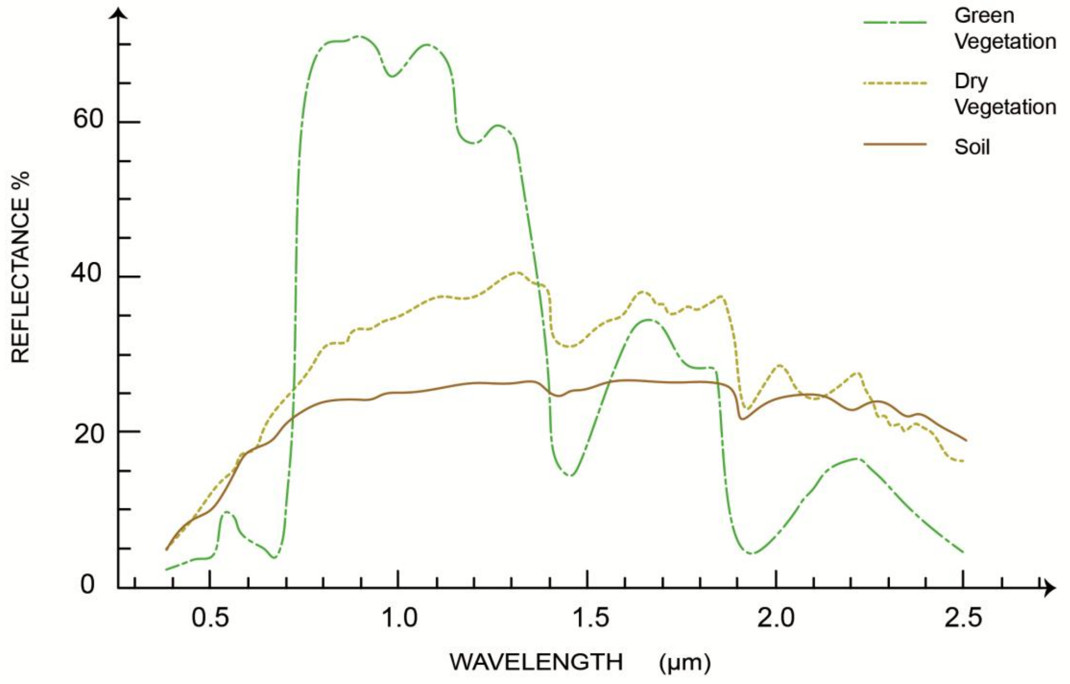


Figure 3. Example of spectral reflectance curves for healthy and dry vegetation and soil (Redrawn based on Stöckli 2003)

2.2.1 MODIS on Terra satellite

Two components make up the successful use of the MODIS sensor on the Terra satellite. MODIS were chosen for this study because MODIS has the longest time series record with high temporal and spatial resolution. It has a global coverage every 1-2 days, which makes it a good resource for change detection studies. Due to its properties and usability, MODIS data has been successfully utilized in several studies that have observed the increasing distribution of forest damaged by insects, over large regions (de Beurs and Townsend 2008, Jepsen *et al.* 2009).

MODIS is a component of the Earth observation system (EOS), which is part of the Earth Science Enterprise. The Earth Science Enterprise is a comprehensive program by NASA with the purpose is to study the changing environment on the Earth and use the information gained in studies of earth processes (NASA 2012a). One of the EOS's primary subjects is to study the land surface and its vegetation, which can be done with the Terra and Aqua satellites. These two satellites are considered to be the flagship of the EOS program, providing satellite images with global coverage and very high temporal resolution to facilitate long term global observation. Terra was launched on December 18,1999 and Aqua shortly after on May 4, 2002. Both satellites are orbiting with near-polar, sun-synchronous orbits at an altitude of 705 km and with an inclination angle of 98 degree to the Earth. Terra has an equatorial descending path crossing time at 10.30 am and Aqua an ascending crossing path at 1.30 pm (Lillesand *et al.* 2008, NASA 2012b, Solano *et al.* 2010)

MODIS is one of 5 sensors carried on the Terra satellite. The term MODIS stands for Moderate Resolution Imaging Spectro-Radiometer. It has a field of view +/- 55° giving a scan width of 2330 km and a complete scan cycle that finishes in 16 days. MODIS is multispectral with 36 spectral bands ranging in wavelengths between 0.4 and 14.4 µm (Solano *et al.* 2010, NASA 2012b). Originally, MODIS had an expected lifetime of six years; however, it still delivers images without failure. This long lifetime makes MODIS an excellent resource to analyze long time-series of vegetation change. Another benefit with MODIS products is that they are ready to be used without further rectification; the solar bands have already been absolutely radiometrically calibrated with accuracy better than 5 percent. MODIS data are also atmospherically corrected (Huete *et al.* 1999, Lillesand *et al.*2008).

Several products are delivered from MODIS. The product MOD13Q1 was used in this study. MOD13Q1 has a spatial resolution of 250 meter and contains different data sets, such as 16-day NDVI and EVI composites, single reflectance bands and ancillary data with quality control flags (Solano 2010). The 16-day NDVI composites were chosen ahead of composites of higher temporal resolution, because the study area is frequently covered by clouds. The 16-day composites increases the number of potential cloud free days and were therefore considered the best choice for this study.

2.2.2 Vegetation indices NDVI

Normalized difference vegetation index (NDVI) is one of the earliest developed vegetation indexes and is still one of the most commonly used, because of its simplicity and wide range of applications (Rouse *et al.* 1974). NDVI measures the ratio between the visible red wavelength band and the near infrared band according to the equation (1):

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad \text{Equation (1)}$$

By the mathematical definition, the NDVI value can range between -1 and 1, however, in reality NDVI saturates around a value of 0.85.

The reason NDVI is a good index to use in vegetation studies, is because it is based on the red and NIR wavelength bands. In green healthy vegetation is the ratio in reflectance between the bands large. The ratio is large because the chlorophyll in the photoactive leaves of healthy vegetation will absorb most of the visible red wavelength. In contrast the NIR wavelength will be almost completely reflected by the leaves internal structure when the leaves are healthy. The absorption of red and the reflectance of NIR will result in a high positive NDVI over vegetation (Lillesand *et al.* 2008, Solano *et al.* 2010). Another advantage of using two bands in the equation is that it cancels out the majority of signals that would be attributed to noise due to atmospheric conditions such as variations of solar zenith angles and changing irradiance conditions (Huete *et al.* 1999, Tucker *et al.* 2005). With the noise removed the performance and accuracy of NDVI increases, making it a valuable tool in research analysis

NDVI is used to study phenological characteristics, vegetation cover, plant health and vegetation dynamics. NDVI has a linear correlation to fractional photosynthetic active radiation (fPAR) and is a good indirect indicator to leaf area index (LAI) used, for example, to calculate biomass accumulation (Chen *et al.* 2006, Fan *et al.* 2008). There are a couple of concerns that need to be addressed when using NDVI. First, NDVI is sensitive to background brightness; it systematically increases on darker soils because the signal is similar to the one from vegetation (Huete 1988, Huete *et al.* 1999). Second, NDVI saturates at medium and high vegetation densities before the leaf area index or biomass has reached its maximum, making it problematic to detect small vegetation changes in dense vegetation (Huete *et al.* 1999, Chen *et al.* 2006). Third, NDVI is not linear, NDVI shows a greater increase at small density increases and at higher levels there is reduced sensitivity (Huete *et al.* 1993).

2.3 Active sensors - Lidar

Lidar, which falls into the category of active sensors, supplies its own energy source and is not limited by the time of day it is operated. Thereby the data are not affected by shadows and illumination angles like many passive sensors are (Lemmens 2011). Lidar data has a higher spatial resolution than MODIS, which allows for a more detailed analysis. Many different land cover features can be found within the extent of the 250*250 meter MODIS cells, but since this study aims to identify forest damaged by insects, only forested area are of interest. Lidar data make it possible to create a map of the birch forest distribution that can be used to exclude MODIS cells that are not covered by forest. Lidar is the acronym for ”Laser Imaging Detection and Ranging”. As the name refers, Lidar operates with a laser pulse that is emitted at a very high frequency from a Lidar system mounted on an aircraft. The laser is reflected by the ground or objects above ground, below the carrier and the reflected signals are recorded by a receiving sensor. Tens to thousands of pulses per second can be sent, with the frequency depending on the Lidar system and application it is supposed to be used for (Lemmens 2011).

The most common application of Lidar is to create Digital elevation models, (DEM). It has become a standard procedure to use Lidar to create new DEMs because of its many advantages over photogrammetric methods (Lemmens 2011). Lidar is an asset for detailed hydrology studies because it can create DEMs with a high-resolution, even under the canopy cover.

Besides making DEMs, there are many more applications of Lidar. Lidar is widely used in the creation of 3D models of urban environments to facilitate city development. The forestry industry are beginning using Lidar, largely because so many different forest parameters can be extracted. Some parameters can be directly extracted, such as canopy height, forest distribution and forest cover (Lemmans 2011). Even individual trees can sometimes be classified to species (Heinzel and Koch 2011).

Information extracted from Lidar can be used as input for modeling above-ground biomass, crown and stem volume and other related forestry parameters (Mallet and Bretar 2009). Lidar often works in a wavelength of 1060nm, which is part of the near infrared spectrum. This is particularly helpful in forestry applications because vegetation reflects wavelengths of 900, 1060 and 1500 nm almost completely (Mallet and Bretar 2009, Lemmans 2011, Heinzel and Koch 2011).

The properties of Lidar do not only depend on the wavelength it operates in, the footprint size of a pulse also affects the reflectance signal. Lidar measures a footprint in which size depends on the system and the flying height, normally around 0.2-3 m (Mallet and Bretar 2009). The footprint will not hit just a single feature. When the pulses are penetrating through different structures in a forest, part of the pulse will be reflected back at different levels of the tree. This will generates multiple return points, with different heights and intensities, from a single laser pulse. The first return point from a tree will be from the top of its canopy, whereas the last return point will potentially penetrate to the ground (figure 4). The multiple return points can be classified into classes for different features by applying algorithms or filters to them (Mallet and Bretar 2009, Lemmans 2011). Some systems can record the property of the full wavelength form throughout the pulse, providing information about the structure of the whole canopy (Mallet and Bretar 2009, Lemmans 2011).

When Lidar points are recorded it is called a 3D point cloud, because each pulse carries information of the points position in x,y and z orientation. The cloud is an irregular and unorganized collection of unclassified points. Once classified they can be used in applications such as building a DEM, however the cloud points first need to be filtered to select only the ground points and then interpolated into a grid to create a continuous surface (Mallet and Bretar 2009, Lemmans 2011).

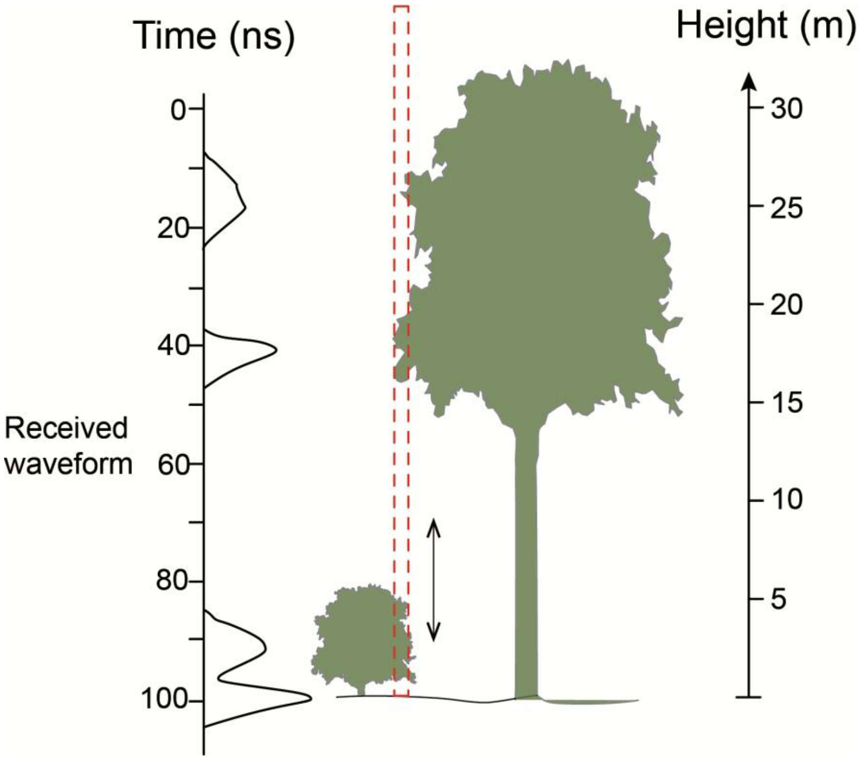


Figure 4. An example of a profile for a full wavelength pulse penetrating vegetation (Redrawn based on, Mallet and Bretar 2009).

2.3.1 Lidar scanning of Sweden

An aerial Lidar scanning covering the entire nation of Sweden is currently under process. The aim of the Lidar scan is to produce a new national elevation model called "*Nya nationella höjdmodellen*", which has a higher resolution than the old one (Lantmäteriet 2012). This new elevation model was used in the topography analysis of the study.

The intention of "*Nya nationella höjdmodellen*" is to create a DEM with very high resolution with a standard error less than 0.5 meter for a 2 meter grid. The Lidar scanning has a very high accuracy with less than 0.1 meter positioning error in vertical direction to a flat surface. In heterogenic, very steep terrain and where ground levels are not consistent, Lidar can be considerably less accurate. The vertical accuracy of Lidar has been measured to be around 0.3 meter (Lantmäteriet 2012).
The scanning was planned to take place outside of the growing season, so there would be an increase in ground hit points, particularly in regions covered by dense continuous forest (Lantmäteriet 2012).

The information from the aerial Lidar scanning of Sweden can be used for more than just creating the new DEM. Almost raw Lidar data can be accessed from the Swedish land survey institution. This Lidar data was used to create the forest cover map for this study. The data are delivered in tiles sized 2.5 x 2.5 kilometers and they are projected in the SWEREFF 99 TM reference system in the plane and RH2000 for the height system.The Lidar data products come pre-processed from an automated classification method, but the classification is rough and only contains four classes (ground, water, bridges, and unclassified points). The points classified as ground points and unclassified points are used in this study. The "unclassified points" class contains all other points that have been reflected from vegetation and other above ground surfaces. Each tile contains ancillary information, for example the scanning period and a thumbnail showing point density per m^2 (Lantmäteriet 2012). The Lidar scanning were done October 2010 for the study area. More detailed specifications for the Lidar scanning of Sweden are found in Table 1.

Table 1. Detailed technical specification for the Lidar scanning of Sweden.

Point density	0.5–1 points per square meter
Flying altitude:	1700-2300 meter
Scanning angle:	± 20º C
Side overlap:	20%
Footprint on the ground:	0.5 meter

2.4 Change detection analysis

Change detection techniques are utilized to analyze remote sensing data for changes in the environment between two temporal periods. Many change detection methods have been created to target specific applications. Different methods of change detection techniques are used to survey urban development, land cover and vegetation (Lunetta, R.S. 1999). The basis of change detection studies is to use a multi temporal data set of two or more images, acquired at the same time but at different years or periods that cover the same spatial region. The method is then applied to identify and quantify areas which have undertaken a change, natural or anthropogenic; from the previous scene (Lunetta, R.S. 1999, Coppin et al 2004). Before performing the change detection, the most important task is pre-processing the data to make them normalized for all images in the time series. By minimizing the noise to signal ratio, it increase the probability that the detected temporal change is realistic and not an error from ignored or unsatisfactory calibration. Corrections that are necessary to normalize the data between years for these kinds of studies are at the least: image geometric registration, radiometric calibration and atmospheric correction (Lunetta, R.S. 1999, Coppin et al 2004). Conveniently, as described before, all of these corrections are fulfilled by the MODIS data utilized for this project. When the data have been normalized, any change detection analysis can be chosen based on the aim of the project

One of the simplest change detection methods is single band differential, where one image is subtracted from the other. Image rationing is another common and easy method, where the ratio of change between years is analyzed (Lillesand 2008, Coppin et al 2004). There are also many successful advanced pre and post classification methods commonly used, such as principal component analysis (PCA), tasseled cap, change vector analysis (CVA), or a combination of them all (Coppin et al 2004, Lillesand et al 2008, Wang and Xu 2009). These classification methods are mainly used to indentify changes between two images, whereas this study is using a change detection method based on several images from different years. For this reason, another methodology was developed and it is described in detail within the method portion of this study. Readers interested in the other methods mentioned are referred to one of the many reviews articles being published (Lu et al 2003, Coppin et al 2004).

One of the most important steps in the change detection method developed for this study was to process the MODIS time series data so that the annual maximum NDVI value could be extracted for each pixel and year. These values were then used in the change detection analysis to identify damaged forest. TIMESAT is a program that can perform such an operation and it can also remove noise from the time series data to avoid biased results.

2.5 TIMESAT

TIMESAT is a program developed by Lars Eklundh (Lund University, Sweden) and Per Jönsson (Malmö University, Sweden) (Eklundh and Jönsson 2011). It is a program to analyze time series of vegetation indexes so seasonal parameters can be extracted in order to study phenological changes and variations in vegetation, to increase our understanding of local and global dynamic patterns (Jönsson and Eklundh 2002, 2004, Hird and McDermid 2009).

Eleven seasonal characteristics can be extracted by the TIMESAT program (figure 5). Four of these were used for this project: (1) start (a), (2) and stop (b), (3) of season, seasonal maximum value (e), and (4) small seasonal integral (h). A complete list and explanation of the parameters that can be extracted are listed in Eklundh and Jönsson (2011).

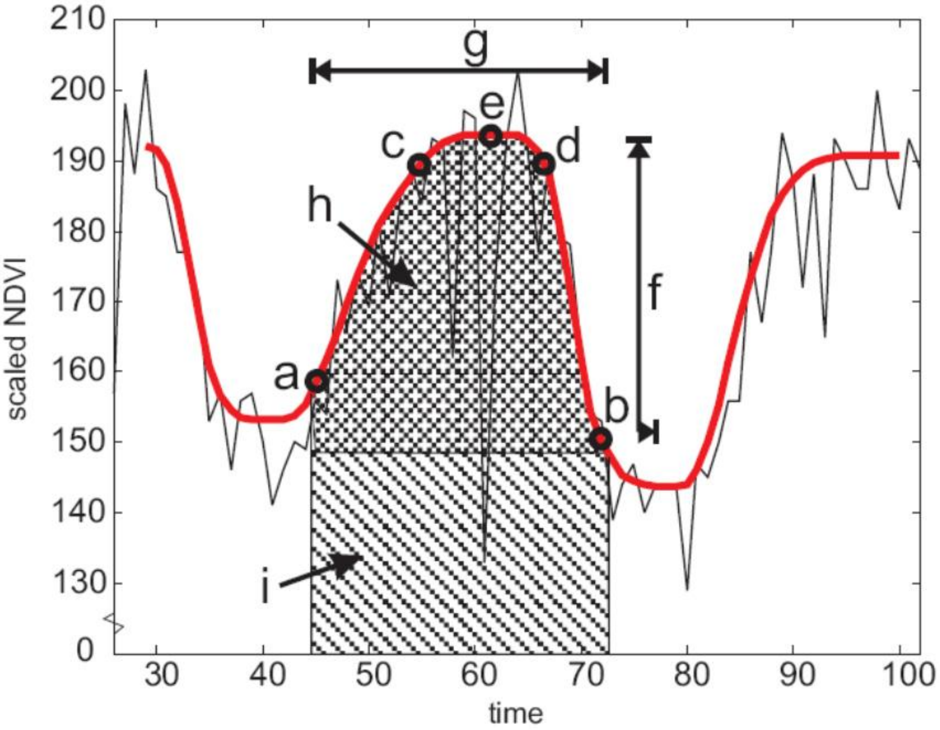


Figure 5. Seasonal key parameters extracted for the analysis of the project: start (a)and stop(b) of season, seasonal maximum value (e) and small seasonal integral(h) Used with the permission of the authors (Eklundh and Jönsson 2011).

TIMESAT applies curve fitting algorithms to the upper envelope, based on a least-square fitting method, to smooth the curve of vegetation index time series (Jönsson and Eklundh 2002, 2004). The program works on a pixel per pixel basis and has three different algorithms; adaptive Savitzky-Golay filter, asymmetric Gaussian and double logistic model functions. It also utilizes a number of different fitting parameters to optimize the curve fitting for best result and to eliminate noise in the data. If data are missing due to a satellite recording problem or bad data quality, the fitted curve can replace the value with an estimated one. TIMESAT can also use ancillary quality flag data to perform a weighted fit to improve the curve fitting result (Jönsson and Eklundh 2002, 2004). TIMESAT has proved to be a good method of reducing noise in time series data. Hird and McDermid (2009) tested different noise reduction methods and found TIMESAT to be superior to other noise reducing methods. The Asymmetric Gaussian fitting algorithm especially had a good result of reducing noise. This ability to reduce noise with the Asymmetric Gaussian fitting algorithm adds more support to why TIMESAT was chosen to analyze the time series data in this study.

This is a very brief description of the asymmetric Gaussian least-square fitting function; a full mathematical description is described in (Jönsson Eklund 2002). The model function is built up by local fitting functions in intervals around the maxima and minima of the time series. The kurtosis of the curves is determined by the local function. Local functions are finally merged to a global function, expanding over the whole time series. Reducing noise by applying the algorithm prepares the data for use in change detection analysis.

3. Geometrids ecology and limitations

Understanding geometrid ecology is important in this study because it helps in understanding the interaction between the birch forest and the geometrids. This in turn can explain the impacts on the forest under climatological prevailing conditions.

3.1 Ecology of the geometrids

The growing season in the Abisko area is short with budburst occurring when the temperature passes approximately 5°C, which starts around the 5th of June and ends around the 10th of September (Karlsen 2008). *Epirrita autumnata* is a small holometabolic moth (full life cycle of egg, larvae, pupae and adult) that flies as an adult (figure 6). It is during budburst that the eggs of *Epirrita autumnata* hatch and the larvae start to feed on the birch leaves, continuing for about a month until it has grown big enough to undergo transformation it pupate at the ground. After two months, in August to October, the flying reproductive moth emerges to mate and lay its eggs in the trees (Bylund 1997, Ruohomäki *et al.* 2000). The geometrid *Operophtera brumata* also exists in the study area. *O. brumata* follows the same life cycle as *E. autumnata,* but hatches from the pupae later and is emerged for a longer time during the growing season (Bylund and Inga 2012). Although previous outbreaks have shown that different species tend to infest different parts of the forest, *O. brumata* can have overlapping habitat with *E. autumnata*. An outbreak in 1954-1955 by *E. autumnata* caused almost complete defoliation and killed a substantial amount of trees on the south side of the lake Torneträsk. In the years *1964*-1965, *O. brumata* was responsible for almost complete defoliation in the middle part of the forest on the north side (Tenow 1972). Another more recent outbreak that caused severe defoliation by *E. autumnata* defoliation was 2004. Babst *et al.* (2009) mapped the defoliation distribution of the outbreak and found that most of the Abisko valley was affected and heavy defoliation was found in the northeast and on the south side where the lake narrows in the middle.

3.2 Controlling factors

Factors that control the birch moths (*E. autumnata and O. brumata)* are; (1) egg mortality in relation to winter temperature, (2) the larvae parasitoids and (3) induced plant defense and variation in food plant quality (Virtanen and Neuvonen 1999).

Temperatures

The main limitation for the birch moth is low winter temperatures. The eggs freeze and die below temperatures of approximately -36°C for *Epirrita* autumnata and -35°C for *Operophtera brumata*

(Nilssen and Tenow 1990). Towards the spring in Mars/April the thermal resistance decreases to around -30°C for both species.

Figure 6. Photo of a mature flying Epirrita autumnata, autumn moth (Photo: Marco Giljum).

Parasites

Field experiments performed by Klemola *et al.* (2012) show that birch forest utilize herbivore-induced plant volatiles (HIPVs), which are an indirect plant defense used when infested by autumnal and winter moth larvae. The tree releases chemical compounds of green leaf volatile cues, which are signaling substances used to attract hymenopteran parasitoids. The parasites use the geometrids as their host during its germinal stage (when the parasites grow to become adult) and kill the geometrid by utilizing it as nutrient source before it hibernate as a pupae. Highest parasitic rates were found at tress that had not yet withered, showing that trees can induce the defense system very fast. These cues also attract natural predators of the moth, such as birds that can more easily find larvae on infested trees (Mäntylä 2008). *Eulophus larvarum* was found to be the most active parasitoid specie in low altitudes and *Cotesia jucunda* at higher altitudes (Virtanen and Neuvonen 1999).

Birch forest compensation and rejuvenation

The consequences of defoliation can sometimes be seen several years after the infestation occurred, because of the short growing season. The leaf production in Abisko valley had recovered by 75% in 1987, 32 years after the large outbreak event in 1954-1955, whereas the recovery on the north side of Torneträsk only 2% of the foliage was recovered in 1990 after the defoliation of 1964 (Tenow et al. 2001). Stem radial growth was reduced in the years after infestation, probably because of redistribution of nutrient to essential plant functions, such as an increased amount of nitrogen and phosphorus in new leaves, to increase the photosynthetic efficiency (Hoogersteger and Karlsson 1992, Tenow *et al.* 2004). Summer temperature is also important for the recovery of the forest. Compared to cold summers, high summer temperatures make the trees recover faster due to good growing conditions (Karlsson *et al.* 2004).

Another factor controlling the rejuvenation and recovery in the forest is that *Epirrita autumnata* infest mature birch trees to a higher degree than young trees. Older trees are more covered in lichens and contain cavities suitable for the moth to lay its eggs in. Additionally, as trees age they are considered better food quality, probably because they have a reduced defense capacity (Bylund 1997). Rejuvenation strategies in polycormic trees can also depend on the degree and severity of defoliation.

The rejuvenation occurs either by basal sprouting or new shoots from surviving older stems. Basal sprouting occurs more often when the trees have defoliation concentrated to the apical domain. In severe defoliation basal sprouting can kill the old stem due to nutrient depletion (Karlsson et al 2004, Tenow *et al.* 2004). Heavy defoliation of the apical domain also improves the light condition for the basal sprouts. In the other strategy, new shoots from the surviving stems emerge and make the tree survive by producing enough new leafs for recovery. The new shoot strategy results in the heterogeneity of the forest, with a mixture of young and new trees together with older ones (Tenow *et al.* 2004).

4. Methods

4.1 Conceptual analysis design

The overview of the conceptual model used in this study is displayed in figure 7. The right panel shows some additional steps of creating the forest map from Lidar. The analyses in this study were performed by following the steps described by the model. (1) Download and prepare the16-day NDVI composites. (2) Import and apply a curve fitting algorithm to the raw time series data by the program TIMESAT. (3) Extract seasonal parameters from the fitted curve (seasonal max NDVI). (4) Import and calculate the Z-score values used to demonstrate the rate of forest change in ArcMap. (5) Based on a researched threshold value, classify the forest into the classes; non-infested, likely infested and highly likely infested. (6) Mask the classified MODIS image with forest cover map. (7) Produce the final product of classified forest.

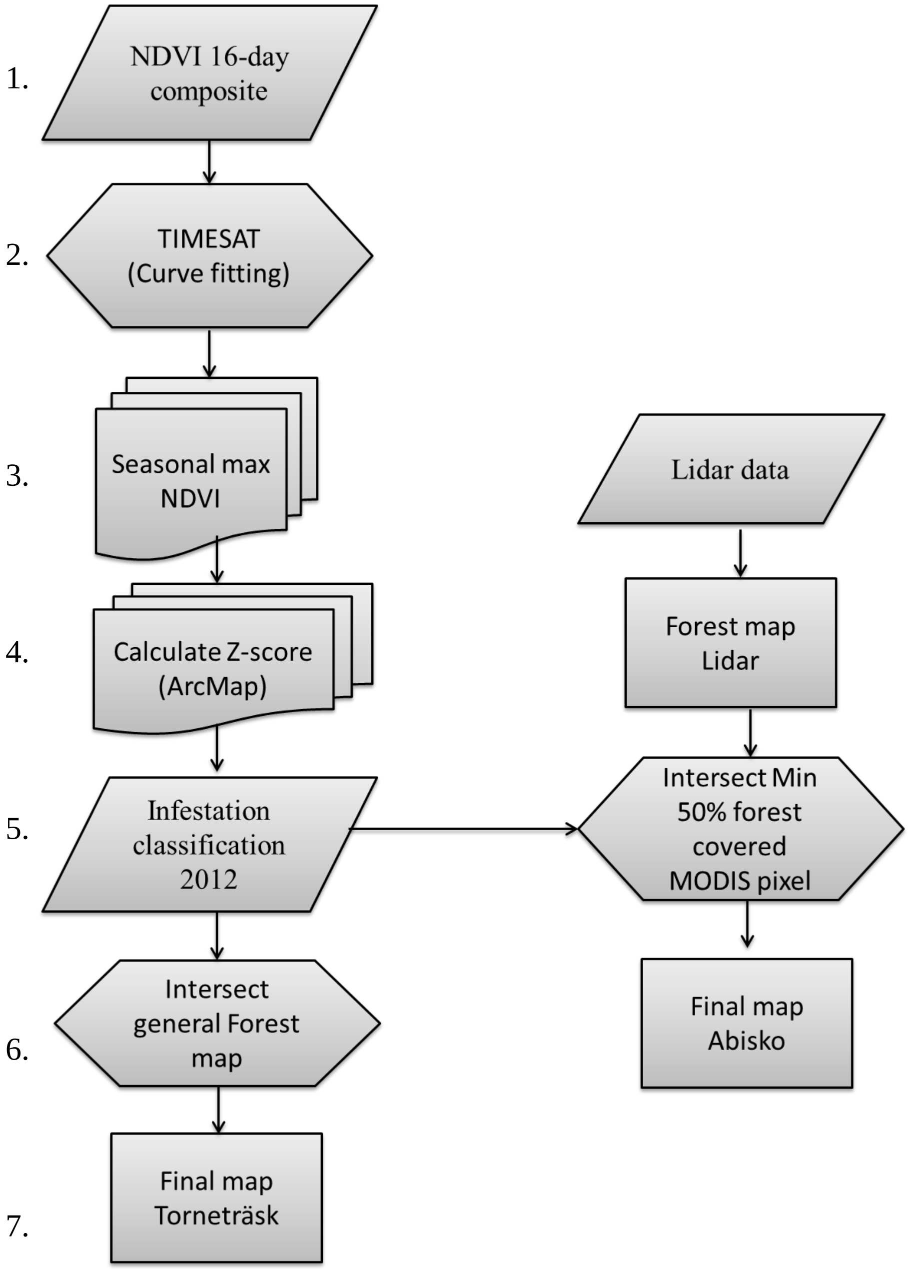


Figure 7. Conceptual flow chart of the methodology used in the study.

4.2 MODIS data acquisition and preparation

MODIS data can be collected from multiple databases online. The data for this project was downloaded from NASA (LP DAAC) land processes distributed active archive center via an ftp server ftp://e4ftl01.cr.usgs.gov/. The data is delivered in the standardized HDF-EOS format (hierarchical data format-earth observing system) using the MODIS sinusoidal projection. All the scenes available between 2001 - 2012 were downloaded and included in this study, equaling a total of 270 scene images spanning over almost 12 complete growing seasons.

A change detection method, based on the assumption that NDVI is lower during a year of infestation compared to a normal year, was developed as a part of this study. Previous studies have shown that NDVI correlates negatively with high larval densities, thus an increase in larval density will increase defoliation of the Birch trees and thereby reduce the NDVI value (Jepsen *et al.* 2009). The principle of the change detection method is to find a threshold value that indicates when the NDVI has decreased more than what is expected in the normal inter annual variation. Any NDVI below the threshold value would thereby be classified as infested with a power of strength. For the purposes of this study, the range of normal inter annual variation will be referred to as "normality value" i.e. not infested forest. The years 2001, 2002, 2003 and 2009 were selected to create the normality value. These four years were selected because out of the range of data available (2001-2012), the forest in these years have had the longest time to recover from the preceding infestations (1995 and 2004) and hence these years will carry the least traces from previous infestations. The time needed for a forest to be completely recovered from an infestation varies, however, the forest around Abisko was noted to be visually recovered from the 2004 infestation after field visits during 2009 (personal email communication with Bylund). The years that were suitable for computing the normality value were also controlled using TIMESAT. An example of how the NDVI varies annually is illustrated in Figure 8, which displays the NDVI change in one pixel during the time period 2001-2012. There is a distinct drop in NDVI for 2004 and 2012 indicating an infestation. Years 2010 and 2011 were not used because the NDVI was lower in some areas, which could be an indication that the geometrid population had already started to increase in 2010. As part of an effort to follow a precautionary principle in this study, the values for 2010 and 2011 were excluded.

4.3 TIMESAT analysis

Following the MODIS *data acquisition and preparation*, a curve fitting algorithm was applied to the raw NDVI data. All four curve fitting algorithms, as discussed previously, were tested on the data. The Asymmetric Gaussian algorithm had the best performance compared to the other two algorithms available in TIMESAT based on visual evaluation. The Asymmetric Gaussian algorithm produced a consistent smooth fitting curve, without any sudden peaks or drops around the raw data (figure 8). After the curve fitting parameters had been adjusted, the data were then extracted for the change detection method. To analyze and identify the threshold value that defines infested forest, annual maximum NDVI values were extracted on a pixel per pixel basis for the years 2001, 2002, 2003, 2009. The maximum NDVI values were also extracted for 2012, to be classified for infestation based on the defined threshold values.

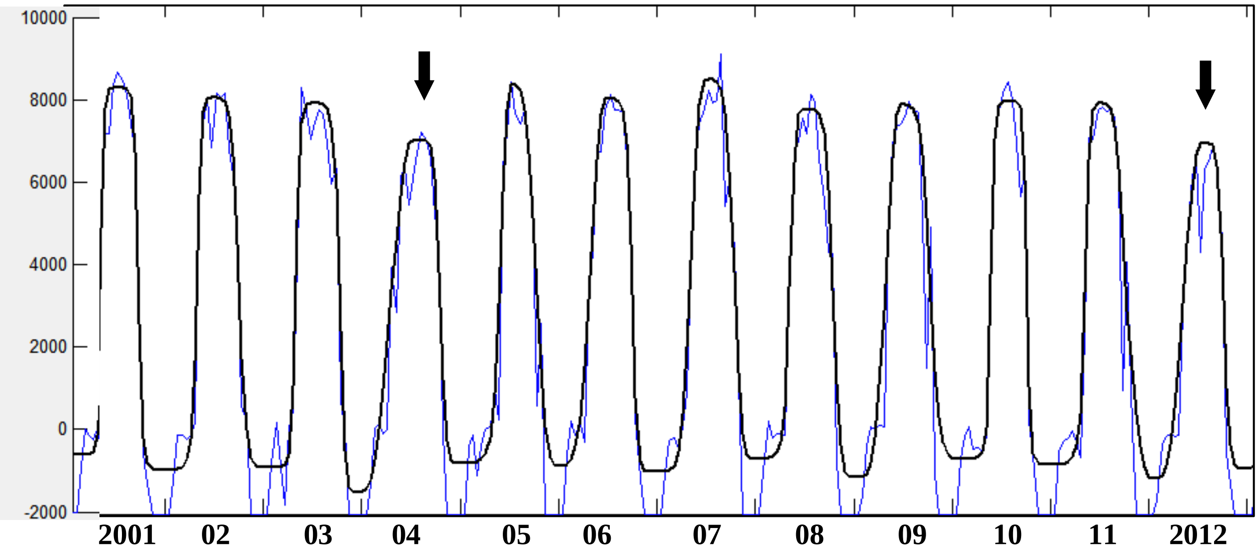


Figure 8. MODIS time series covering 12 years (2001-2012) from which seasonal maximum NDVI values were extracted. The blue thin line is the raw NDVI data, the black thick line is the fitted curve from TIMESAT. Y-axis show scaled NDVI value, x axis show 2001 – 2012. The reduction in NDVI during infested years can clearly be seen by the reduced peak in 2004 and 2012.

4.4 Change detection method

Once maximum NDVI values were extracted by TIMESAT, the change detection analysis was performed. To identify if a pixel in 2012 deviated more than the natural inter-annual variation of the non-infested years, standardized z-score statistics were used. z-score values were calculated for each cell and for each year using Equation (2). The z-score value for 2012 was then compared to the values of the uninfected years 2001, 2002, and 2003 to identify infested forest. This resulted in pixels with a lower NDVI than normal receiving a negative z-score value.

$$Z = \frac{\chi - \mu}{\sigma}$$ Equation (2)

χ = maximum NDVI 2012

μ = mean of max NDVI value for the years
2001, 2002, 2003 and 2009

σ = standard deviation of max NDVI for the years
2001, 2002, 2003 and 2009

All pixels with a negative value could not be classified as infested because there must be room for the natural inter-annual variation in NDVI between non-infested years. Another way to define a threshold value for the infested forest and non-infested forest thus had to be defined. Locations known to be infested in 2012 were obtained on sketch maps and from GPS coordinates collected by people who had visited the area during the infestation (Bylund, Landström and Giljum, personal communication). The z-score values from the known infested areas were extracted for years of infestation and for years without. Z-score values were compared and the years under infestation were found to have considerably lower z-scores than the years without infestation. Ten locations were verified to both have reduced values and to being infested.

The z-score values during years without infestation ranged between -1.397 to 1.386 (2001, 2002, 2003 and 2009) for the verified locations. This range was defined to be for the non-infested forest class. The z-score range for 2012 with confirmed infestation was between -2.296 to -9.661. However, it cannot be assumed that all forest with a z-score value below -1.397 was infested, especially not since the infested forest had a verified value of -2.296 or lower. As a solution, the infested forest was split into two subclasses; “likely infested” and “highly likely infested”. “Likely infested” forest was defined by a z-score range of -1.4 - -2.0 and “highly likely infested” by a z-score value below -2.0. A summary of the classification threshold values are found in Table 2. The reason for the middle class name of “likely infested” is that most of the z-score values for non-infested forest were closer to 0 than -1.4. It was also believed that values higher than -2.296 could be infested, but this was not found due to low sample size. The most important reason to define the threshold values into three classes was so the “non-infested” and “high likely infested” classes, which minimize the risk to have them misclassified.

Table 2. A list of the Z-score threshold values, separating the forest classification

Forest classification	
Classification	**Z-score**
Non-infested	> -1.4
”Likely infested”	-1.4 - -2.0
”Highly likely infested”	< -2.0

Another approach was also tested in this project by using the extracted area value of the small integral under the fitted curve from TIMESAT (figure 4.(h)). The integral value acted as a cumulated NDVI during the active feeding period of the Birch moth. The active period is from the beginning of May with budburst, until the beginning of July before the moth spins its cocoon (Ammunét *et al.* 2009). MODIS images corresponding to the active feeding period were the consecutive images 9-13 from the total of 23 per year (Julian day 144 - 208 i.e. 23 May – 26 July). This time period was chosen to capture the defoliation that occurred only during the active feeding period of the moth. If re-foliation occured outside the active feeding period and were included, the analysis can miss forest that actually were infested and skew the result. An experimental study found that 50% of defoliation could be re-foliated a few weeks after defoliation, but to what extent this is true for the study area was not fully known (Hoogesteger and Karlsson 1992). The preliminary results showed that the use of the small seasonal integral captured changes poorly as forest classification appeared to be random and not reliable. This approach was thereby excluded from further analyzes and will not be presented in the results.

4.5 Minimum forest cover analysis

As mentioned previously, the birch forest growing around Abisko varies in vegetation cover. Not all areas are covered with birch forest. Since the spatial resolution of MODIS is relatively large, a mixture of land cover types can be found within a MODIS pixel. As a result, the NDVI for pixels not completely covered by forest may be affected because of the variation in ground cover. To avoid this discrepancy with NDVI values for areas not dominated by forest a birch forest map was created with Lidar. The forest cover map was used to mask out MODIS pixels that were covered with a minimum of 50% birch forest.

4.6 Forest mask for the Abisko study area

The first step in creating the forest mask was to remove outliers and noise from the Lidar data. Return points with unrealistically high height values were removed. The second step was to identify the forest. The forest was identified by using only Lidar pulses with multiple returns. This execution assured that only return signals that passed through several layers of vegetation would be classified as forest (figure 5). The tree cover was then interpolated to a grid with 10 meter spatial resolution. A resolution of 10 meter was chosen to best represent the forest cover, compared to an ortophoto of the same area. The result was further validated by subtracting the height value of the ground classification from the forest classification to find the tree height. The tree height was in the range of the actual tree height in the area of 1.5 – 6 meter.

4.7 Forest mask for the Torneträsk study area

For the Torneträsk study area not covered with Lidar data, another forest map was used. It was created from a vegetation map provided from the Swedish land survey. The vegetation map is in vector format with polygons classified into different vegetation cover classes (Lantmäteriet 2009). It was produced from infrared aerial photo interpretation made by the Swedish land survey. The actuality of the map is 1978 – 1991 and the wide range is because different areas were surveyed at different times (Lantmäteriet 2009). There was no class for specific tree species, instead the forest was grouped into main categories of deciduous and coniferous with several subclasses of forest. Since almost all the forests in the Torneträsk study area are birch forest, the deciduous forest class was used for representation. Classes of other vegetation types, if mainly covered with deciduous forest, were also included. These deciduous forest classes were extracted to be used as the forest mask.

4.8 Altitude interval analysis

Previous studies performed on insect infestation in the Torneträsk area have shown that the distribution and intensities of insect infestation in previous years varied by elevation (Virtanen and Neuvonen 1999, Tenow *et al.* 2001 and Babst *et al.* 2009). To investigate if the topographical variation affected the infestation of 2012, the topography of the study area was divided into elevation classes with 100 meter intervals. To divide the area into intervals the new national elevation model was used, which has a resolution of 2 meters (Lantmäteriet, 2012). The area was separated into 4 elevation classes starting from 342m, which is the Torneträsk lake and the lowest point in the area. The elevation classes were set as 342-450 , 451-550 , 551-650 and >650 (m. a.s.l.). A more narrow interval was not used because it would have made many MODIS cells belong to two classes of elevation and interfere with the result by uncertain elevation membership.

5. Results

5.1 Lidar forest cover map

The forest cover map derived from Lidar data, as seen in Figure 9, gives a good visualization of the distribution of the forest. The forest follows the area surrounding the lake Torneträsk at the lower altitudes of the mountain. The forest continues in the south west direction of the figure, along the river into Abisko valley. The map illustrates the heterogeneity of the landscape, where mires, bogs and heath vegetation were mixed together with forest stands.

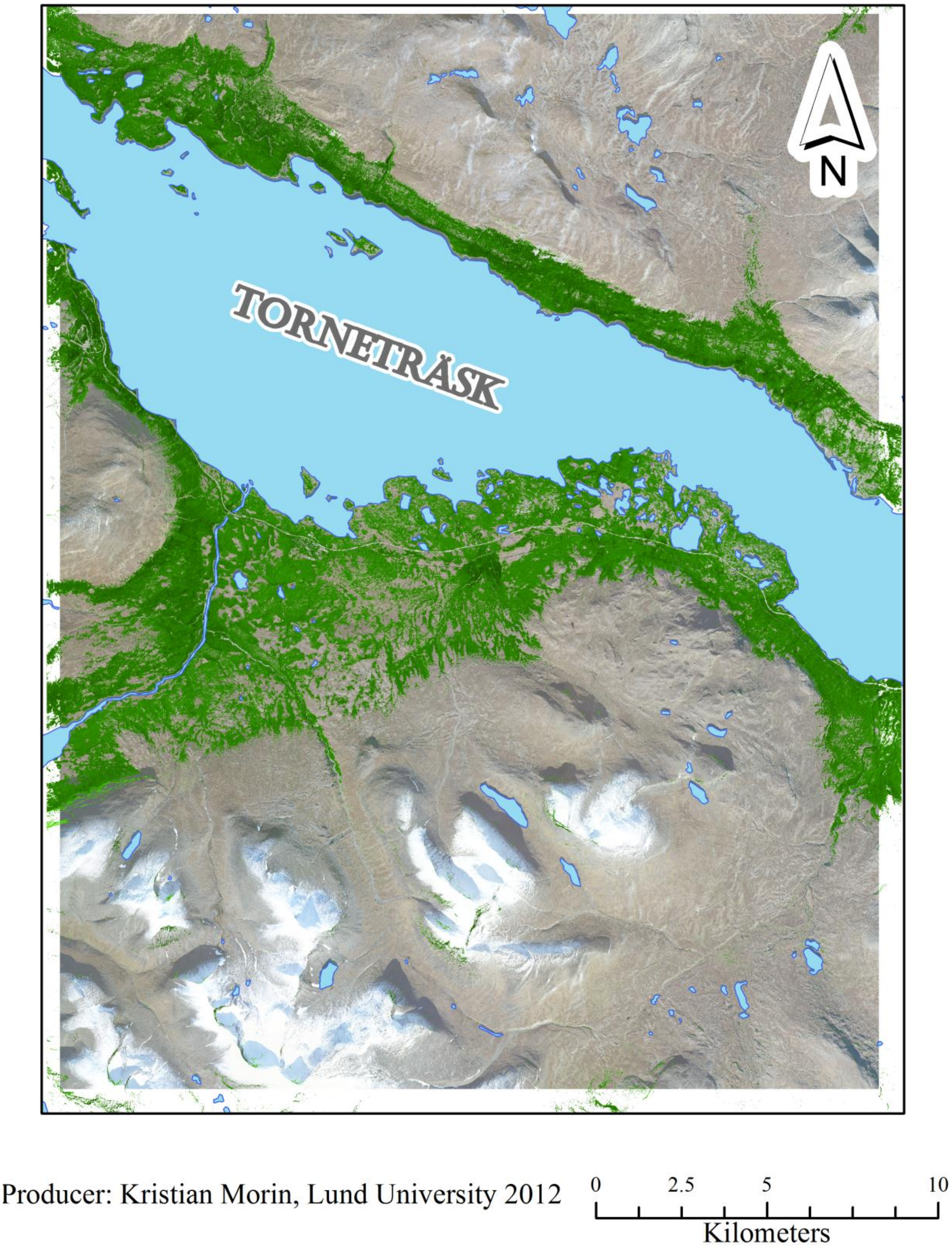


Figure 9. Forest distribution around Abisko with a spatial resolution of 10 meter created from Lidar analysis on top of an ortophoto basemap (@ Lantmäteriet, Dnr: i2012/927).

5.2 Final map -Abisko study area

The map in Figure 10 reveals the infestation distribution of the birch forest in 2012. The forest was infested on both the north and south side of the lake, but the south side was clearly more affected and covered larger areas. The infestation pattern on the south side area was more agglomerated and cohesive compared to the north side. In the Abisko valley the infested area was more fragmented with a higher degree of uncertain classification. The fragmented pattern continued along the river Abiskojåkka to the small lake in the bottom left corner, Ábeskojárvi.

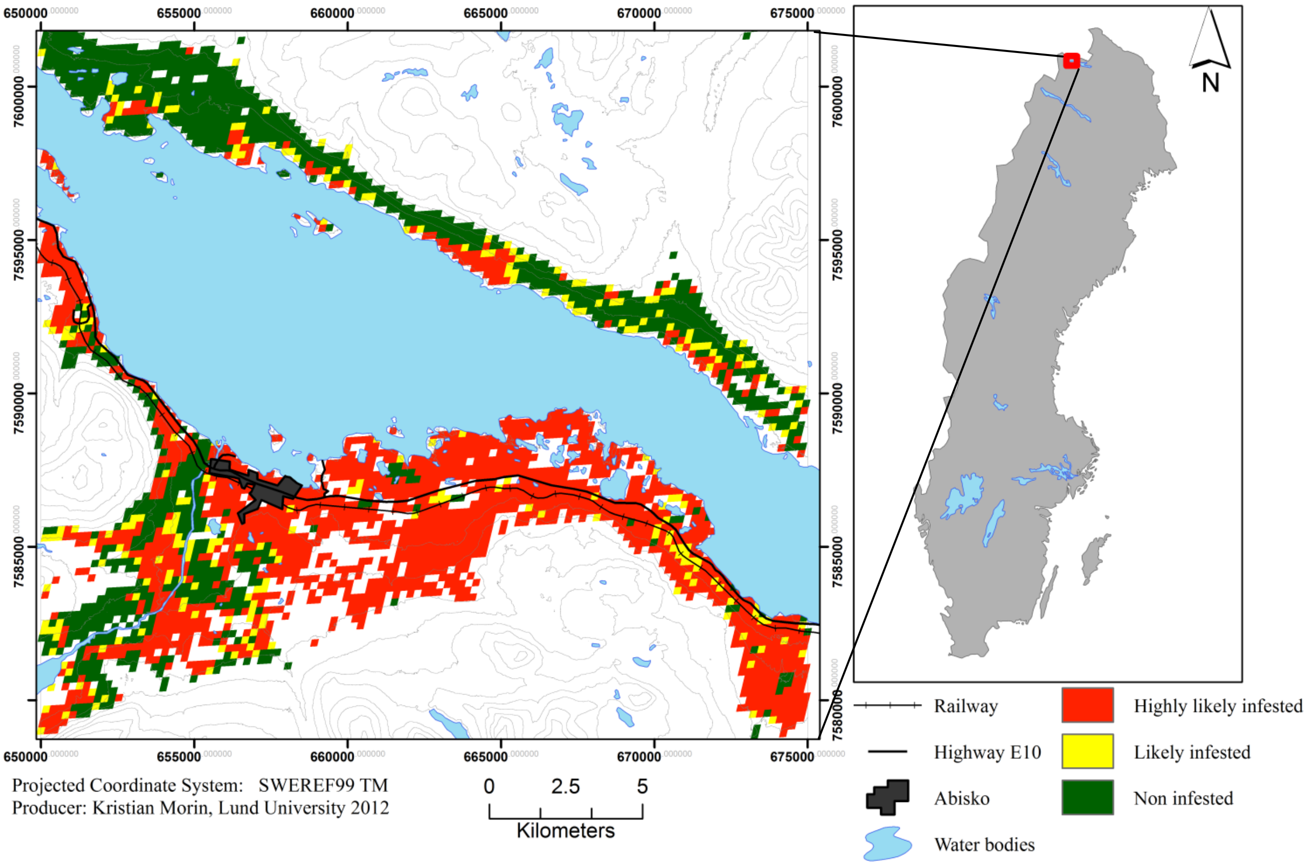


Figure 10. The final map showing the classification and distribution of infested forest in the Torneträsk area (@ Lantmäteriet, Dnr: i2012/927).

The total area covered by forest in the Lidar study area was approximately 146.4 km^2. 54.3% of this was classified as highly likely infested (Table 3). About 10% of the forest was classified as likely infested. Adding up areas classified as highly likely infested and likely of being infested showed that strikingly 94.3 km^2 or 64% of the total forest was affected by the infestation in 2012.

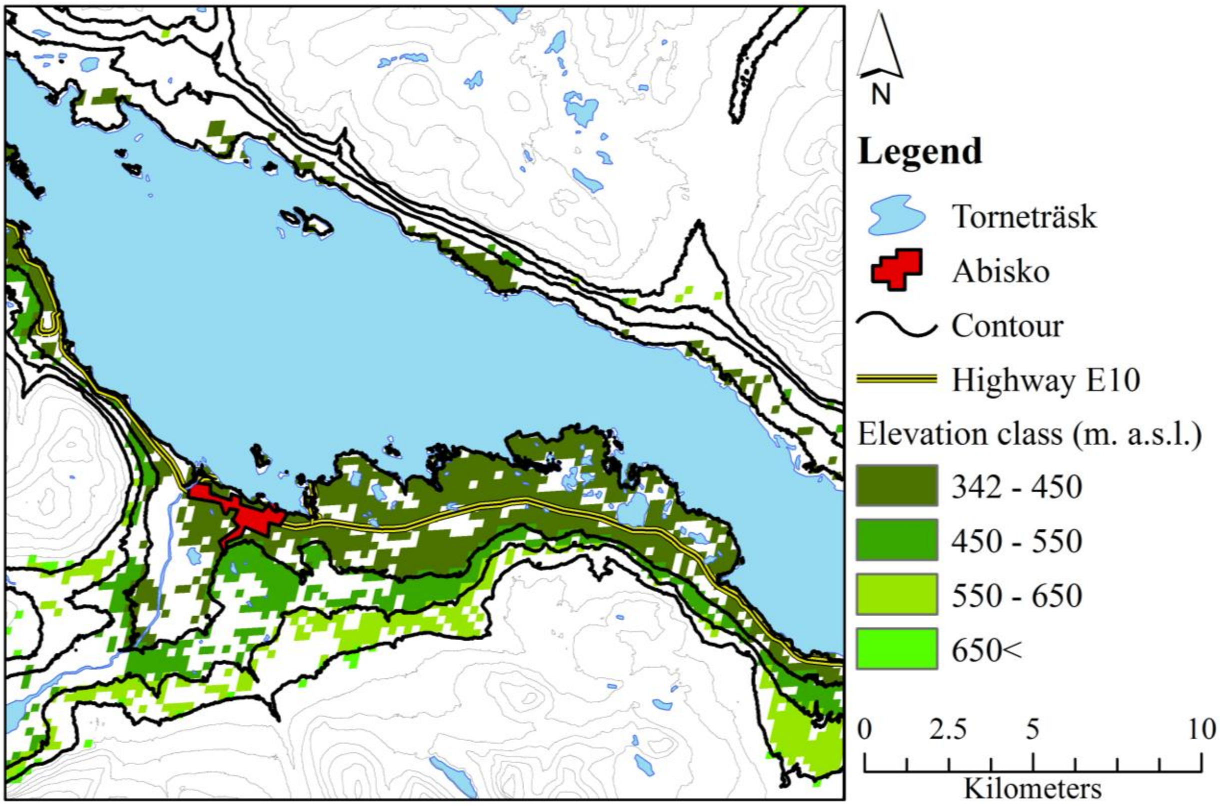
Table 3. Area and percentage of total forest in each infestation class.

Forest area in each infestation class		
Infestation class	**Area km^2**	**Percentage**
Highly likely infested	79.5	54.3%
Likely infested	14.8	10.1%
Non-infested	52.1	35.6%
Total	**146.3**	

5.3 Topographic infestation distribution

Figure 11 visualizes the topographical forest distribution among the defined elevation intervals. The result of the topographical distribution was that more than 50% of the area in the lowest elevation interval 342-450 m. a.s.l was covered by forest. The percentage of forest cover within each interval was decreasing by increasing elevation. There was only 2.5% of forest cover in the highest elevation class above 650 m. a.s.l. (Table 4.).

The lowest elevation class also had the highest percentage of the total infested forest at 30% (Table 3). However, although the percentage of forest cover was decreasing at higher elevation, the ratio of infested forest to total area was not. The ratio of infested forest to total area was evenly distributed without any significant change between elevation intervals (Table 4.). There was no evidence that forest at a particular elevation class was more prone to infestation.



Producer: Kristian Morin, Lund University 2012

Figure 11. Topographical distribution of highly likely infested forest at the intervals 342-450, 450-550, 550-650 and >650 m. a. s. l (@ Lantmäteriet, Dnr: i2012/927).

Table 4. Forest cover within each elevation interval and total forest cover within the study area.

Topo interval	**Area km^2**	**Percentage cover**
342-450	76.2	52.1%
450-550	41.4	28.3%
550-650	25.1	17.6%
650<	3.7	2.5%
Total	**146.4 km^2**	

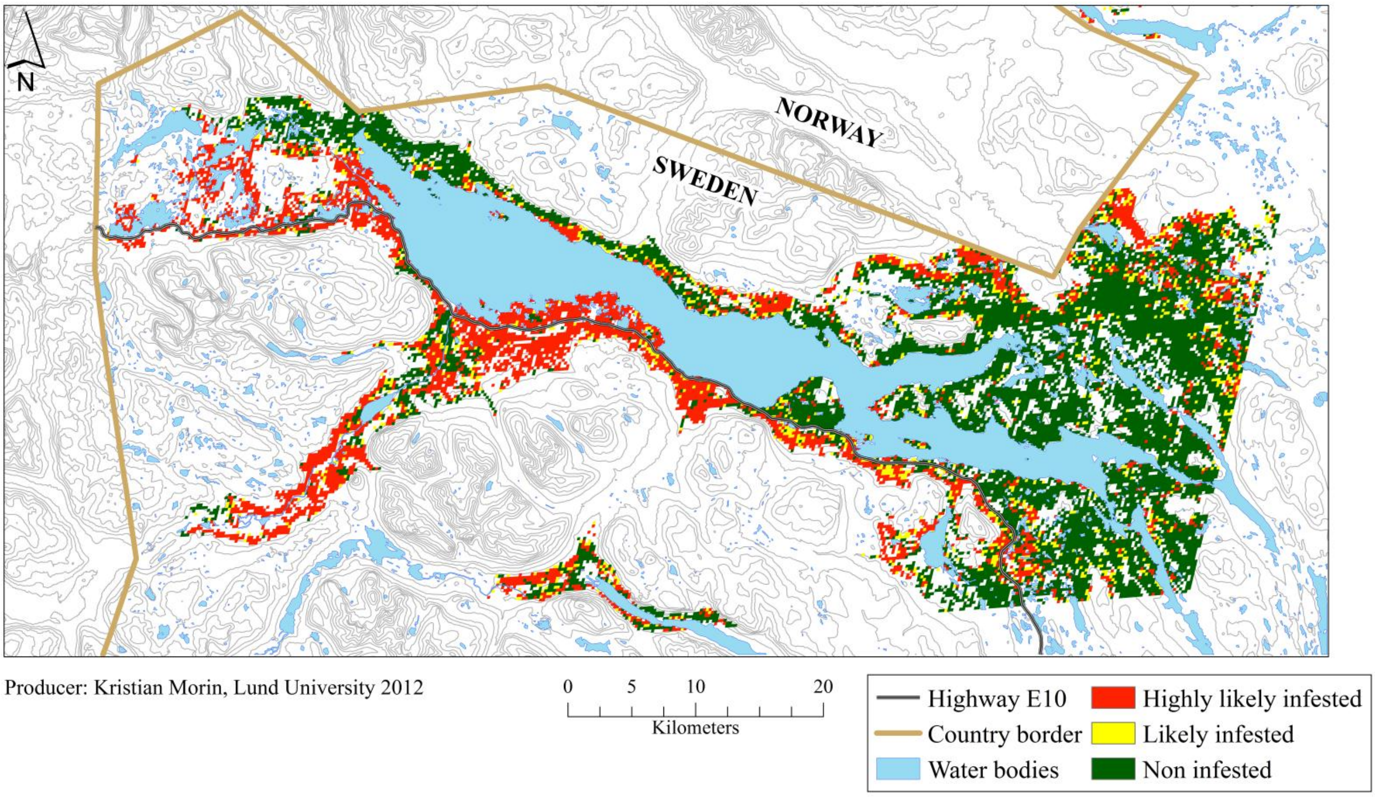
Table 5. Ratio of infested forest in each topological interval

Topo interval	**Area km^2**	**Percentage of infected forest in interval**	**Ratio Infected/Total**
342-450	45.1	30.8%	59.2%
450-550	18.8	12.8%	45.4%
550-650	14.2	9.7%	56.4%
650<	1.5	1.0%	39.7%
Total	**79.5 km^2**		

5.4 Infestation in Torneträsk study area

Figure 12 shows the distribution of infested forest covering the extent of the whole Torneträsk study area with MODIS.

Forest in the Torneträsk study area covered approximately 791.4 km^2, in which 32% or 251.4 km^2 was infested in 2012 (Table 5). The majority of the forest was not infested and only about 10% was classified as likely infested. The forest infestation was more dominant in the southern part of Lake Torneträsk. Infestation in the Abisko valley extended far into the southwest part of the landscape, as displayed in figure 12. Close to the Norwegian border in the northwest corner of the Torneträsk study area, the infested forest was following the highway E10. The east part of the lake was not as heavily infested as the west.



Producer: Kristian Morin, Lund University 2012

Figure 12. Overview of the infestation in the Torneträsk study area (@ Lantmäteriet, Dnr: i2012/927).

Table 6.

Forest area in each infestation class with MODIS

Infestation class	**Area km^2**	**Percentage**
Highly likely infested	251.4	31.7%
Likely infested	76.0	9.6%
Not-infested	464.0	58.7%
Total	**791.4**	

6. Discussion

6.1 Evaluation of method and accuracy of the result

All the field observations received for this study had to be used as input into the change detection analysis, which is why no empirical map accuracy assessment could be performed. The lack of field measurement was because it was not possible to design and conduct field measurements in the timeframe of this study or to be *in situ* of the active feeding period of the geometrids. However, I argue that the created maps have high accuracy for several reasons; **(1)** Threshold values ranged from -1.397 to 1.386 for non-infested forest and <-2.0 for highly likely infested forest. A precautionary principle was used to determine the high likely infested threshold, so there would be no overlap with the non-infested forest class. By having an interval between these two opposite classes, it minimized the chance for non-infested forest to be classified incorrectly. **(2)** The curve fitted to raw seasonal NDVI data, smoothed by the TIMESAT program, kept its characteristics and effectively reduced noise, as illustrated in figure 6 with the very close fit to the raw data. **(3)** Bylund and Landström who visited the area during the infestation of 2012 confirmed the infestation classification as correct in regards to the places they had visited, and according to their knowledge and judgments of the distribution (email communication with Bylund and Landström). **(4)** Outbreaks can be expected to follow a similar pattern of distribution if they occur consecutively. The 2012 outbreak followed a similar pattern of distribution as that found for 2004 by Babst et al. (2009). During both outbreaks the north side of the lake was not as heavily infested as the south.

The threshold values that were defined to separate the forest classification will affect the resulting maps that show the distribution of infestation in the forest. With more field samples available, the threshold value will have a higher precision and an increased accuracy of classification. Since field observations were limited in this study, it was a source of error that may have affected the result negatively, by either over or under estimating forest that was infested. The forest classified as highly likely infested was probably underestimated, because there was most likely a larger variation in the NDVI value for infested forest that was not captured due to the low sample size. A more extensive fieldwork design, particular for this type of study, would capture more of the variation of the NDVI so that the forest could be classified with a higher accuracy.

6.2 Lidar analysis and forest cover

Lidar data showed to be successful for use in the mapping of forest in the Abisko study area. One concern with the creation of the map was that the return points reflected by forest would not be dense enough to create a reliable map with a high resolution. However, by comparing to an ortophoto taken of the same area in 2008, the Lidar data with a raster resolution of 10×10 meter was found to represent the forest distribution in the study area. The forest was clearly separated from mires, heath vegetation and water bodies. The product was an up to date forest cover map, much more detailed than the digitalized version of the more generalized vegetation map from 1979-1991. Attempts were made to use a smaller grid size, but an underestimation of the forest cover resulted. The Lidar was scanned outside the growing season, and therefore there were not enough Lidar points reflected from vegetation to use a smaller grid size. To improve the forest cover map with a higher spatial resolution, Lidar must either: have to be scanned at the time when the forest is in full lush to increase the number of return points from vegetation, or another Lidar system with a higher frequency of pulses per second should be used (Lemmens 2011).

To show the distribution of infested forest in the Torneträsk study area, a forest cover map was also required. Lidar data was not available for this area, therefore the more generalized vegetation map from 1979-1991 was used to mask out the forest. Unfortunately, this map cannot be analyzed with the same detailed approach as with the Lidar forest cover map for the Abisko study area, because it was too generalized and too old. For instance, some of the mires and heath vegetation were classified as forest. Both of these factors reduce the accuracy of the forest cover map. Nonetheless, the map still showed the distribution of forest for a large regional scale and could be used to mask the infested forest. The drawback of the map was that it could not be interpreted in detailed as the Lidar forest cover map can be. Maps showing the distribution of infested forest at a large scale provide valuable information to research on the dynamics of geometrid defoliation on forest, because the synchronous outbreaks can cover very large areas.

It can be hypothesized that a forest cover map is not necessary to show which forest has been infested, because infested forest would receive a z-score value to be classified as infested anyway. Similarly, areas without a negative change would be classified as “non-infested”. However, a forest cover map was necessary for the study area, because it has a high and variable topography with many of the mountains having snow-covered peaks almost all year round. Since the snow cover can vary quite significantly throughout the year, it could be classified as infested forest inaccurately. The interpretation of the map is also much more difficult if the forest is not clearly masked out to show the forest distribution.

6.3 Topographical variation in infestation

Previous studies have shown that forests at certain elevations become more infested and defoliated than at other elevations (Tenow 1972, Virtanen *et al.* 1998, 1999, Babst *et al.* 2009). One possible explanation is that the forests are more prone to become infested at some elevation intervals and are affected more strongly. The topographic distribution of the 2012 infestation was investigated in this study. The result showed that there was no significant variation of topographic infestation between elevation intervals. It is difficult to explain why the topographic distribution varies between outbreak years, but it is possible that the variation only occurs occasionally, locally and is not repeated for each infestation event. For example, the north side of Torneträsk was completely defoliated in 1954-1955 between 400-460 m. a.s.l. and it was caused by *O. brumata (*Tenow 1972). This infestation on the north side did not have the same pattern as the infestation in 2012. The difference in distribution was probably because *E. autumnata* was the most active moth in 2012. Additionally, the monocormic forest on the north side had probably still not recovered from the infestation of 1954-1955 (Tenow *et al.* 2001) and thus had a limited amount of forest that could be infested. Another explanation is that the topographic variation is affected by the microclimate within the topological structures, which is not consistent between years (Babast *et al.* 2009). It was found that the upper part of the slope and those slopes with high inclination were not as heavily infested and the same was found locally in 2012, where the upper slope on the mountain top at the west side of Abisko had a small area of non-infested forest. The upper parts of the forest on the north side of the lake were also non-infested in 2012. If closer equidistance than 100 meter were used, such a pattern might become more generalized for the whole study area. However, by using a closer interval, of for example 50-meter equidistance, it would make the MODIS cells overlap between intervals much more because of the moderate spatial resolution of MODIS. A sensor of higher resolution would be required to use a closer interval.

6.4 Spatial resolution

Sensors with low spatial resolution are a limitation in change detection studies because the sensors measure the reflectance from an area, rather than a point on the surface and consequently, will contain different land cover types within one pixel. This is especially true when the study area is in a heterogeneous landscape. It is more difficult to identify a change in one land cover type if several cover the pixel, which will reduce the accuracy of the classification. The same mixed pixel problem also exists when a sensor of high spatial resolution is used, however the number of mixed pixels would be less. MODIS has only a moderate spatial resolution, which is why it should be questioned as to whether a sensor of higher resolution would be better for use in this study. SPOT 5 with a high resolution of 10 × 10 meter was evaluated for potential use in the initial stage of this study. Downloaded SPOT 5 scenes were often covered by clouds and it was not possible to create a cloud free mosaic with the same size as the Torneträsk study area. For this study, the problem with sensors of high spatial resolution was that they did not have sufficient temporal resolution to find cloud free images for the whole study area, and during the active feeding period of the geometrids. In addition, considering the change detection method of this study that required cloud free data from several years, acquired at the same date, it made it very difficult to find suitable data for the whole study area. SPOT 5 or other high resolution satellites could be useful as a tool to validate the classification result from MODIS, but using only high resolution sensors would not have been possible for this study. Using MODIS also ensures that it would be possible to make annual classifications of forest at a regional scale, because cloud free data will always be available as long as MODIS can deliver images.

6.5 Composites and vegetation indexes

The 16-day NDVI composite from MODIS was used in this study. As explained in the background, the 16-day NDVI composite was chosen to increase the numbers of cloud free days that could be analyzed. After analysis, it showed to be capable of identifying infested birch forest, but other composites of different temporal resolution should also be tested, to find which composites provide the best classification result. Composites of higher temporal resolution could benefit the study, because it would be possible to follow the development of the growing season and find a more exact start of defoliation. Different temporal resolutions of composites were tested in a study performed by Spruce *et al.* (2011). The result of the study and several articles listed in the article all found the best classification result of gypsy moth defoliation of deciduous oak tree by using single date NDVI, better than both 8- and 16-day NDVI composites. Therefore, it is possible that other composites could have provided a better result, but once again, cloud cover can be difficult to avoid in the study area and for that reason, it is likely that single data NDVI would not have been suitable. However, the 8-day NDVI composite or self-produced composites of higher temporal resolution could be alternative data to increase the classification accuracy.

The choice of which vegetation index used can also affect the classification result and it can be valuable for future studies to compare the results of different vegetation indexes to the result of this study. Vegetation indexes that replace the NIR band with a water absorption band, such as SWIR (MODIS band 6 or 7), were found to be more sensitive and better at detecting defoliation caused by gypsy moth (Beurs and Townsend 2008). The classification accuracy of infested forest increased considerably when a SWIR band was included compared to NDVI, and the accuracy increased additionally if composites of higher temporal resolution than 16-day were used. One concern by using a SWIR band is that it is only available with a spatial resolution of 500 meter with MODIS and need to be down scaled to 250 meter resolution before the vegetation index can be calculated. Since the use of a SWIR band in the vegetation index has shown a positive result, it should be considered for use in future studies of mapping defoliation by geometrids.

6.6 Improvements and future work

The forest in the northern Sweden should continue to be monitored because there are so many factors that control the interaction between geometrids and the birch forest. It is not possible to predict what will happen to the forest in the future if climate change continues in the same way as today. Only by continued monitoring of the infestation on birch forest can the interaction between the forest and the geometrids be better understood.

A weakness of this study was the limitation of field measurements and validation data. The first natural step to improve the result for future studies is to design fieldwork to collect data specifically for the study. With more field observations, the threshold value classifying the forest can be fine-tuned to increase the classification accuracy. Detailed field data that describes the defoliation percentage is also desirable, because then the forest could be classified into several classes describing the severity of defoliation intensity. The same validation data could also be used to statistically validate the accuracy of the Lidar forest cover map.

Another effort that should be performed to improve the result in future studies is to use composites of higher temporal resolution and to try the performance of using another vegetation index other than NDVI. A suggestion for vegetation index choice is a modified NDVI where the NIR band is replaced with a band in the short wave infrared range, such as MODIS band 6 or 7. Furthermore, to get a better understanding of the topographic variation in infested forest, it would be interesting to investigate if the inclination of the slope and the aspect angels can explain more of the topographic variation than elevation.

7. Concluding remarks

- Mapping the distribution of damaged birch forest caused by an outbreak of geometrids was successfully performed by using NDVI time-series data, between 2001 to 2012 from MODIS satellite data. A significant amount of the forest was infested by geometrids in 2012. 54% or 80km^2 of the forest in the Abisko study area and 31.7% or 251.4 km^2 in the Torneträsk study area was found to be "highly likely infested" by geometrids in 2012. The method based on threshold values to classify forest as "non-infested", "likely infested" and "highly likely infested" proved to be a reliable change detection method.

- Lidar data was used to create an up to date forest cover map with a high resolution of 10*10 meters that kept the heterogenic integrity of the study area. From the map, it was clear that the mixture of mires, heath vegetation and birch forest was separated from the forest.

- A topographical analysis of the distribution of infested forest found that the infestation was equally distributed among different elevation intervals in the Abisko study area. No intervals emerged to be significantly more infested than the others. Factors, such as slope and aspect were discussed as alternative factors controlling the topographical distribution of geometrids.

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Reference list

Ammunét, Tea., Klemola, N., Heisswolf, A. and Klemola, T. 2009. Larval parasitism of the autumnal moth reduces feeding intensity on the mountain birch. Oceologia, 159: 539-547.

Babst, F., Esper, J. and Parlow, E. 2009. Landsat TM/ETM+ and tree-ring based assessment of spatiotemporal pattern of the autumnal moth (Epirrita autumnata) in northernmost Fennoscandia. Remose Sensing of Environment, 114: 637-646.

de Beurs, K.M. and Townsend, P.A. 2008. Estimating the effect of gympsy moth defoliation using MODIS. Remote Sensing of Environment, 112: 3983-3990.

Bylund, H. 1995. Long-term interactions between the autumnal moth and mountain birch: the role of resources, competitors, natural enemies, and weather. Ph.D. thesis, Swedish University of Agricultural Sciences.

Bylund, H. 1997. Stand age-structure influence in a low population peak of *Epirrita autumnata* in mountain birch forest. Wiley, 20: 319-326.

Bylund, H. and Inga, B. 2012. *Fjällbjörkmätaren och fjällbjökskogen- en kunskapssammanställning* [pdf] Available at: <http://www.slu.se/Global/externwebben/centrumbildningar-projekt/centrum-for-biologisk-mangfald/Dokument/publikationer-cbm/cbm-fristaende-publikationer/biologiskmangfaldfjallbjorkskog.pdf> [Accessed 25 October 2012]. Sveriges Lantbruksuniversitet, Uppsala.

Chen, P-Y., Fedosejevs, G., Tiscareño-López. M. and Arnold, J. G. 2006. Assessment of MODIS-EVI, MODIS-NDVI and vegetation-NDVI composite data using agriculture measurements: an example at corn fields in western Mexico. Environmental Monitoring and Assessment, 199: 69-82.

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

Fan, L., Gao, Y., Brück, H. and Bernhofer, Ch. 2008. Investigating the relationship between NDVI and LAI in semiarid grassland in Inner Mongolia using in-situ measurements. Theoretical and Applied Climatology, 95: 151-156.

Heinzel J, K. and Koch, B. (2011) Exploring full-waveform Lidar parameters for tree species classification. International Journal of Applied Earth Observation and Geoinformation, 13152–160.

Heliasz, M., Johansson, T., Lindroth, A., Mölder, M., Mastepanov, M., Friborg, T., Callaghan, T.V and Christensen, T.R. 2011. Quantification of C uptake in subartic birch forest after setback by an extreme insect outbreak. Geophysical research letters, 28, L01704.

Helle, T. 2001. Mountain Birch forest and reindeer husbandry. In: Wielgolaski, F. E. (ed): Nordic Mountain Birch Ecosystem, The Parthenon Publishing Group, London 27: 279-291.

Huete, A., Juistice, C. and Leeuwen, W.V. 1999. *V.3. Algorithm theoretical basis document* [pdf] Available at: <http://modis.gsfc.nasa.gov/data/atbd/atbd_mod13.pdf>, [Accessed 28 November 2012].

Huete, A. R. 1988. A Soil-Adjusted Vegetation Index (SAVI). Remote sensing of environment, 25: 295-309.

Holmgren, B. and Tjus, M. 1996. Summer air temperatures and tree line dynamics at Abisko. Ecological Bulletins, 45: 159-169.

Hoogesteger, J. and Karlsson, P.S. 1992. Effects of defoliation on radial stem growth and photosynthesis in the mountain birch (*Betula pubescens ssp. toryuosa*). Functional Ecology, 6: 317-323.

Jepsen, J. U., Hagen, S.B., Hogda, K.A., Ims, R.A., Karlsen, S.R., Tommervik, H. and Yoccoz, N.G. 2009. Monitoring the spatio-temporal dynamics of geometrid moth outbreaks in birch forest using MODIS-NDVI data. Remote Sensing of Environment, 113: 1939-1947.

Jönsson, P. and Eklundh, L., 2002, Seasonality extraction and noise removal by function fitting to time-series of satellite sensor data, IEEE Transactions of Geoscience and Remote Sensing, 40: 1824 – 1832.

Jönsson, P. and Eklundh, L., 2004, Timesat - a program for analyzing time-series of satellite sensor data, Computers and Geosciences, 30: 833 – 845.

Karlsson, P.S., Tenow, O., Bylund, H., Hoogesteger, J. and Weih, M. 2004. Determinants of mountain birch growth in situ: effects of temperature and herbivory. Ecography, 27: 659-667.

Karlsen, S. R., Tolvanen, A., Kubin, E., Poikolainen, J., Høgda, K, A,. Wielgolaski, F. E. And Makarova, O. 2008. MODIS-NDVI-based mapping of the length of the growing season in northern Fennoscandia. International Journal of Applied Earth Observation and Geoinformation, 10: 253-266.

Karlsson, P.S. and Weih, M. 2003. Long-term patterns of leaf, shoot and wood production after insect herbivory in the Mountain Birch. Functional Ecology, 17: 841-850.

Klemola, T., Ammunét, T. Andersson, T., Klemola, N. and Ruohomäki, K. 2012. Larval parasitism rate increases in herbivore-damaged trees: a field experiment with cyclic birch feeding moths. Oikos, 121: 1525-1531.

Lantmäteriet. 2009. Produktbeskrivning: GSD-Vegetationsdata [pdf]. Availabe at: <http://www.lantmateriet.se/Global/Kartor%20och%20geografisk%20information/Kartor/produktbeskrivningar/Vegetationsdata/Kvalbeskr_vegdata.pdf > [Accessed 7 Januray 2013].

Lantmäteriet, 2012. *V.14. Product description: Lidar* [pdf] Available at: < http://www.lantmateriet.se/Global/Kartor%20och%20geografisk%20information/H%C3%B6jddata/Produktbeskrivningar/laserdat.pdf>, [Accessed 23 November 2012].

Lemmens, M. 2011. Geo-information: Technologies, Applications and the Environment. Springer Dordrecht Heidelberg London New York: ISBN 978-94-007-1666-7 .

Lillesand, T. M., Kiefer, R. W., and Chipman, J. W.. 2008. Remote Sensing and Image Interpretation. 6th edition. New York: John Wiley & Sons Ltd.

Lu, D., Mausel, P., Brondizio, E. and Moran, E. 2003. Change detection techniques. International Journal of Remote sensing, 25: 2365-2407.

Lunetta, R.S. 1999. Applications, project formulation, and analytical approach. In: Lunetta, R.S. and Elvidge, C.D. (ed): Remote sensing change detection –Environmental monitoring methods and applications, Taylor & Francis Ltd, London, 1-19.

Mallet, C. and Bretar, F. 2009. Full-waveform topographic lidar: State-of-the-art. ISPRS Journal of photogrammetry and remote sensing, 64: 1-16.

Mäntylä, E., Alessio, G. A., Blande, J.D., Heijari, J., Holopain, J.K., Laaksonen, T., Piirtola, Panu. And Klemola, T. 2008. From Plants to Birds: Higher avian predation rates in trees responding to insect herbivory. PLos One, 3: e2832.

NASA. 2012a. *EOS Program Description, National Aeronautics and Space Administation*- Available at: <http://eospso.gsfc.nasa.gov/eos_homepage/description.php>, [Accessed 30 November 2012].

NASA. 2012b. *Data, National Aeronautics and Space Administation*. Available at: http://modis.gsfc.nasa.gov/data/>, [Accessed 30 November 2012].

Neuvonen, S., Ruohomäki, K., Bylund, H. and Kaitaniemi, P. 2001 Insect herbivores and herbivory effects on mountain birch dynamics. In: Wielgolaski, F. E. (ed): Nordic Mountain Birch Ecosystem, The Parthenon Publishing Group, London 27: 207-222.

Nilssen, A. and O. Tenow. 1990. Diapause, Embryo Growth and Supercooling Capacity of *Epirrita autumnata* Eggs from Northern Fennoscandia. Entomologia Experimentalis et Applicata, 57: 39-55.

Polarforsknings sekretariatet. 2012. Abisko naturvetenskapliga station. Available at: <http://www.polar.se/abisko/abisko-naturvetenskapliga-station>, [Accessed on 11 December 2012].

Rouse, J W, R H Haas, J A Schell, and D W Deering. "Monitoring vegetation systems
in the Great Plains with ERTS." *Third ERTS-1 Symposium NASA.* Washington
DC: NASA SP-351, 1974. Vol 1, 309–317.

Ruohomäki, K., Tanhuanpää, M., Ayres, M.P., Kaitaniemi, P., Tammaru, T. and Haukioja, E. 2000. Causes of cyclicity of Epirrita autumnata (Lepidoptera, Geometridae): grandiose theory and tedious practice. Popul Ecol, 211-223.

Solano, R., Dian, K., and Jacobson, A. 2010. V.2.0. MODIS Vegetation Index User’s guide[pdf] Available at:< http://vip.arizona.edu/documents/MODIS/MODIS_VI_UsersGuide_01_2012.pdf> , [Accessed 28 November 2012].

Spruce, J.P., Sader, S., Ryan, R.E., Smoot, J., Kuper, P., Ross, K., Prados, D., Russel, J., Gasser, G., McKellip, R. And Hargrove, W. 2011. Assessment of MODIS NDVI time series data products for detecting forest defoliation by gypsy moth outbreaks. Remote sensing of environment, 115: 427-437.

Stöckli, R. 2003. *NDVI Measurements with simple radiometric and photographic method.* The Marble Research, <http://bluemarble.ch/wordpress/2003/01/07/ndvi-measurements-with-simple-radiometric-and-photographic-methods/> [accessed 28 December 2012].

Tenow, 0. 1972. The outbreaks of Oporinia autumnata Bkh. and Operophtera spp. (Lep., Geometridae) in the Scandinavian mountain chain and northern Finland 1862-1968. Zoologiska Bidrag från Uppsala. Supplement 2.

Tenow, O., Bylund, H. and Holmgren, B. 2001. Impact on Birch forests in the past and the future of outbreaks of two geometrid insects. In: Wielgolaski, F. E. (ed): Nordic Mountain Birch Ecosystem, The Parthenon Publishing Group, London 27: 223-239.

Tenow, O., Bylund, H., Karlsson, P.S. and Hoogesteger, J. 2004. Rejuvenation of a mountain birch forest by an *Epirrita autumnata* (Lepidoptera: Geometridae) outbreak. Acta Oceologica, 25: 43-52.

Tucker, C. J., Pinzon, J.E., Brown, M.E., Slayback, D. A., Pak, E. W., Mahoney, R., Vermote, E. F. and Saleous, N. E. 2005. An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. International Journal of Remote Sensing, 26: 4485-4498.

Virtanen, T., Neuvonen, S. and Nikula, A. 1998. Modelling Topoclimatic patterns of egg mortality of Epirrita autumnata (Lepidoptera: Geometridare) with a geographical information system: predictions for current climate and warmer climate scenarios. British Ecological Society, 35 311-322.

Virtanen, T. and Neuvonen, S. 1999. Performance of moth larvae on birch in relation to altitude, climate, host quality and parasitoids. Oceologia, 120: 92-101.

Wielgolaski, F. E. 2001 Vegetation sections in northern Fennoscandian mountain birch forest. In: Wielgolaski, F. E. (ed): Nordic Mountain Birch Ecosystem, The Parthenon Publishing Group, London 27: 23-46.

Wolf, A., Kozlov, M.V. and Callaghan T.V. 2008. Impact of non-outbreak insect damage on vegetation in northern Europe will be greater than expected during a changing climate. Climatic Change, 87: 91-106.

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

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