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# Detection of grassland management intensity using MODIS satellite imagery

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## FOREWORD

This report presents 8 months of research in the context of my MSc thesis in Geo-Information Science and Remote Sensing at Wageningen University. The topic has some backgrounds related to my Bsc Forest and Nature Conservation, where I also did some research on meadow birds. This was one of the first times that I was able to do research using ArcGIS and ERDAS Imagine related to meadow bird management, which made it very interesting for me. It took a lot of time to get familiar with the MODIS data and Python scripting combined with ArcGIS, but I managed and I had pleasure working on this research. I searched for a topic that was more related to natural problems and I came to this topic, based on the use of remote sensing data. The background was very interesting and the possibilities of the satellite imaginary seemed to work out good. I liked the combination between Remote Sensing and ArcGIS in this topic. Many things that I have learned during the courses came across during the research.

Special thanks goes to Rob Kole from the agricultural nature association Ark & Eemlandschap, situated in Bunschoten-Spakenburg. He supplied me with detailed grassland management data on parcel level from a small area in Eemland. This data is used as first test and calibration of the first mowing detection model, what made it possible to apply the model to the whole Arkemheen-Eemland afterwards. Without this data, it would have been more difficult to analyse the results and apply the model to other, larger areas. I know Rob from my bachelor thesis, where I did research to the blacktailed godwit in Arkemheen-Eemland. It was nice to meet each other again after a few years.

Also I would like to thank in particular my supervisors Lammert Kooistra, Sander Mücher and Alex Schotman for their great support and feedback during the research. Without my supervisors, I would not have seen some things which were very important to this research. Finally I would like to thank John Stuiver for giving some hints to get my Python scripts working.

Martin Lips, October 2011.

# INDEX

## SUMMARY

The management intensity of the grasslands in The Netherlands has increased during the last decennia. An earlier first mowing date, deeper drainage and a decrease of the total area of grasslands led to a decline of the meadow bird populations. Since 2000 many projects started  to slow down the population decline of the meadow birds. But these efforts haven't stopped the population declines. The meadow bird protection concentrates now on the larger areas with high densities of meadow birds, to spend the available subsidies as efficient as possible. This means that the current management should be reconsidered for the selection of areas. This is however, difficult, because there is no grassland management data available for such large areas.

The objective of this study was to develop a methodology based on the analysis of remote sensing data to identify intensive and extensive managed grasslands. Because of the size of the grassland areas and the possibilities of satellite imagery, this has been done using 16-days and 8-days MODIS EVI time series, which are available since 2000. Although the spatial resolution of 250 meters is not that detailed, the daily revisit of the Terra satellite makes it possible to detect the grassland vegetation development through time. Two methods are tested to classify extensively and intensively managed areas in the area Arkemheen-Eemland. The EVI-values of the 16-days MODIS time series are summed for the years and only the spring period of 2007-2010. Both groups of management contain pixels with low and high summed EVI values. There was too much overlap in the result, what made classification based on the summed EVI values impossible.

Furthermore, a model has been developed in this study to derive the first mowing day per pixel in the study areas Arkemheen-Eemland and Laag-Holland for the years 2007-2010. Exact management data were available for a small area in Eemland. The developed model gave some good results using the 16-days EVI time series. The 8-days EVI time series contain too much noise and are not suitable for the detection of the mowing date. After this pilot area, the model is applied to the study areas Arkemheen-Eemland and Laag-Holland. The validation data, based on management contracts of parcels involved with meadow bird protection, has some limitations. Only the date after which mowing was permitted was known, but not the exact mowing date. Therefore, weather data was used as well, to recognise patterns in the by MODIS estimated first mowing days. As expected, the more intensively managed pixels have an earlier mowing date than extensively managed pixels. The differences of first mowing days between the years can be linked with the weather conditions during spring. This indicates that the model for estimation of the mowing dates performed well. The derived mowing dates can be used as an indication of management intensity, although the spatial resolution of 250 meters lacks detail for estimation of the mowing dates on parcel level.

Validation for Laag-Holland gave results which were comparable to Arkemheen-Eemland. This indicates that the model is applicable to other areas or maybe for whole The Netherlands. The model should be validated for other areas to estimate this.

# 1. INTRODUCTION

The topic is introduces in this chapter. The relevance is given in section 1.2. The problem definition in section 1.2 deals with the motivation for this study. The research objectives are described in section 1.3, followed by the research questions in section 1.4. This chapter ends with the report outline in section 1.5.

## 1.1 RELEVANCE

During the last few decennia the decline of the Dutch meadow bird populations has become a hot topic. Several organisations started with research on meadow birds to get more knowledge about the causes of the declining populations. Different studies came up with the same conclusion. The intensification of the Dutch dairy farming was appointed to be the cause of the decline. Mowing of the fields started earlier in the spring period than 20 years ago, due to agricultural land improvement by draining and early spring management activities (van 't Veer *et al.* 2008, Mooij 2007, Schekkerman 2008). Grass species that are used nowadays are rich in proteins and earlier in the season ready to be harvested, the so-called turbo-grasses (Verhulst *et al.* 2008).

Due to these management changes, the juvenile meadow birds, e.g. black-tailed godwit (*Limosa limosa*) and redshank (*Tringa tetanus*), are not able anymore to grow up in their traditional habitats. The juveniles require long but not too densely growing grass vegetation with herbal species and its associated insect life. This grassland type is not common due to the early mowing and the unfavourable composition of the vegetation. The juveniles can't move through the vegetation if the grass vegetation is too dense (Verhulst *et al.* 2008). Regenerating grass vegetation is not as rich in insects as not mowed grass vegetation. In recently mowed, short grassland vegetation they can't hide for avian predators. The mowing activities lead to disasters at the nest locations and the juveniles into the grass vegetation while the grass is being mowed (Schekkerman 2008, Lips 2008). To stop the decline of meadow bird populations, it is important to enable favourable habitat conditions during their grow-up period between April and the end of June.

## 1.2 PROBLEM DEFINITION

Many projects have started that focus on grassland management to stop the decline of the meadow bird population. Nature organizations are involved in these projects as well as dairy farmers. Some parts of meadow bird protection areas do have a delayed mowing management, but it is still insufficient for the juveniles (Schekkerman *et al.* 2005, Verhulst *et al.* 2008, Mooij 2007, Lips 2008, Schekkerman 2008, Van Miltenburg 2008). Recently, the national government stopped with most grants for nature management of meadow birds. Less money is available to prevent the decline of meadow bird populations. Therefore, measures must be taken in most valuable meadow bird areas to stop the population decline.

An optimal meadow bird area meets several important local criteria (van 't Veer *et al*. 2008). Firstly, the landscape has to fulfil a few conditions. Meadow birds are mainly found on grasslands on clay and peat soils in large open areas, without many buildings, trees, roads and other objects which have a disruptive influence to meadow birds because of predator housing. The size of an area is also important; in larger areas the perspective for the meadow birds is better. Secondly, the water level during the breeding- and chick grow-up period should be not too low. Ideally between 20-40 cm below surface during spring (van 't Veer *et al.* 2010). The adult birds need earthworms, which can be found in wet grassland soils. In areas with a deeper groundwater level, the densities of the meadow birds are less high than in wetter areas (van 't Veer *et al.* 2008 and 2010). Thirdly, the management of the grasslands plays an important role in the opportunities for the chicks to grow up, as they forage at insects in the longer grass vegetation. Therefore, it is important to have data available which contains information about the management intensity. The management intensity includes the mowing frequency and the speed of the grass growth, which can be influenced by e.g., fertilization and the water level. A low management intensity is necessary for chicks to grow up as mentioned in section 1.1. Herb-rich grassland vegetation can be found in the less intensively managed areas, mostly combined with a low fertilization rate and a high groundwater level.

An urgent issue for the meadow bird management is that it is hard to find the locations where the meadow bird protection management has a high chance to succeed. Mowing data are badly recorded and it is a lot of work to have this data available for research. A farmer mows his parcel when he is able to do so. Meadow bird areas extend thousands of hectares and therefore it's hard to measure the management intensity of all parcels and to compare them. Participation of farmers in meadow bird protection projects is voluntary, which makes it complicated to have success with the management. The hotspots for introducing meadow bird management are the places where the necessary management forms are already present or possible to develop, with as less compensation money as possible. The lack of available data about the management is one of the major problems. Because of the immense sizes of meadow bird areas, it is almost impossible to detect the management without satellite observations. Therefore, opportunities of using remote sensing techniques to gather information about grassland management and provide information on most optimal locations for meadow bird conservation must be investigated.

To be able to follow the grassland development and its associated management through a season, relevant time series of satellite observations may be a solution. The spatial resolution (pixel size) of an image should be useful for detection of grassland changes. The management of individual parcels is not very important, as the meadow birds are not dependent of the management of just one parcel. It is more important to get knowledge of the management at larger scale, to define the management differences between the Dutch meadow bird areas. These areas have surfaces of hundreds till thousands of hectares. To be able to detect differences in management intensity within the areas as well, the best suitable spatial resolution should be between 10 and 250 meter.

The temporal resolution is very important, because of the vegetation changes caused by e.g. mowing and the grass growth. Therefore, usable images of once a week till once every 2 weeks are necessary. The data must be comparable to each other and free of errors caused by atmosphere and clouds. Therefore, time series of satellite images are needed for detection of the grassland management through the seasons of a few years, which are ready to be used. Making a trade-off between spatial and temporal resolution is always the problem, because there is no earth observation system available which supplies both by a high resolution. Based on these requirements, MODIS (Moderate Resolution Imaging Spectroradiometer) satellite images could be a suitable source to use for this project. There are 16-days and 8-days composited time series available, based on daily satellite observations, with a spatial resolution of 250 meters (Lillesand *et al.* 2008). The vegetation development can be measured with the NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) (Akiyama & Kawamura 2007, Lillian *et al*. 2008). On forehand it is known that the NDVI is more able to distinguish vegetation abundances and to classify different vegetation types, e.g. forests and different crop species. The EVI is better able to distinguish differences in vegetation structure and biomass. Research in China proved that the NDVI is also able to estimate the total amount biomass. The EVI gives a good estimation of the amount of proteins in the vegetation (Akiyama & Kawamura 2007).

## 1.3 RESEARCH OBJECTIVES

The objective for this research is to develop a methodology that makes it possible to determine the management intensity of grasslands using satellite imagery. With this methodology, the meadow bird protection projects and its associated research can be supported.

Using the results, it should be possible to detect the grasslands with an extensive management at larger scale. These areas are hotspots for meadow birds and should be further analysed for meadow bird protection. It will not be possible to detect the management of individual parcels, because of the resolution of MODIS (250 meter). For accurate management data at parcel level, field data is still required.

## 1.4 RESEARCH QUESTIONS

1. Which satellite image products are most suitable for detection of the grassland vegetation development and management?
2. Can the relative management intensity be distinguished per pixel using time series data?
3. Can the first date of mowing accurately be detected by vegetation index time series?
4. How to validate management regimes derived from satellite imagery?
5. Is the methodology also applicable to other areas for detection of extensively managed grassland areas?

## 1.5 REPORT OUTLINE

Chapter 2 focuses on the backgrounds of the topic, which provides input for the methodology in chapter 3. In chapter 4, the results are analysed. The discussion about the results can be found in chapter 5. Finally, the conclusion and recommendations for improvements are included in chapter 6.

# 2. BACKGROUND

This chapter presents background information that is relevant for this research. In section 2.1 information about the Dutch grassland management is given. Section 2.2 contains information about meadow bird protection. Section 2.3 goes more into detail on available remote sensing data and methods for detection of vegetation dynamics.

## 2.1 GRASSLAND PHENOLOGY AND MANAGEMENT IN THE NETHERLANDS

Grassland is the main land use of the Netherlands and can be found on all soil types. The management and use of grasslands can be very different. In this research, uses of interest are restricted to agricultural and natural grasslands. Both grassland types differ in management intensity.

Agricultural grasslands have been used by farmers for forage and grazing for cattle, using the measures grazing during the spring and summer at fields nearby the stable, and mowing at the fields which lie further away, during the growing season. The mowed grass is ensilaged to serve as forage during the winter, when the cattle stay in the stable.
Natural grasslands are often encountered in nature reserves, where the management is more focussed on natural targets. Therefore, these grasslands have a less intensive management, reflecting a lower mowing frequency and less or no use of fertilisers. The groundwater level is often more natural (higher), to bring more gradients in the area that can be used by a lot of species. This management results in grassland vegetation that is more herb rich than intensive grassland vegetation, and it has a more open structure as well. Mowing of natural grasslands is in most cases restricted to the period after the first of June.
In general, agricultural grassland differs from natural grassland by the management and its abiotic conditions. The agricultural grasslands are more productive than the natural grasslands (figure 1), caused by the use of seed mixtures with more productive grass species, (heavy) fertilisation, a regular mowing regime and deep drainage. The grass is mostly used by farmers as forage for the cattle during winter, when grazing is not possible and the cattle stay in the stable. Although the mowed grass loses its green colour, the energy and proteins still remains in the grass.

The photosynthesis that drives grass growth is most affected by sun light and temperature, which have a positive correlation. The groundwater level of the growing place also affects the grass growth. Grass growing at wet places has a lower growing speed than grass at drier soils, although very dry soils have a lower growing speed as well. These preconditions for grass growth make clear that it also depends of the weather during spring. In cold or cloudy and wet springs, the grass grows very slow. In these years, the farmers are not able to mow the grass early in the season. This means that the difference in mowing management between intensively managed agricultural grasslands and the extensively managed natural grasslands can be very small (Terwan *et al.* 2002).

The last decades the management of agricultural grasslands has been changed. More powerful and faster tractors and larger mowing machines have made it possible to mow more grassland area per hour, from 1.6 hectares to 4.8 hectares per hour (Terwan 2002). Thereby, the global warming causes warmer springs in The Netherlands, resulting in an earlier start of the grass growth. The first mowing of grasslands take place up to two weeks earlier than around 1980. Mostly in the beginning of May with fluctuations between years caused by the weather conditions (Terwan 2002, Natuurbericht Website). Research has proven that there is a strong relation between the first mowing date and the summed average daily temperature since January. Around 50% of the intensively managed agricultural grasslands in meadow bird areas are mowed when the sum of the temperature meets 890 degrees Celsius (Teunissen *et al.* 2008, Kleijn *et al.* 2009).

**Figure 1: Difference in vegetation structure of extensive natural grassland (left) and intensive agricultural grassland (right). The photos are taken in Eemland at the end of May 2011 (Martin Lips).**

## 2.2 MEADOW BIRD PROTECTION

The increased management intensity of the agricultural grasslands caused a dramatic decline of the meadow bird populations in the Netherlands. The black-tailed godwit is a typical Dutch meadow bird, around 60% of the global population breeds on the Dutch grasslands (Van Betteray *et al.* 2011). Figure 2 shows that the population of the black-tailed godwit (Grutto) declined dramatically since 1990.

The main cause of the negative trends is a lack of suitable grassland area for chicks, caused by the early mowing in spring. The chicks of the black-tailed godwit need also longer, not-mowed grass during the grow-up period between the end of April up to the beginning of June (Schekkerman *et al.* 2005). Grasslands with not-mowed long grass contain a rich insect life, especially when the vegetation is herb-rich. The chicks eat insects which live in the grassland vegetation around bill height.

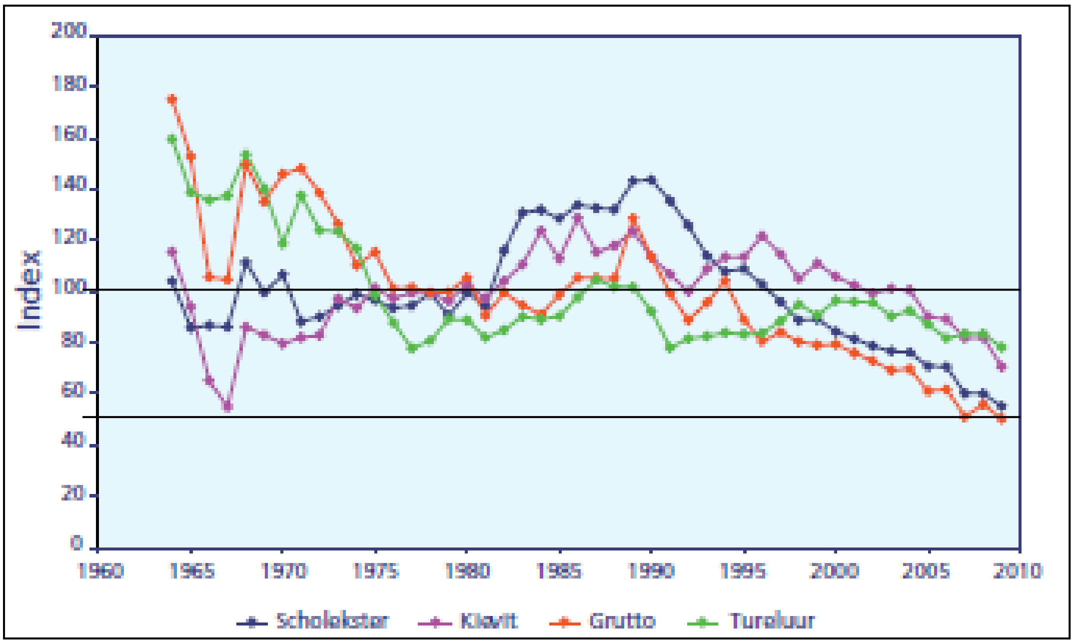



**Figure 2: Population trend of four Dutch meadow bird species, from 1965-2010 (Van Betteray *et al.* 2011)**

To improve the breeding success of the meadow birds and as attempt to stop the decline of the meadow bird populations, the government introduced different subsidy arrangements for meadow bird protection on grasslands between the years 2000-2010.
The first arrangement was introduced in 2000 and last till the end of 2006. This arrangement was called SAN (Subsidy arrangement Agricultural Nature management) for the by farmers owned and managed parcels and SN (Subsidy arrangement Nature management) for the nature organisations (Teunissen & Wymenga 2007). These arrangements were part of the broader subsidy arrangement 'Programma Beheer' that was introduced in the year 2000 for conservation of natural and environmental values. Farmers participated in this funding scheme by management contracts for (a part of) their parcels, where management measures have been taken to improve the breeding success or/and vegetation structure for meadow birds. For meadow birds, there were subsidized measures available, involved with nest protection, delayed mowing management with different rest periods during the breeding period. There were four categories of meadow bird areas formulated, also known as management packages, with defined minimum densities of birds and species as requirements for participation (Teunissen & Wymenga 2007).
For farmers, there were two ways to participate in the SAN arrangement. They could participate individual or together as collective (Teunissen & Wymega 2007). At January 1 of the year 2007, the SAN arrangement was followed by the PS(A)N arrangement (Provincial Subsidy arrangement (Agricultural) Nature management). In fact, the active management contracts were not changed, because the contracts of the S(A)N were closed for a period of 6 years. The main change was that the amount of funding had been determined by the Dutch provinces and not by the government.
On December 31 of 2009, the PSAN arrangement and all active management contracts came to an end. The PSAN arrangement has been replaced by the SNL (Subsidy arrangement Nature and Landscape) at January 1, 2010. The SNL arrangement exists of other management packages than the (P)S(A)N arrangement and contributes more to a regional approach of the meadow bird problems (SNL Website). This arrangement is more focussed to support the meadow bird protection in the areas with higher meadow bird densities.

## 2.3 REMOTE SENSING

Earth observation by satellite systems has been applied in many research fields during the last decades. There are numerous satellite systems available (table 1) for detection of changes at the earth surface. Which satellite system is most useful for a research depends of which changes will be investigated. For this research, the detection of vegetation changes in grasslands caused by management should be detectable. Therefore it is important, that there is comparable data available for at least a few years.

The spatial and temporal resolution of the used time series influence the possibilities for detection of phenological vegetation changes. For the selection of the best suitable satellite system and its time series, a balance should be found between the spatial and temporal resolution. The temporal resolution, also known as revisiting time, should have an interval that makes it suitable for detection of the event where is focussed on. In this research, the focus is on the mowing management of the grasslands. Those grasslands have a mowing interval of at least four weeks, during ideal weather conditions (field observation in 2011). Therefore, it is important that the temporal resolution is smaller than four weeks. Thereby, not all images of a satellite system are usable, caused by clouds and other atmospheric noise (Verbesselt *et al* 2011). The temporal resolution should provide accurate measurements for the aim of the research.

Single band reflections can be used as input for the calculation of vegetation indices. These indices have been developed as green vegetation biomass indicators. The most relevant vegetation indices for this research are the NDVI (Normalised Difference Vegetation Index) and EVI (Enhanced Vegetation Index). The NDVI and EVI have been used for detection of vegetation changes. The NDVI formula uses the red and near-infrared band for calculation of the vegetation index value. The drawback of the NDVI is, that the index is more chlorophyll sensitive and saturates in areas with high biomass, for example grasslands (Kawamura *et al.* 2005, Evrendilek & Gulbeyaz 2008). The EVI is also sensitive to dense vegetation while reducing the noise of canopy background and aerosol sources using constants in the EVI formula. The EVI is more responsive to canopy structural variations, canopy type, plant physiognomy, and canopy architecture (Kawamura *et al.* 2005).

The EVI formula:

$$EVI = (1 + L)\frac{\rho NIR - \rho Red}{\rho NIR + C1 * \rho Red - C2 * \rho Blue + L}$$

Where the reflectance values of the near-infrared (NIR), red and blue bands are used, combined with some constants for reduction of soil- and aerosol influences on the EVI values. L is a canopy background calibration factor that normalizes differential red and NIR extinction through the canopy, and C1 and C2 are the weighting factors for the aerosol resistance. The coefficients adopted in the EVI algorithm are L = 1, C1 = 6, and C2 = 7.5 (Liu & Yang 2001, Chengyuan *et al.* 2008).

Time series of the vegetation indices can be used for detection of phenological vegetation dynamics through time (Verbesselt *et al* 2011, Cheng 2006). Characteristics of time series are that the extent of the data is the same for all revisits, so that the pixels have the same extent on all images. The used sensors, data inquiry and processing were all measurements the same, resulting in comparable image data.
The time series of the Moderate Resolution Imaging Spectroradiometer (MODIS), as part of the NASA's Terra platform, have been proven to be accurate for detection of seasonal rice growth and grassland cover densities (Cheng 2006), and also classification of grazing intensities was successfully performed in the steppe in Mongolia (Kawamuraa *et al.* 2005). The NDVI and EVI time series has been applied in many vegetation-related fields.

**Table 1: Overview of remote sensing satellite systems relevant for monitoring grasslands (MODIS Website, MERIS Website, SPOT Website, Landsat Website, Satellite Imaging Corporation Website, ESA Website).**

| Satellite system/sensor | Temporal resolution (day) | Spatial resolution (m) | N Bands |
|---|---|---|---|
| **MODIS** | 1 | 250-500-1000 | 36 |
| **MERIS** | 3 | 300 | 15 |
| **SPOT** | 26 | 2.5-25 | 4 |
| **LandSat** | 16 | 15-30 | 7 |
| **Quickbird** | 3.5 | 2.4 | 3 (Red, Green and NIR) |
| **Sentinel 2 (ESA, launch 2013)** | 2-3 | 20 | 13 |

# 3. METHODOLOGY

This chapter describes all steps that were taken during this research. First, some background information about the study areas is given. Thereafter, a complete overview of the input datasets (section 3.2), the data pre-processing steps (section 3.3), data processing steps (section 3.4) and the method for analysis and validation (section 3.5). A flow chart with the most important data pre-processing and processing steps can be found in appendix A. For many steps, Python scripts are used, which are included in appendices P to U.

## 3.1 STUDY AREAS

In this section is given a description of the study areas Arkemheen-Eemland and Laag-Holland. Maps of the land use and location of the study areas are presented. The land use, grassland management and some characteristics of the areas are described.

### 3.1.1 ARKEMHEEN-EEMLAND

Arkemheen-Eemland is used as primary study area for testing results of the developed models. The extent that is used for Arkemheen-Eemland, is a rectangle based on the Dutch RD-coordinates 480,000 (north), 462,000 (south), 143,000 (west) and 165,500 (east). The area is situated in the middle of the Netherlands, in the north of the provinces Utrecht and Gelderland near the cities Amersfoort and Nijkerk (figure 3). The main characteristic of Arkemheen-Eemland is that the landscape is very open and the main land use is agricultural grasslands, mostly located on peat- and clay soils.

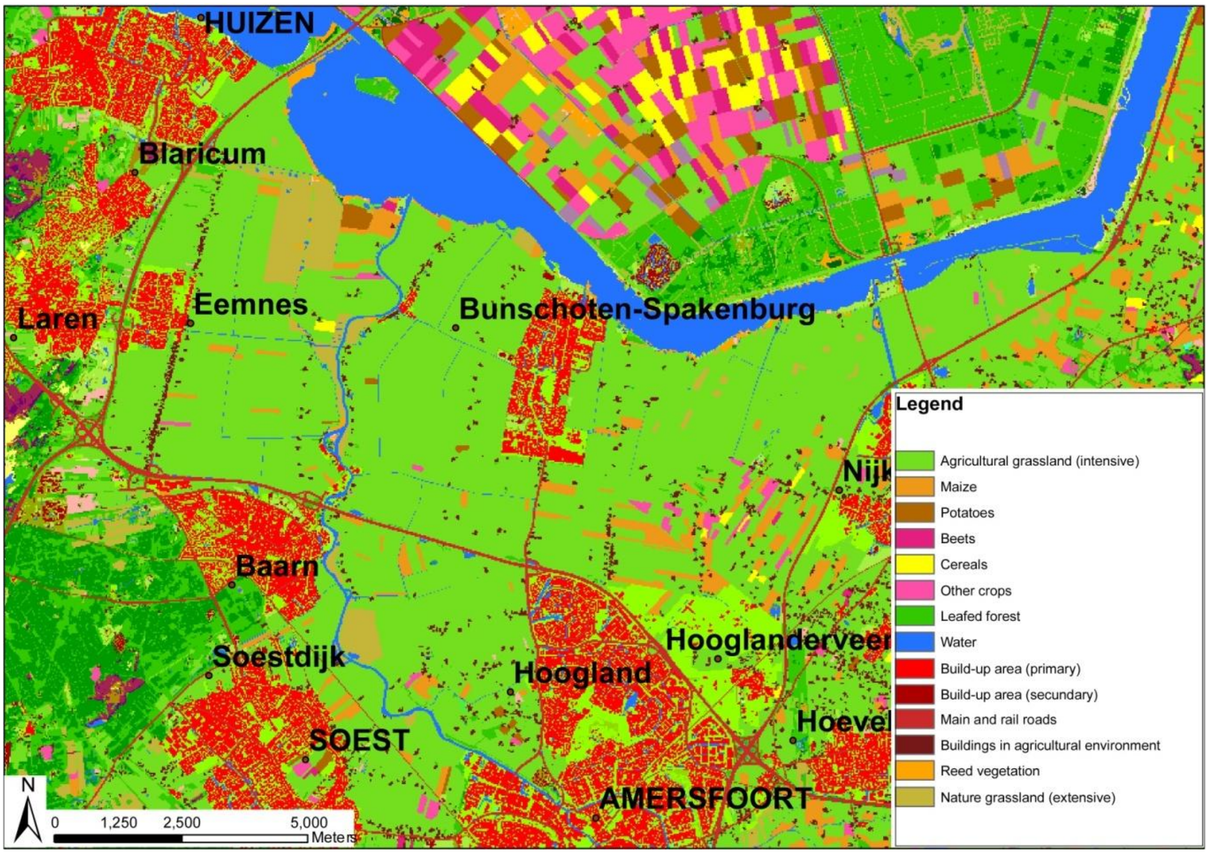



Figure 3: Land use map of Arkemheen-Eemland with the land use situation in 2009 (LGN 6).

Arkemheen-Eemland exists of two different areas: Arkemheen situated in the province Gelderland in the east and Eemland in the province Utrecht at the western side. Both areas have their own rich history, which influences the daily management in the areas. In general, the grassland management in Arkemheen is less intensive than in Eemland. This is caused by the fact that Eemland is an area with peat soils, where the parcels are exchanged and the farms are relocated in the area in the last decade of the 20$^{st}$ century to give a boost to the agriculture in this area. The groundwater levels have been reduced to make it possible for farmers to mow the parcels earlier in spring. There is also a large nature reserve situated in the north of Eemland, where the association Natuurmonumenten takes care of the meadow birds, here the management is very extensive.
Arkemheen is a marsh of the former Zuiderzee (nowadays called IJsselmeer), with many former rifts and a top soil that mainly exists of clay. At the moment, it still is (one of) the only remaining grassland area(s) where no parcel exchanges and farm relocations took place at large scale. The farmers that operate in this area are relatively small and the distance from the farm to the grassland parcels is larger than in Eemland or many other areas, because the farms are located at the edges of Arkemheen but not in the area itself. The combination of the high groundwater levels, small parcels and big distances from farm to the grasslands result in a land use that is more extensive than the management in Eemland. In Arkemheen there is a nature reserve as well, managed by Staatsbosbeheer (the Dutch Forestry Commission).
In Arkemheen-Eemland, a lot of difference in management intensity can be found. There are a lot of farmers with differences in management and also some nature organisations have reserves in the area as well. These nature reserves have a less intensive management to provide suitable habitats for meadow birds.

### 3.1.2 LAAG-HOLLAND

The area Laag-Holland is used to test if the methodology for detection of the first mowing date, which has been developed for Arkemheen-Eemland, is applicable to other areas as well. The extent of this area can be found in figure 4. The area is situated in the province Noord-Holland, north of Amsterdam. This study area covers some smaller polders including De Beemster, De Schermer, Zeevang, Waterland Oost, Het Tiske and Zaanstreek.
The land use of Laag-Holland mainly exists of agricultural grasslands. There are a lot of nature reserves, especially in the southern part of the area. There are a few polders situated in Laag-Holland with relatively high densities of meadow birds (van 't Veer *et al.* 2010).
The northern part contains better clay soils, where arable lands can be found. The southern area is composed of peat soils, where the abundance of water is larger. There are some areas in Laag-Holland where the abundance of water is large. For example the polder Oostzaan east of Zaandam, where 40% of the land use exists of water (Scharringa & Van 't Veer 2008). Especially in the southern part, the grassland management is extensive because of the reserves and the agricultural nature management.

In comparison to Arkemheen-Eemland, water plays a larger role in the southern part of Laag-Holland. In the northern part of Laag-Holland are more arable lands situated than in Arkemheen-Eemland. But the grassland management is comparable; there are places with extensive nature reserves, and more intensive agricultural grasslands as well.

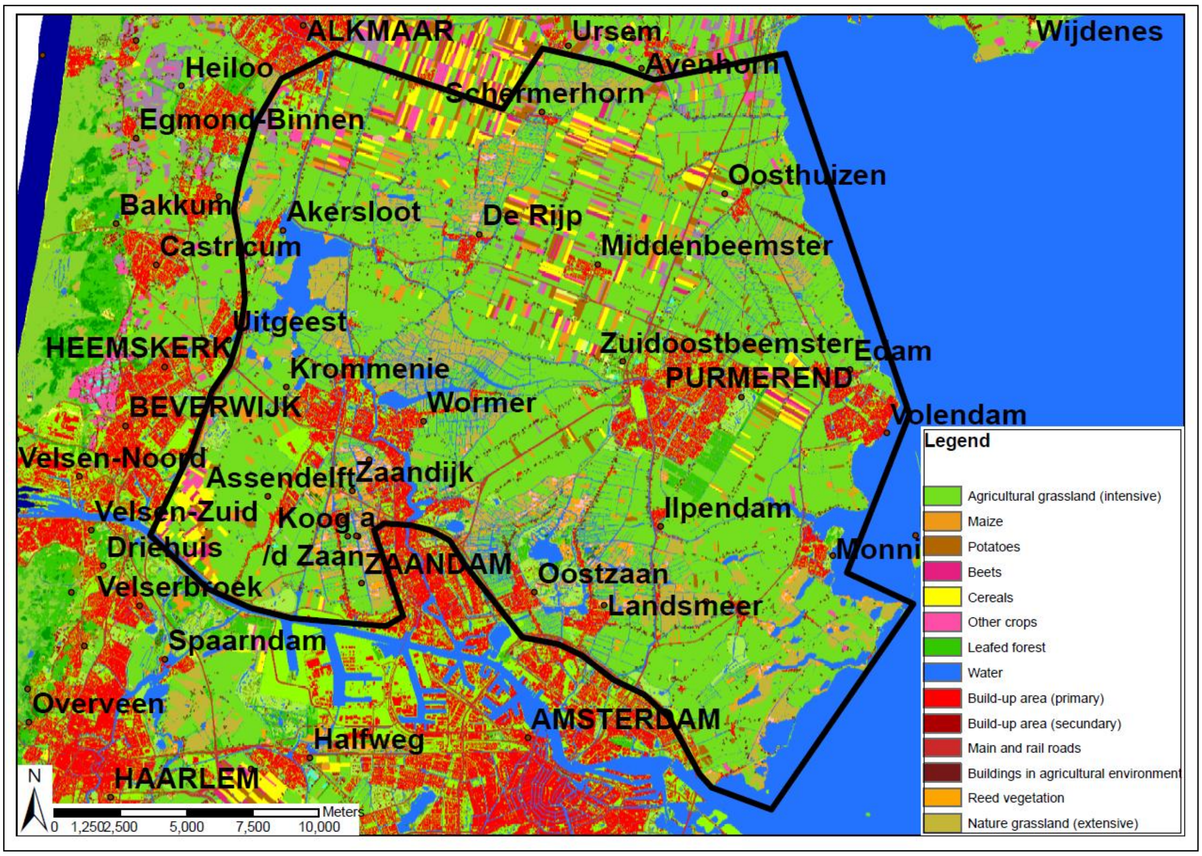



**Figure 4: Land use map of Laag-Holland (2009) with the boundary of the study area (LGN 6).**

## 3.2 INPUT DATASETS AND TIME SPAN

This section contains an overview of the used datasets and the time span that is used.

**MODIS datasets**

The purpose of this research is to detect the management intensity of grasslands. Therefore, vegetation index time series can be used, as they respond to (green) biomass and fluctuations in the amount of grassland biomass can be detected (section 2.3). With the available data products of the MODIS (Moderate Resolution Imaging Spectroradiometer), fluctuations of the grassland biomass should be detectable, caused by the management of the grasslands. The NASA Terra satellite with the MODIS sensor aboard crosses the Netherlands just before midday.
During this research, time series of the Enhanced Vegetation Index (EVI) were used, with an composition interval of 16 days and 8 days. This interval means that the best of the daily observations, with a low viewing angle and as less clouds and atmospheric noise (aerosols) as possible, is used to represent the 16-days or 8-days interval as single value (Solano *et al.* 2010). All data is downloaded in TIFF format from the online web tool MRTWeb, that can be found at the LP DAAC (Land Processes Distributed Active Archive Center) Website (LP DAAC Website).

The 16-days MODIS vegetation product MOD13Q1 is used to detect vegetation changes in time, with a composition interval of 16 days. The spatial resolution, also known as pixel size, is 250 meter. The data is used from the years 2007-2010 and is composed of the required EVI vegetation index and also some quality control datasets, but these datasets are not used during this research.

Because of the mowing interval of 4 weeks between two mowing times at grasslands and the fast growing speed of grassland vegetation (section 2.1), it was not sure if the 16-days EVI time series were able to detect the mowing date accurately. Therefore, 8-days time series of the EVI, based on the single band MODIS products (MOD09Q1 and MOD09A1) were used as well. To be able to produce the 8-days EVI vegetation index manually, the data of the MODIS 8-days single band reflection product MOD09Q1 with a spatial resolution of 250 meter for band 1 (red) and band 2 (NIR) and MODIS 8-days single band reflection product MOD09A1 with a spatial resolution of 500 meter for band 3 (blue) have been used.

**Land Use Map of the Netherlands**

The land use map of the Netherlands (LGN6) exists of a raster dataset with a pixel size of 25 meters. The pixel value of every pixel represents the major land use of 2009, covered by that pixel (Hazeu *et al.* 2010). An impression of the land use map is given by figure 3 and 4. The LGN 6 dataset has been used for a selection of MODIS pixels with at least 70% grassland coverage (section 3.3).

**Management data of the grasslands**

Management data of the grasslands are used for validation. From a small area in Eemland, (figure 6) the management is recorded by farmers in 2010. This was done for meadow bird management purposes, but for this research the data was suitable as well.

This dataset is used to validate the method to determine if the mowing regime can be derived out of the MODIS EVI vegetation index time series. The input data exists of Excel tables from every farmer that recorded the management per parcel, for the months April, May and June of 2010. A polygon shape file with the parcels is linked by a unique parcel number to the management data in Excel.

For validation at larger scale for both study areas, a database with the PSAN/SNL management contracts is used (section 2.2)(Alterra and Dienst Regelingen, Ministry of EL&I). This database contains the management contract data of the parcels which are involved with subsidized meadow bird management. These management contracts contain management information for grassland parcels, where some management requirements are agreed to protect the meadow birds, for example a delayed first mowing date. This dataset is only available with all four years (2007-2010) in one shape file, and exists of a polygon layer with the parcels and the management contract, with start date and end date of the contracts. This data is available for the whole of the Netherlands.
Additionally, a dataset with all nature reserves of Staatsbosbeheer (the Dutch Forestry Commission) is used. This dataset is available for every year as well. In this dataset, the management targets for the parcels, belonging to reserves, are described shortly.

## 3.3 PRE-PROCESSING

**MODIS datasets**

After downloading the files from the MODIS servers, the first step was to transform the data to the Dutch coordinate system (RdNew in ArcMap). The scripts for this procedure, with step A1, B1 and C1 are described in appendix A. This was done by the Python scripts, which can be found in appendices P, Q and T. These scripts use the ArcGIS Project Raster tool to transform the data to the Dutch national coordinate system and clips the area of interest, in this case the whole Netherlands, out of the images for further use. For this transformation there are three methods for transformation in ArcGIS: nearest neighbour, cubic convolution and bilinear interpolation. Only with the nearest neighbour method, the original cell values remain. The transformed raster gets the cell value of the nearest original cell. Bilinear interpolation uses the four direct-neighbour pixels and cubic convolution uses 16 neighbouring pixels for calculating a weighted average (ArcGIS Help). All three methods were tested and the difference in computed values were very small (appendix N). Therefore, the cubic convolution method is used for all data transformations of the products MOD09A1, MOD09Q1 and MOD13Q1, as the transformation of the pixel coordinates is affected by all directions.
All data that has been downloaded, was scaled to integer (multiplied by 10,000) to spare data volume on the web servers of NASA (Solano *et al.* 2010). The integer format takes less data volume than the floating point data format. To make the data usable, all data has been scaled back to the original EVI values after downloading, using a scaling factor of 0.0001.

The 8-days EVI time series were processed (step A2) by a Python script (appendix R), with the single band reflections as input data (MODIS products MOD09Q1 and MOD09A1). This code applies the scaling factor 0.0001 to all needed bands (1,2 and 3) first, to get the original band reflection values. This step was necessary, because of the use of constant factors in the EVI formula (section 2.3). After this step, the EVI formula was applied for the years 2007-2010, with the 8-days time series as final output. An example of the parcel map overlaid by the MODIS raster can be found in figure 5.

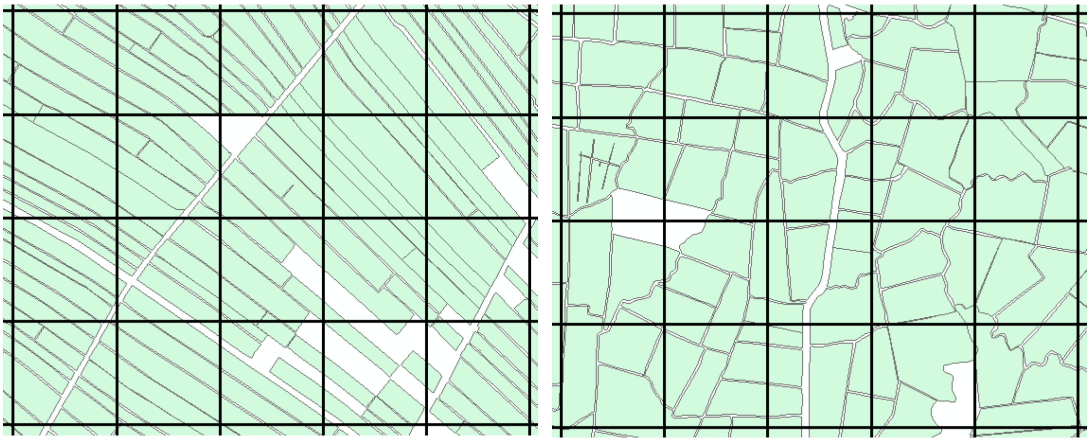


Figure 5: Projection of 250m MODIS raster laid over the parcel map (Ministry of EL&I, Dienst Basisregistraties) in an area with peat soil in Eemland (left) and clay soil in Arkemheen (right), with its typical parcellation pattern.

**Land Use Map of the Netherlands**

With use of the LGN 6 land use map, a sub-dataset is created that contains only the agricultural- and natural grasslands (step D1 in appendix A). Based on this sub-set, a mask containing all MODIS pixels is created with at least 70% coverage of grassland areas (step D2). This is done to minimize the influence of other land use on the results.

For this step the LGN 6 dataset is used. Pixels often cover also buildings (farms), other crops, water bodies and roads. One MODIS pixel covers an area of 250x250 meters and a LGN 6 pixel covers 25x25 meters. All MODIS pixels existing out of grasslands for at least 70 % were covered by at least 70 LGN6 pixels with the land use agricultural- or natural grassland.

With the 70% rule of grassland coverage, there are enough pixels left within the study area to be able to recognise patterns in the model output. In figure 7, all pixels with at least 70% grassland coverage are presented.

**Management data of the grasslands**

The data of the small area with the known management was investigated. From the 24 covering pixels, 9 pixels were not usable. There were some maize fields in the area and from one farmer, it was impossible to link the Excel data to the parcels. The 15 suitable MODIS pixels were extracted from the data and transformed to polygon layer. For every pixel, the first mowing day is derived out of the management data, and added in the attribute table for further analysis. An overview of the 15 pixels is given in figure 6.

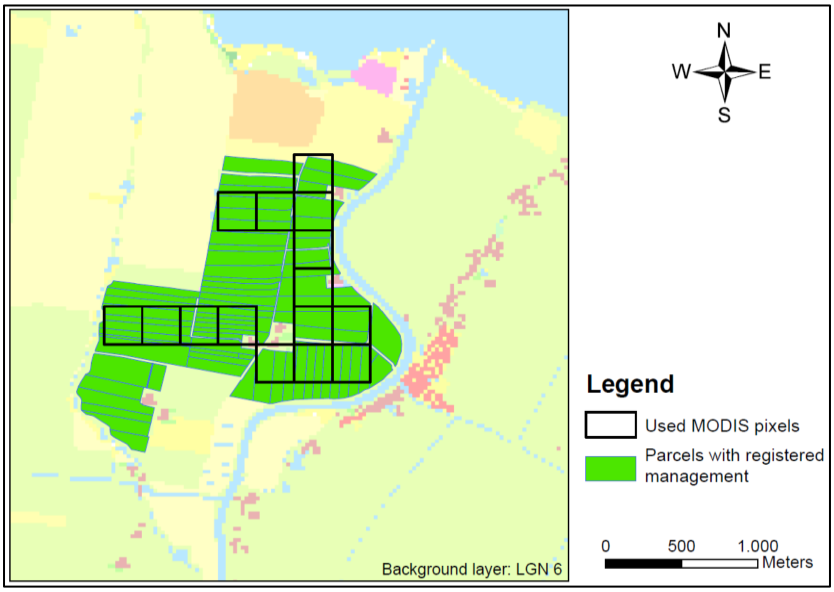



**Figure 6: Location of the 15 pixels with known management, near Eemdijk in Eemland.**

The PSAN/SNL shapefiles contain management information of a part of the grassland parcels distributed through the area. This information is provided by a polygon shapefile that contains parcels and the management contract per parcel of the years 2000-2011. It was needed to create datasets separated per year and only with the management contracts of interest (appendix A, steps E1, E2 and E3).
In the PSAN/SNL dataset requested management packages were also included, but this does not mean that the contracts ever became active. A request for a contract by a farmer needs to be assessed by the authority (Dienst Regelingen, Ministry of EL&I) before a management contract will be agreed by the government, depending on preconditions, for example that the farmer operates in an area with meadow birds which benefit from the management contract (section 2.2). The government decides if the management contract can become active, or that the request will be rejected and never become active. The first step (E1 in appendix A) was, to create a data subset without the by farmers requested contracts, which were not permanently assigned by the government, and thus never became active. With the second step (E2 in appendix A), only the management packages that are related to the grassland management were selected (table 2).
The management packages 4235 and 4245 are more related to botanic management, with the aim to get herbaceous-rich vegetation. Natuurmonumenten uses these management packages also for the meadow bird reserve in Eemland, where the farmers have contracts with additional appointments. In case of this reserve, all parcels may not be mowed before June 15. It is possible that some parts of these areas have an earlier mowing date if farmers participate in PSAN/SNL with this management package. Only 25-30% of these areas have to be without mowing till June 8. At the final third step (E3 in appendix A), subsets were created with the active contracts (at April 1) for each year separate.

The reserves of Staatsbosbeheer with the description meadow bird grassland, other short vegetation and flower rich grasslands are extracted from the reserve dataset of Staatsbosbeheer for every year (step F1 in appendix A). It is assumed that these areas have an extensive management as well. Together with the extensively managed PSAN/SNL parcels, these areas can be used for validation. The selections from the SNL/PSAN dataset and the suitable reserves of Staatsbosbeheer out of the dataset of Staatsbosbeheer are merged to one dataset (step E4 in appendix A). The final datasets contain all known parcels with extensive management (relevant PSAN/SNL management packages and reserves of Staatsbosbeheer), per year separately. These polygon datasets of each year have been transformed to raster with a pixel size of 10 meters and the extent the same as the MODIS data(step E5). The MODIS pixels that were covered by the extensively managed parcels for at least 70%, are extracted as extensive MODIS pixels for the corresponding year (step E6). These layers are used as mask layers to create data subsets of the MODIS time series for analysis later.

**Table 2: For validation used management packages from the PSAN and SNL subsidy arrangements that are related with extensive grassland management (Teunissen & Wymenga 2006, SNL Website).**

| Management packages | Description | First mowing date not before |
|---|---|---|
| 1804, 1904, 2104, 3111, 8001 | Meadow bird grassland with rest period | June 1 |
| 1805, 1905, 2105, 3121, 8002 | Meadow bird grassland with rest period | June 8 |
| 1806, 1906, 2106, 3131, 8003 | Meadow bird grassland with rest period | June 15 |
| 1807, 1907, 2107, 3141, 8004 | Meadow bird grassland with rest period | June 22 |
| 8005 | Meadow bird grassland with rest period | July 1 |
| 8006 | Meadow bird grassland with rest period | July 15 |
| 8008 | Meadow bird grassland with rest period | August 1 |
| 4235 | Species-rich meadow bird grassland | ≥ 25% after June 8 |
| 4245 | Very species-rich meadow bird grassland | ≥ 30% after June 8 |
| 8041 | Meadow bird grassland with rest period | June 15, but before August 1 |

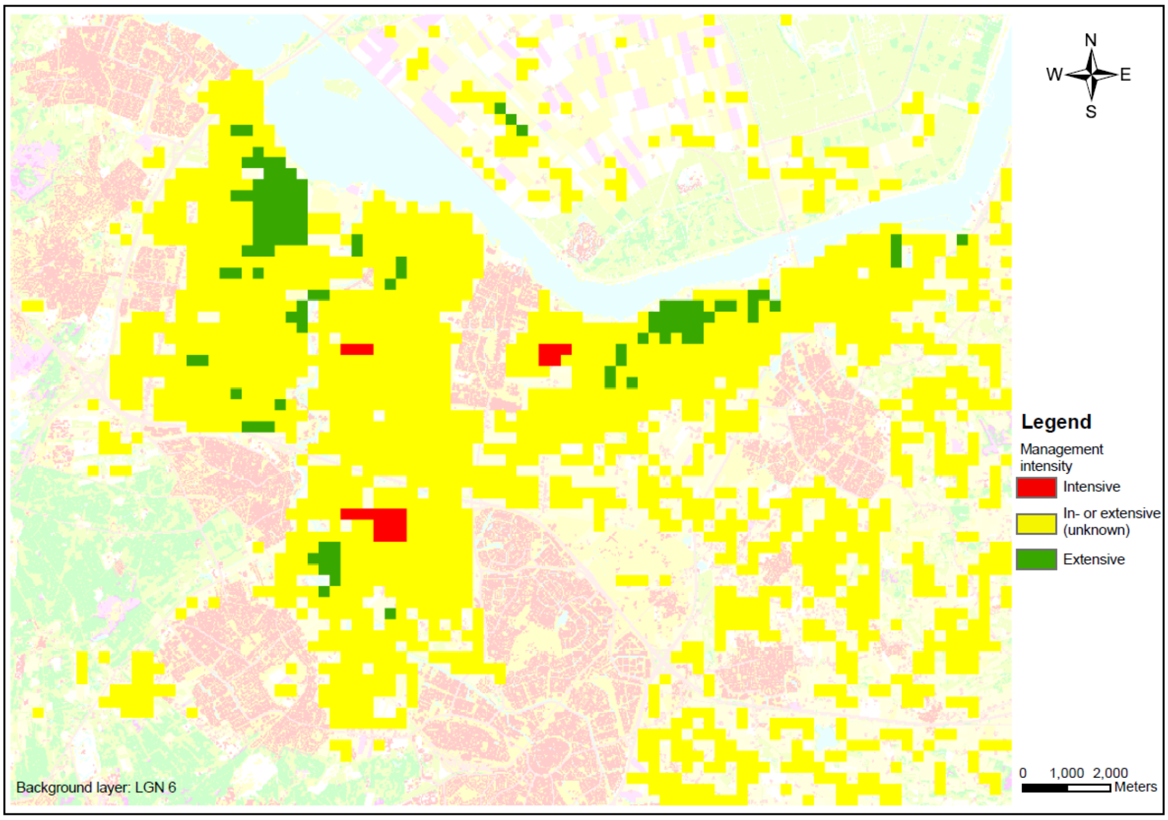



**Figure 7: Distribution of intensively, extensively and unknown managed grassland pixels in Arkemheen-Eemland in 2007.**

**Table 3: Amount of MODIS pixels with at least 70% grassland coverage, per management type in Arkemheen-Eemland.**

| Management/Year | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| **Intensive or extensive (unknown management)** | 1916 | 1902 | 1899 | 1936 |
| **Intensive** | 20 | 20 | 20 | 20 |
| **Extensive** | 114 | 128 | 131 | 94 |

In the spring of 2011, a few field visits to Arkemheen-Eemland gave information about the grassland management as well. Based on these visits, in total 20 intensive grassland pixels were selected from the MODIS data. All these pixels are located not far from the farm and were mowed before June 1, which means intensive management. It is assumed that these areas had an intensive land use in the years 2007-2010 as well. These pixels are used for validation of the management. Figure 7 shows the distribution of these pixels in Arkemheen-Eemland for the year 2007. Between the years, the amount of pixels is a bit different for the groups unknown and extensive management (table 3). This is caused by the ends of existing management contracts and starts of new management contracts of the PSAN/SNL arrangement, and the replacement of the PSAN arrangements by the SNL arrangements in 2009 (section 2.2). At January 1 of 2010, the PSAN arrangement was replaced by the SNL arrangement. This caused a drop of the total amount extensively managed pixels, because fewer farmers were participating in this arrangement.
The intensively managed pixels are defined based on field visits in the spring of 2011. It is assumed that the management of all these 20 pixels was intensive during all years.

## 3.4 PROCESSING

Within the data processing phase two grassland management models have been developed. The first model distinguishes pixels in classes of intensive management and extensive management. And in the second model for every grassland pixel the first day of the year with mowing activity is derived from the EVI time series. Below both methods are explained in more detail.

### 3.4.1 DISTINGUISH OF INTENSIVE AND EXTENSIVE

For detection of the difference between intensively and extensively managed pixels, there are two methods used.

The first method that is used, is calculating the sum of the EVI for each year for the years 2007-2010 (appendix A, step C2). It is assumed that the vegetation in extensively managed areas grows slower, has a lower density and contains more herbal species than on intensively used grasslands, caused by for example differences in the used amount of fertiliser and more influence of water during spring. Figure 8 shows some spectral signatures of the EVI over a year, from pixels where the management intensity is known. In general, the EVI appears to be lower at extensively managed grassland pixels during the year.

The second method is to take only the sum of the EVI of the spring from March 22 up to April 23 (day 81 up to 113) (step C3 in appendix A). Extensive grasslands, which are often moist and get less fertiliser, grow with less speed than the drier intensively managed grasslands. Therefore, it is supposed that the extensive grasslands have a lower summed EVI value of the spring than the intensively managed grasslands.

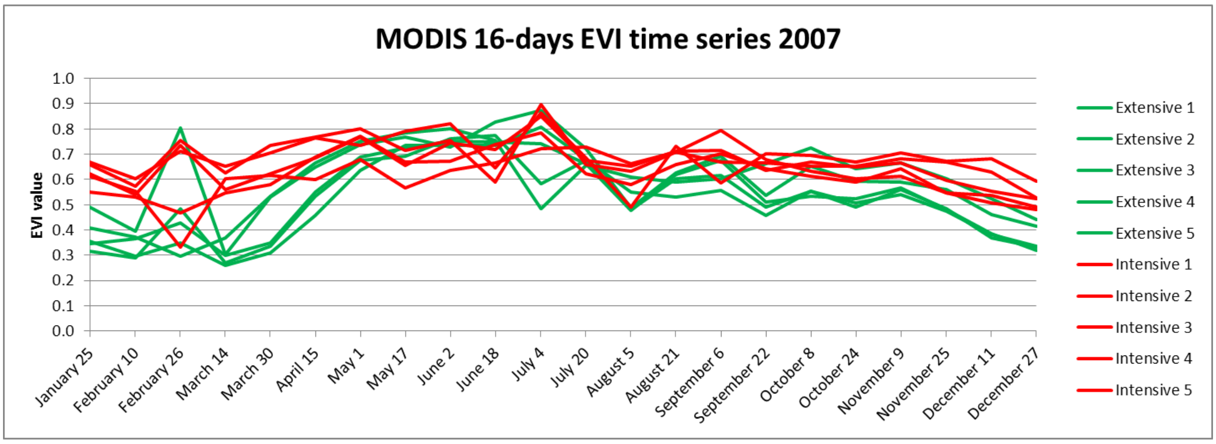



**Figure 8: EVI values of 5 intensively and 5 extensively managed grassland pixels. The extensive areas have lower EVI values during the year, especially in spring and autumn. The pixels are random selected.**

### 3.4.2 DERIVING OF THE FIRST MOWING DATE PER PIXEL

The objective of this part of the research is to identify when a pixel is mowed for the first time in the year, for the four years 2007-2010. The time series of the EVI vegetation index give a representation of the available relative biomass of an area covered by a pixel. This feature of the EVI time series can be used for detection of the mowing management.

The python code of this model can be found in appendix S (8-days time series) or appendix U (16-days time series). In appendix A, the mowing detection takes place at step A2 and D4.

The model takes the EVI 16-days or 8-days time series as input. The range of dates that were used are day 81 (March 22) up to day 209 (July 28). These dates are used, because it is known that the first time of mowing normally takes place between the beginning of April and the beginning or middle July, depending of the weather and the management.

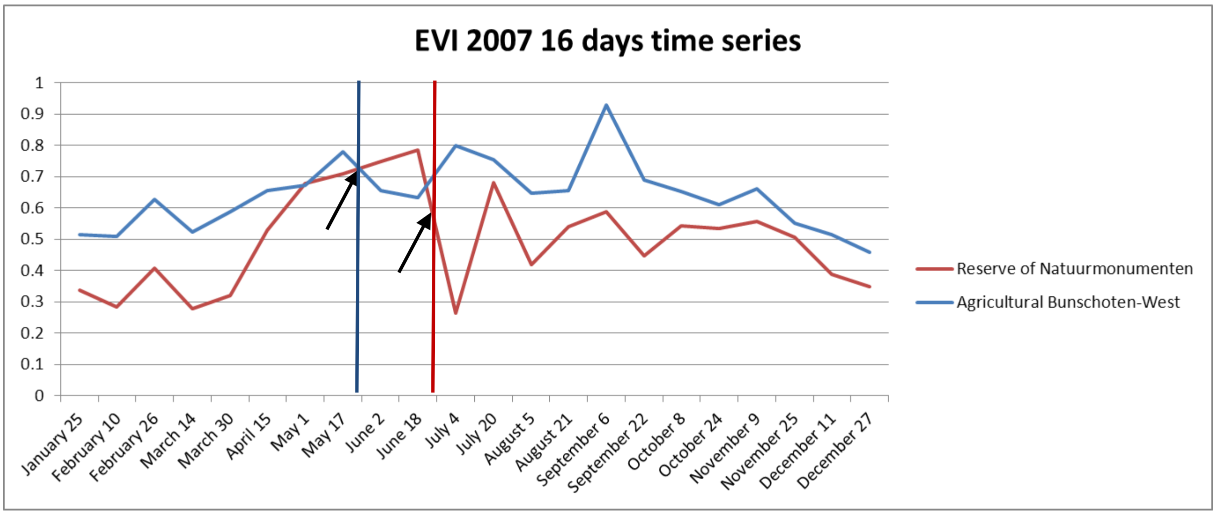



**Figure 9: Graph of the EVI of two pixels with different management intensity. The arrows and lines indicate where it is assumed that the EVI responds to mowing activities. As expected, the extensively managed reserve was mowed later than the intensively managed pixel.**

First, the model compares the different 16-days intervals with each other and creates a new grid with the difference in pixel value, for every two following MODIS EVI dates. For example, when day 81 has a pixel value of 0.47 and day 97 has pixel value 0.53, the difference is 0.06 and positive. It is assumed that an increase of the EVI indicates an increase of biomass. When the EVI trend is negative, it is assumed that there has been mowed (figure 9). For each time step, a difference raster is created, with for every pixel the difference between them. The EVI values can fluctuate through time for the same amount of biomass, caused by for example cloud covering, aerosols, and sensor errors. Therefore, a 'mowing threshold' should be taken into account, to prevent the model of detecting noise in the EVI as mowing activity. When the difference between both EVI values is higher than the mowing threshold, the pixel can be interpreted by the model as mowed. A conditional statement checks if a pixel fulfils the requirement for mowing activity. If this is true, the cell value in the difference raster will be changed to the mean day of the two compared MODIS images. If there is no mowing activity detected at all, the cell value is set to 9999.

This has been processed for every time step, with temporal rasters as result for each 16-days interval for one year. Finally, these rasters are merged to one final raster, representing the first mowing day per pixel. The cell statistics tool in ArcGIS is used for this task. The minimum cell value of the same pixel in all rasters is kept in the final raster, representing the first detected mowing date of that pixel.

Different mowing thresholds have been tested to evaluate how the EVI behaves in relation to the management. This model has used for the 16-days and 8-days EVI time series for the years 2007-2010.

## 3.5 ANALYSIS AND VALIDATION

The methods for analysis and validation are described in this section. In section 3.5.1, the methods for validation of the classification of the management intensity are explained. Section 3.5.2 deals with the method for analysis and validation of the derived first mowing days.

### 3.5.1 CLASSIFICATION OF INTENSIVELY AND EXTENSIVELY MANAGED GRASSLANDS

For both methods (sum EVI year and sum EVI spring), the results have been tested for Arkemheen-Eemland. The resulting summed EVI maps of the year are split up in three different groups of pixels: extensively managed reserves, early mowed intensive agricultural areas, and all remaining pixels with intensive or extensive (unknown) management (figure 7).

The summed EVI of the year and spring of the groups early mowed and late mowed are compared to each other to see if there are significant differences between the groups and between the years. Therefore, in total eight statistical tests are used in SPSS. The used tests depend on the distribution of the data (Laerd Statistics Website). For a few tests, the distribution was normal and an independent-samples t-test could be performed. The other tests have been done with not-normal distributed (skew) data and therefore a Mann Whitney U test was suitable. If there are significant differences between both groups, the p-value should be $<0.05$. However, this is only an indication of the similarity between the groups. Therefore the data is also plotted as bar plots to make the overlap of the data visible. The intensively and extensively managed pixels should be distinguishable by visual interpretation or automatized classification. A large overlap in the summed EVI values makes it impossible for classification between intensively and extensively managed pixels.

### 3.5.2 DERIVING OF THE FIRST MOWING DATE PER PIXEL

For the dataset of the small area with 15 pixels where the real mowing date is known, there is evaluated how well the management can be derived out of the EVI pixel data. This is done for the 16-days and 8-days EVI vegetation index time series. This step gives an idea about the accuracy of the detection of the first mowing date, and what the best value is for the mowing threshold (section 3.4.2). For calculation of the total accuracy for the 15 pixels (table 7), the following formula is used:

$$Accuracy\ \% \ = \frac{Ngood * 100}{Ntot - Nbad}$$

Where Ngood represents the total of good detected pixels with a marge of 10 days, the Ntot is the total amount of pixels (15), and Nnot stands for the total amount of pixels whereof the mowing date is not detected by the model between the end of March and end of July (section 3.4.2).

The next step is to analyse the mowing detection accuracy for Arkemheen-Eemland for the three pixel groups, described in section 3.3. The intensively managed pixels will be mowed earlier than extensive pixels. The extensively mowed pixels are not mowed before June 1 in general. From all grassland pixels with unknown management, it is assumed that most of them are managed intensive and thus that within this group the most frequent mowing date is situated before June 1, at the end of April or in May. Weather data of the KNMI (Koninklijk Nederlands Meteorologisch Instituut) weather station De Bilt, included in appendix L. Monthly weather descriptions are given in appendix M. These data are used to recognise relationships between the detected mowing dates and the weather during spring.

After analysis of the mowing detection in Arkemheen-Eemland, the same has been done for Laag-Holland for validation. Knowledge is acquired if the same mowing threshold is usable for detection of the first mowing date of grasslands in Laag-Holland as well. This can be used as indicator for the application possibilities of the model for other areas in the Netherlands. In Laag-Holland, there are two groups of pixels; extensively managed pixels and pixels with unknown management. The sample sizes can be found in table 4 and the distribution of the pixels are projected on the map in figure 10.

**Table 4: Amount of MODIS pixels with at least 70% grassland coverage, per management type in Laag-Holland.**

| Management/Year | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|
| **Intensive or extensive (unknown management)** | 3765 | 3735 | 3727 | 3645 |
| **Extensive** | 305 | 335 | 343 | 425 |

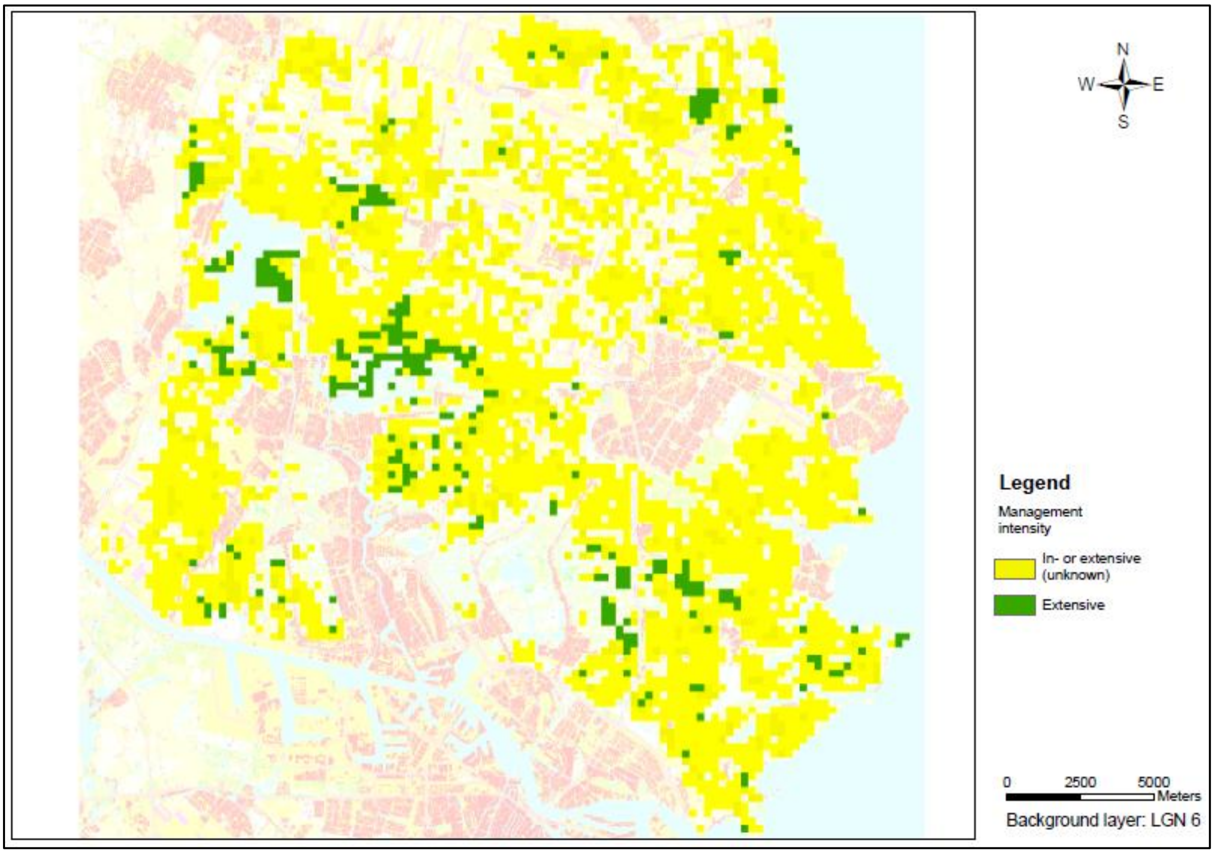



**Figure 10: Distribution of extensively and unknown managed grassland pixels in Laag-Holland in 2007.**

# 4. RESULTS AND ANALYSIS

In this chapter, the results are analysed and explained. This is done for the classification of the management intensity based on the summed EVI over the year and spring in section 4.1. An analysis of the mowing detection can be found in section 4.2.

## 4.1 CLASSIFICATION OF INTENSIVELY AND EXTENSIVELY MANAGED GRASSLANDS

The result of both methods are discussed in this section. Firstly, the results of the summed EVI values of the years are evaluated. In section 4.1.2 the results of the method using only the summed EVI of the spring period is validated.

### 4.1.1 SUM EVI WHOLE YEAR

The EVI vegetation index values of the 16-days time series are summed separately for the years 2007-2010. This has been done for the complete study area Arkemheen-Eemland.

Statistical tests prove that there is a significant difference between the sums of the EVI for groups of pixels with intensively and extensively management (table 5). The results of the tests indicate that the groups are significantly different. However, these tests cannot guarantee that the range of the summed EVI year values have no overlapping values. Therefore, a bar plots is created using SPSS (figure 11). Tabular statistics are included in appendix B. Maps of all years can be found in appendix D, to make visible the spatial behaviour of the summed EVI year values.

The results show that there is an overlap in the summed EVI values for both groups of interest, early mowed and late mowed pixels. For 2007 and 2008, the similarity between both groups is less than in 2009 and 2010. In comparison to the group of pixels where the management is not known (early or late mowed), the early mowed pixels do have a relatively high summed EVI value. The group of late mowed pixels have a relatively low summed EVI value. This confirms the expectations so far.

**Table 5: Results of statistical tests of similarity of the summed EVI year, between the groups intensively and extensively managed pixels. The tests indicate that the groups are significantly different in all years.**

| Year | Used statistical test | Significance |
|---|---|---|
| **2007** | Independent samples t-test | $t = 8.419$, $df = 132$, $p < 0.001$ |
| **2008** | Mann Whitney U | $U = 350$, $N = 148$, $p < 0.001$ |
| **2009** | Independent samples t-test | $t = 4.241$, $df = 149$, $p < 0.001$ |
| **2010** | Mann Whitney U | $U = 353$, $N = 114$, $p < 0.001$ |

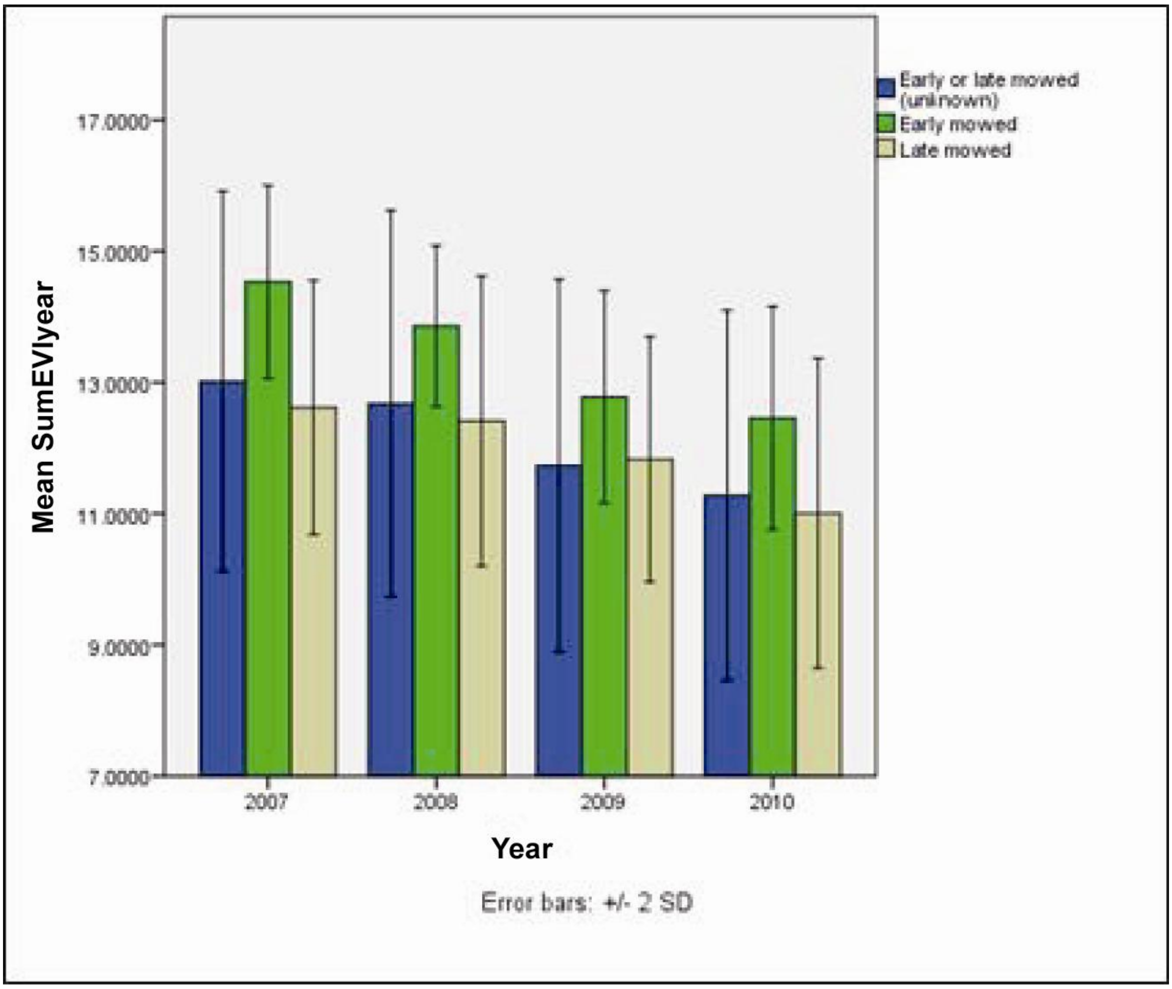



**Figure 11: Bar plot of the differences in summed EVI values for the years 2007-2010, between early and late mowed pixels, with standard deviation error bars. A table with min, max, mean and standard deviation for each group and year is included in appendix B.**

The group of early mowed pixels is represented by the highest summed EVI values for all years (figure 11). The more dense grass vegetation on intensively managed grasslands is reflected by higher EVI values.

Interesting is that the summed EVI values are the highest in 2007, and that this decreases during the next years, with the lowest summed values in 2010. This can be explained by the fact, that in 2007 the spring started with very hot and sunny weather (appendix L and M). For this reason, the grass grew fast, what caused high biomass early in spring and therefore high EVI values. Only some farmers have mowed the grass before the rainy period that started around May 6. During this wet period, farmers were not able to harvest the long grass. Therefore, most of the grasslands were not mowed before the start of this wet period, and could not be mowed before June.

The years 2009 and 2010 have a lower sum of the EVI, and there is more overlap in the EVI value between the intensively and extensively pixels. This is caused by the low temperatures in the spring of 2010. And in 2009, early mowing because of the good weather in spring may have resulted in low EVI values. In a spring that the grass grows slowly, the management between the different grasslands differs not so much, since the grass has not grown enough to be mowed.

However, the data overlap makes classification between intensive and extensive management impossible.

### 4.1.2 SUM EVI ONLY SPRING

The EVI vegetation index values of the 16-days time series are summed for the spring period. This is done for the four years 2007-2010, for the whole study area Arkemheen-Eemland.

Statistical tests proof that there is a significant difference between the groups of pixels with intensively and extensively management (table 6). The results of the tests indicate that the groups are significantly different. However, these tests cannot guarantee that the range of the summed EVI year values have no overlap.

The bar plot in figure 12, table statistics in appendix C and the maps in appendix E show that there is an overlap in the summed EVI spring values for both groups, early mowed and late mowed pixels. In 2008, the similarity between both groups is smaller than for the other years. In comparison to the group of pixels whereof the management is not known (early or late mowed), the early mowed pixels have a relatively high summed EVI spring value, and the late mowed pixels have a relatively low summed EVI value.

The year 2010 has the lowest summed EVI values and the largest data overlap between the groups, which is caused by the cold spring (figure 12 and appendices L and M). The grassland vegetation grew slowly, this is represented by low summed EVI values. The springs of 2008 and 2009 provided good weather conditions for the grass growth and therefore the summed EVI spring values were higher. The data overlap is less than in the other years.
Again, overlaps of the summed EVI values of both groups prevent the possibilities for classification of extensive and intensive managed pixels.

**Table 6: Results of statistical tests of similarity of the summed EVI spring, between the groups intensively and extensively managed pixels. The tests indicate that the groups are significantly different in all years.**

| Year | Used statistical test | Significance |
|---|---|---|
| **2007** | Independent samples t-test | $t = 6.205$, $df = 132$, $p < 0.001$ |
| **2008** | Mann Whitney U | $U = 141$, $N = 148$, $p < 0.001$ |
| **2009** | Mann Whitney U | $U = 544.5$, $N = 151$, $p < 0.001$ |
| **2010** | Mann Whitney U | $U = 548{,}5$, $N = 114$, $p = 0.004$ |

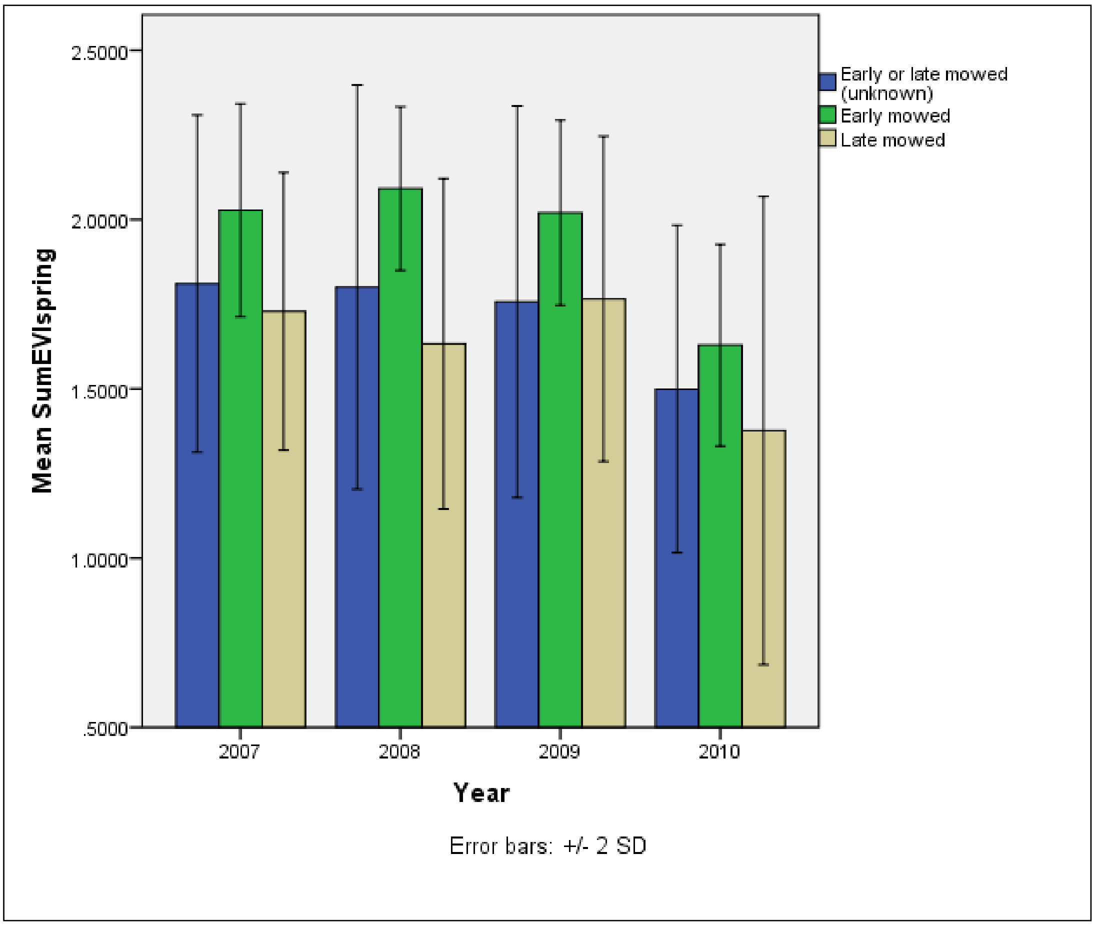



**Figure 12: Bar plot of the differences in summed EVI values for the springs of the years 2007-2010, between early and late mowed pixels, with standard deviation error bars. A table with min, max, mean and standard deviation for each group and year is included in appendix C.**

## 4.2 DERIVING OF THE FIRST MOWING DATE PER PIXEL

This chapter exists of the results and validation of the first mowing day detection model. Firstly, the results of the model are described. The model is validated and calibrated using accurate management data of a small area (4.2.2). Using this calibration, validation is done for Arkemheen-Eemland (4.2.3) and Laag-Holland (4.2.4).

### 4.2.1 DESCRIPTION OF THE MODELLING RESULTS

The model output for each year exists of 250 meter raster images with the detected first mowing day per pixel. The detected first mowing days for 2007 for the study area Arkemheen-Eemland can be found in figure 13. The other years are included in appendix F.

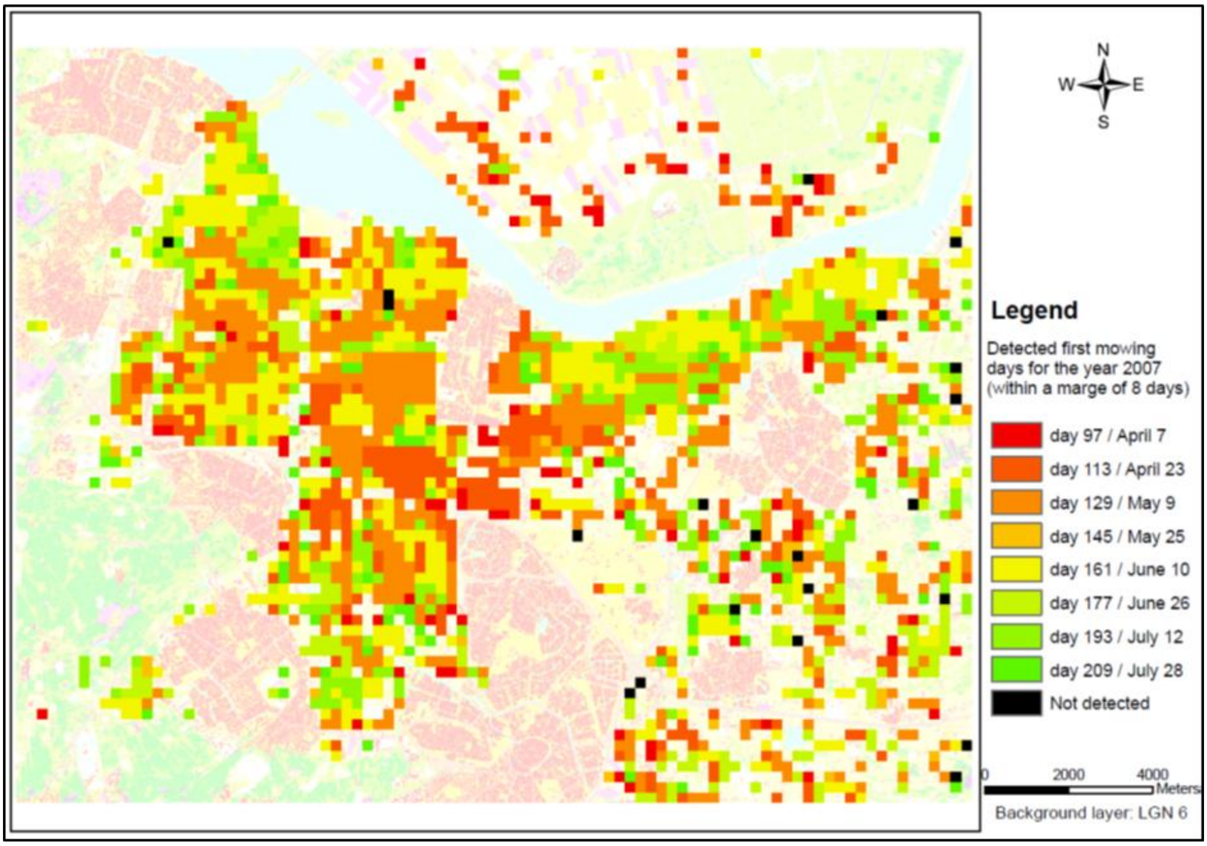



**Figure 13: Detected first mowing dates in 2007 for Arkemheen-Eemland, using a mowing threshold of 0.06. The MODIS EVI 16-days time series are used.**

Figure 13 shows the modelling results of the first mowing dates for Arkemheen-Eemland in 2007. For each cell with at least 70% grassland coverage, the first mowing date is estimated. The difference in management between Eemland (western part) and Arkemheen (eastern part) of this area is visible. Arkemheen was mainly mowed later for the first time than Eemland, what is also described in section 3.1.1.

For further analysis, groups of pixels with distinction between extensive, intensive and unknown management have been analysed. The results of the analysis are described in the next sections.

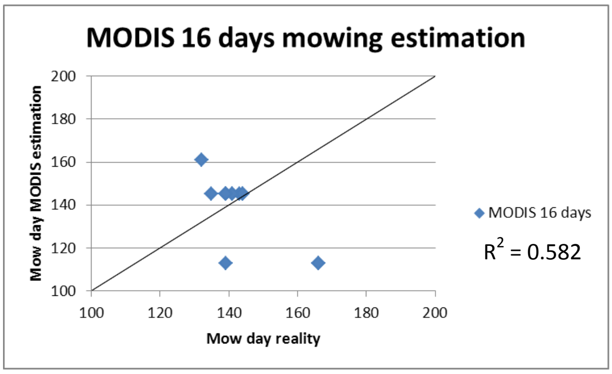
### 4.2.2 DETECTION OF FIRST MOWING DATE FOR 15 PIXELS IN EEMLAND

For the small area in Eemland, the management of 15 pixels is known for the year 2010. The mowing dates are estimated by the model, using the EVI 8-days and 16-days time series. For this estimation, a 10 days uncertainty range has taken into account as reliable between the real mowing date and the estimated mowing date by MODIS. The model has applied with different mowing thresholds. In table 7, the results between both time series have made visible.
The results show that the 16-days time series have a better accuracy than the 8-days time series. This looks a bit strange, especially when taken into account that farmers mow every four weeks and thus the grass grows fast. It appears that noise in the MODIS data prevents to be able to follow the grass growth by the MODIS 8-days time series. With the 16-days time series, the mowing threshold value with the best result is 0.06 and for the 8-days time series, it is 0.07.

With the 8-days time series, the relation between the first mowing day in reality and determined by MODIS is weak with a maximum accuracy of 33.3% (figure 14 and table 7). for the mowing thresholds 0.07 up to 0.12. The 16-days time series show some outliers, but in general, the correlation with the real mowing date fits well by a maximum accuracy of 71.4% and an R2 of 0.582 (table 7).

**Table 7: Mow detection results of 15 pixels in Eemland by 8-days and 16-days EVI time series for different mowing thresholds. The amount of pixels whereof the first mowing day is detected good, wrong and not, with a marge of 10 days between reality and MODIS.**

| Mowing threshold | 8 days time series pixel detection | | | | 16 days time series pixel detection | | | |
|---|---|---|---|---|---|---|---|---|
| | Good detected | Wrong detected | Not detected | Accuracy (%) | Good detected | Wrong detected | Not detected | Accuracy (%) |
| **0.02** | unknown | unknown | unknown | unknown | 8 | 7 | 0 | 53.3 |
| **0.03** | unknown | unknown | unknown | unknown | 8 | 7 | 0 | 53.3 |
| **0.04** | unknown | unknown | unknown | unknown | 8 | 7 | 0 | 53.3 |
| **0.05** | 2 | 13 | 0 | 13.3 | 10 | 5 | 0 | 66.7 |
| **0.06** | 4 | 11 | 0 | 26.7 | **10** | **4** | **1** | **71.4** |
| **0.07** | **5** | **10** | **0** | **33.3** | 8 | 6 | 1 | 57.1 |
| **0.08** | 5 | 10 | 0 | 33.3 | 6 | 6 | 3 | 50.0 |
| **0.09** | 5 | 10 | 0 | 33.3 | 6 | 6 | 3 | 50.0 |
| **0.10** | 5 | 10 | 0 | 33.3 | 6 | 6 | 3 | 50.0 |
| **0.11** | 5 | 10 | 0 | 33.3 | 6 | 6 | 3 | 50.0 |
| **0.12** | 5 | 10 | 0 | 33.3 | 4 | 7 | 4 | 36.4 |
| **0.13** | 4 | 11 | 0 | 26.7 | unknown | unknown | unknown | unknown |
| **0.14** | 4 | 11 | 0 | 26.7 | unknown | unknown | unknown | unknown |
| **0.15** | 4 | 9 | 1 | 28.6 | unknown | unknown | unknown | unknown |



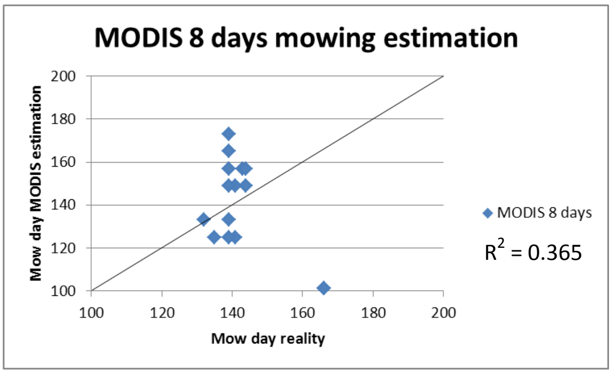



**Figure 14: Relation between real mowing day and the estimated mowing day, detected by the 16-days and 8-days time series with most reliable mowing threshold (16-days = 0.06 and 8-days = 0.07).**

### 4.2.3 DETECTION OF THE FIRST MOWING DATE IN ARKEMHEEN-EEMLAND

Accuracy assessment has been implemented for 15 pixels for which reference data was available. The results of the small area in Eemland give insights in the accuracy of the detection of the first mowing date. The 8-days time series appears to be not very accurate in detection of the first mowing date. Because of the better accuracy, only the 16-days time series are used further. The next step of the analysis was to investigate the accuracy of the model for the complete study area Arkemheen-Eemland as well.
The PSAN/SNL validation data gives no information about the real mowing date, but only gives information of the date up to when mowing is not permitted. Thus, if the by the model determined mowing date lies after this date, it is assumed that the date represents the real mowing date. For more intensively managed grasslands, an earlier first mowing date should be found in springs with normal weather. For the group of pixels with unknown management, it is expected that most of them have a relatively intensive management. Because the PSAN/SNL validation data is less accurate than the management data of the 15 pixels in Eemland, the mowing threshold of 0.06 has used for the analysis of the data initially. Only the 16-days time series have been used further, because of the low classification accuracy of the 8-days EVI time series.

In figure 15, the graphs show which percentage of the pixels has mowed for the first time at the corresponding day of the year. For determining the accuracy of the model, the graphs in figure 15 and the maps in appendix F are used.

The weather during spring strongly affects the grass growth. In cold springs, the grass grows slow and therefore the intensively managed grasslands have a late first mowing date as well. In mild, but wet springs, the farmers are only able to harvest the fast growing grass if they have some days after each other with dry weather. So in springs with much rain or low temperatures, the difference in management intensity between intensive and extensive farmers is smaller than in years with a lot of sun and high temperatures. If the model is accurate this should be visible in the results of the model.

The spring of 2007 started very mild and sunny, but around May 6 (day 126) a period with a lot of precipitation started. Some farmers managed to mow the grass before the rain, although most parcels were not mowed before the rain started to fall. This wet period lasted till June (day 152). In the graph of figure 15, this weather influence is visible in the derived first mowing dates. From the groups of intensive management and the group of all pixels with unknown management (intensive or extensive), a part has been mowed before day 129 (May 9). After that, during the next 16 days there is (almost) no mowing detected, represented by the flat line in the graph. After this 16-days period, the amount of mowed pixels increased. Remarkable is that in comparison to other years, a relatively high amount of pixels has been mowed after day 193 (July 12). June was very wet and thus farmers were not able to mow before the end of June. For this year the results fit with the weather.

In 2008, the spring started with exceptionally mild and wet weather. The second half of March (day 75-91) was colder with some snow, resulting locally in a snow layer. April (day 61-90) was on the cold side but sunny, with little precipitation. In the graph of 2008 at day 97 (April 6) a part of the pixels was already mowed, which is strange because of the weather conditions. It seems that there is another factor responsible for mowing detection than mowing itself between day 81 (March 21) and 97 (April 6). Meteorological data proved that a local snow layer (figure 16) caused the underestimation of the model.

Mild weather dominated the spring of 2009. The grass growth started early and because of the good weather conditions, farmers were able to mow early. The graph of 2009 indicates this good weather conditions as well. For around 70% of the grassland pixels, a mowing date around April 23 is detected.

In the year 2010 the spring was very cold, even in May the grass was still very short (Van ‘t Veer *et al.* 2011). Therefore there was no large management difference between the intensive and extensive farmers. This can be found in the graph in figure 15 as well. The map with the mowing dates per pixel in 2010 shows relatively much pixels, with an underestimation of the mowing date and contains compared to other years a lot of pixels of which the mowing date is not detected. The map with the detected mowing dates in 2010 (appendix F) shows relative many errors, for example pixels with a first mowing day of around April 15. It is assumed that this is too early for this year, because of the cold spring. In comparison to the other years, there are more pixels of which the first mowing date could not be detected. This cannot be explained with available meteorological data.

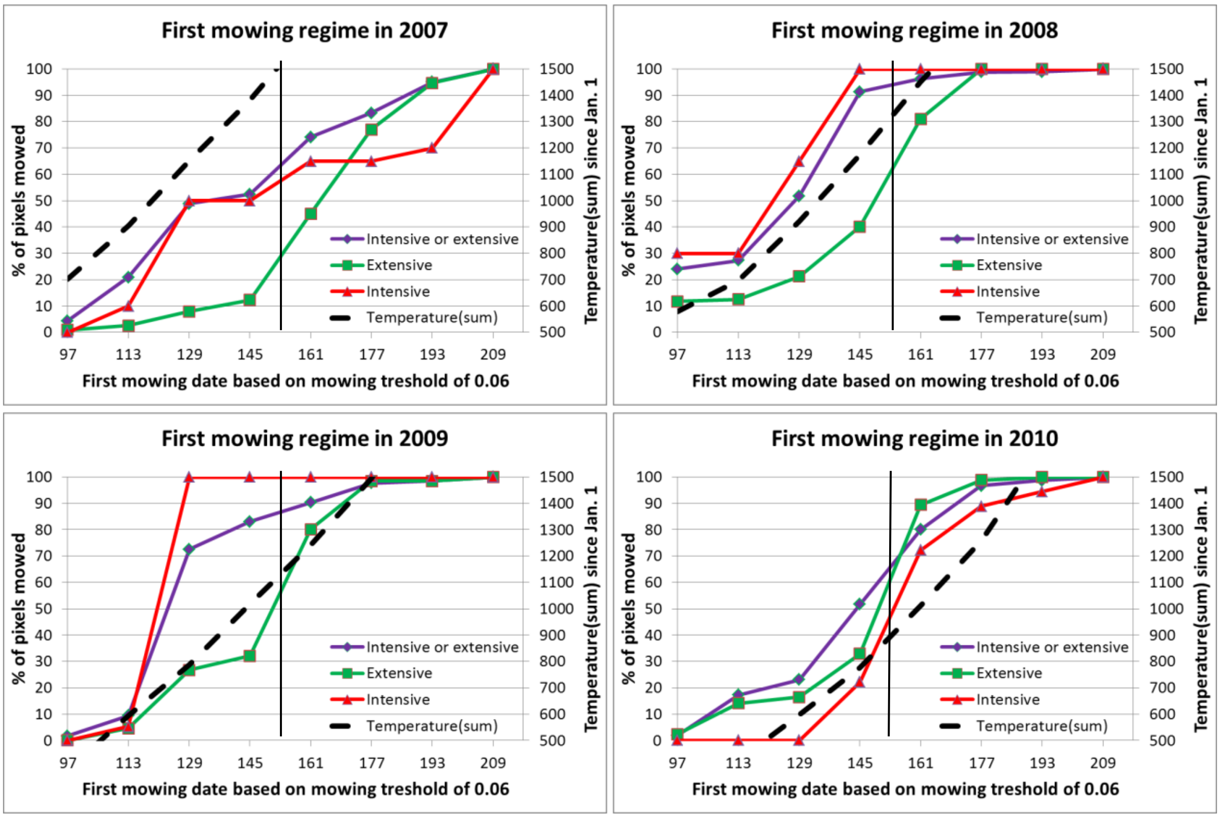



**Figure 15: Cumulative representation of the by the model detected first mowing days of the grassland pixels, for the groups intensive or extensive (unknown), extensive and intensive grassland management in Arkemheen-Eemland. The vertical black lines indicate June 1.**

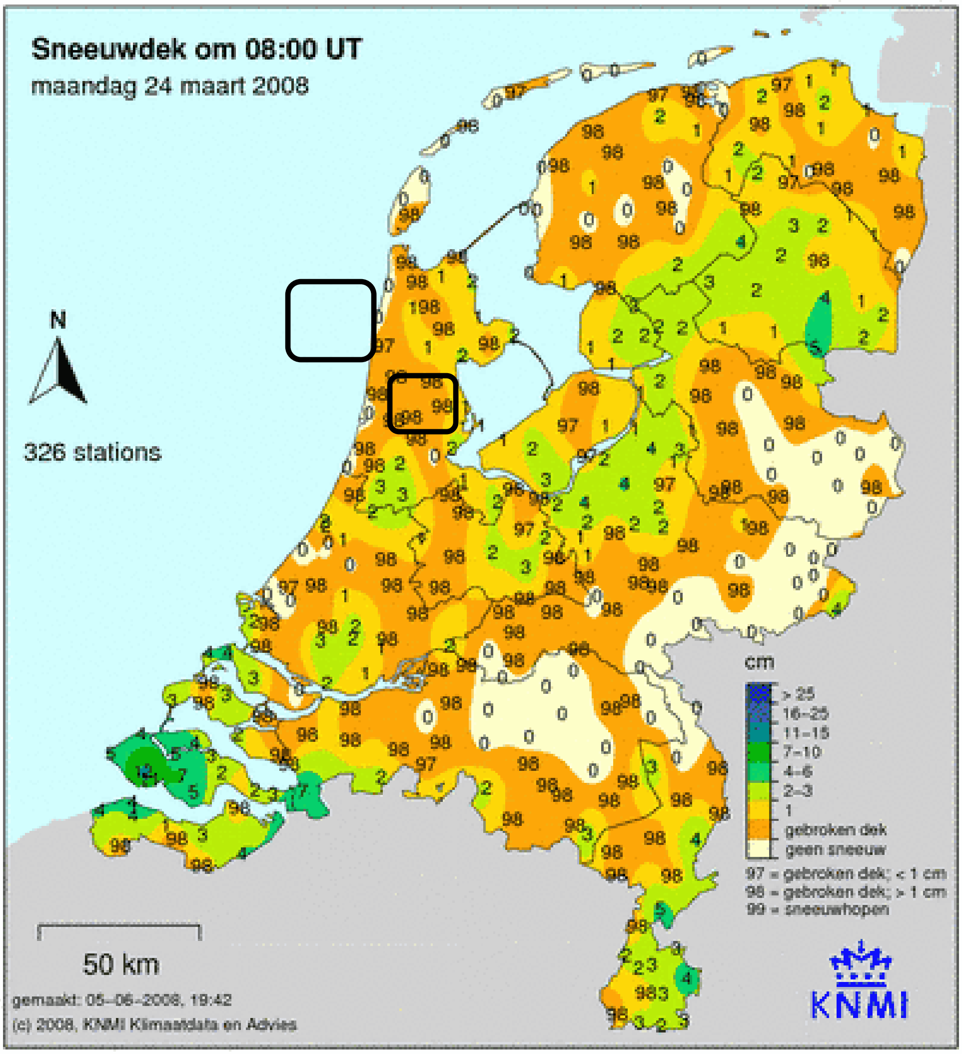



**Figure 16: A snow layer covers the Netherlands at March 24 in 2008 (source KNMI). The area at the Eastside is Arkemheen-Eemland, the western area is Laag-Holland.**

Overall, the graphs in figure 16 show that 30-40% of the extensively managed pixels mowed before June 1. In appendix G maps with the spatial distribution of the erroneously estimated pixels are presented. It is interesting to see, that there are some pixels which are erroneously estimated every year and that most of them are situated separately from other extensively managed pixels. Further analysis shows that most of these pixels are covered for 70-80% by extensively managed parcels. Thus up to 30% of the pixel may have been mowed earlier than June 1, what can be the reason of the 'wrong' estimation.

The summed daily temperature is normally an indicator for the percentage of mowed agricultural grassland area. When the summed temperature meets 890 degrees Celsius, around 50% of the grasslands are mowed, although variations between areas occur (Kleijn *et al.* 2009 and Schekkerman *et al.* 2008). The results in figure 15 show, that in 2007 only 20% of the group pixels with intensive or extensive management was mowed. This can be linked to the rainy weather that made mowing impossible. For the other years, the mowed percentage around the day with a temperature sum of 890 degrees lies with 50% (2008) and 65% (2010) around the expectations. Very nice weather can be an explanation of 75% mowed grasslands in 2009, around the day with the temperature sum of 890 degrees.

Concluded can be that the model is accurate in detection of the first mowing days in Arkemheen-Eemland.

## 4.2.4 DETECTION OF THE FIRST MOWING DATE IN LAAG-HOLLAND

The results of Arkemheen-Eemland show, that there is a correlation between the weather and the derived first mowing dates. The model is validated for Laag-Holland as well, using the same mowing threshold of 0.06. Maps of the results can be found in appendix H.

Figure 17 shows the graphs of the derived first mowing date in the years 2007-2010 for the study area Laag-Holland. Remarkable is that the graphs of Laag-Holland are not very different as for Arkemheen-Eemland (figure 15). This indicates that the model is applicable to other areas in the Netherlands as well.

However, there are some interesting differences between the graphs of both study areas.
For the year 2007, the wet period between day 129 and 145 is visible in the graph of Arkemheen-Eemland and not in the graph of Laag-Holland. The reason of this is unknown, but may be related to small differences in weather- or terrain conditions in Laag-Holland, resulting in mowing activity during the wet period. Clear is, that in both areas around 50% of the pixels with intensive or extensive (unknown) management were mowed around day 129.
For 2008, the graphs between both areas have the same shape. As well as for Arkemheen-Eemland, the graphs start not at 0% mowed pixels, caused by the snow cover as described in section 4.2.3.
In the year 2009, the weather during spring was good for farmers; mowing was possible early in spring. This can be found in the graphs of both areas. The shape of the graphs of the area Laag-Holland fits with the shape of Arkemheen-Eemland.

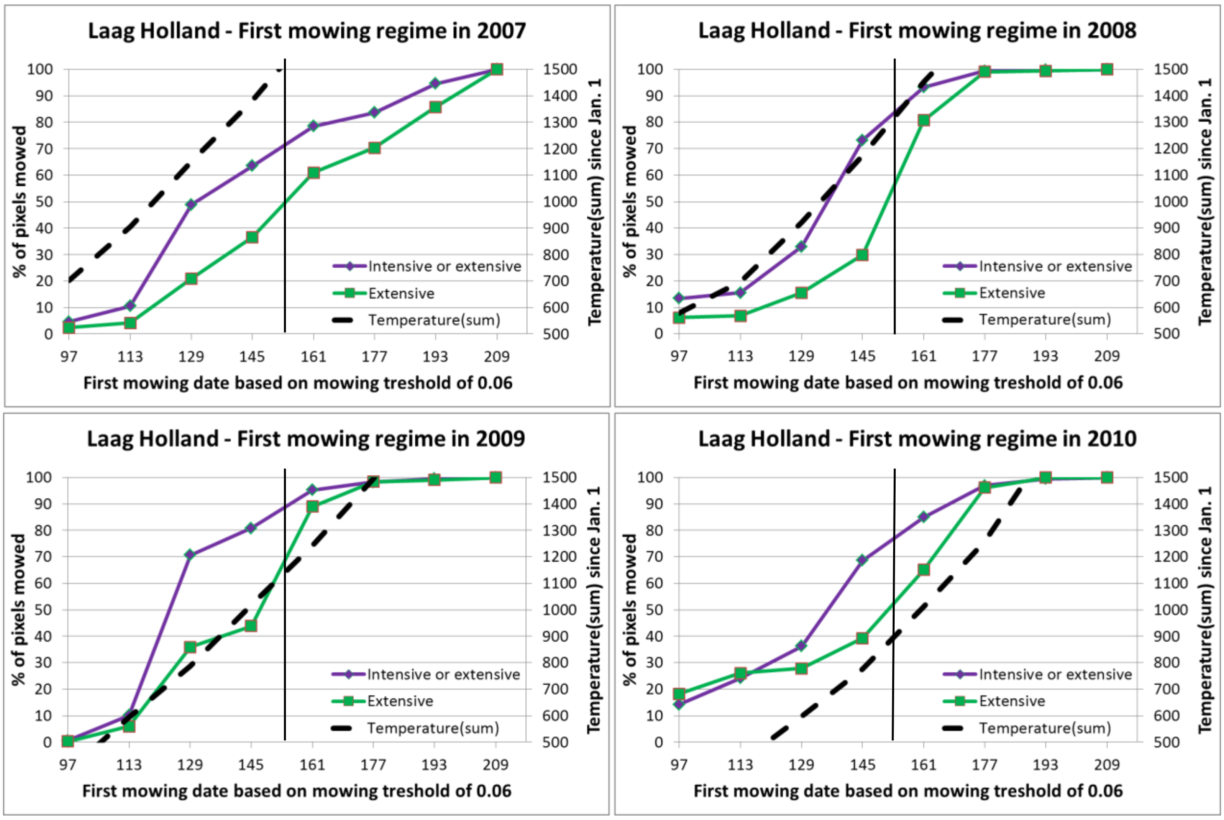



**Figure 17: Cumulative representation of the by the model detected first mowing days of the grassland pixels, for the groups intensive or extensive (unknown) and extensive grassland management in Laag-Holland. The vertical black lines indicate June 1.**

The spring of 2010 was very cold in Laag-Holland too, resulting in less mowing difference between intensively and extensively areas. The graphs of both areas look similar. Remarkable is, that the percentages of the mowed pixels in Laag-Holland are around 20% already at day 97. The reason may be explainable by an increase of surface water area, causing lower EVI values. Water is more abundant in Laag-Holland than in Arkemheen-Eemland. It is not known if there was a snow cover in that period.

Around the day with the temperature sum of 890 degrees Celsius, respectively 60%, 30%, 75% and 75% of the grassland area with unknown management was mowed in 2007-2010. These values lie around or above the expected 50%, but are in general comparable to Arkemheen-Eemland. Only 2007 shows a large difference in the mowed percentage. In Arkemheen, 20% was already mowed and in Laag-Holland 60%. This may be explained by differences between the areas.

# 5. DISCUSSION

In this chapter, the methodology and results are discussed in a broader perspective. Firstly, section 5.1 discusses the classification between intensively and extensively managed grasslands. Section 5.2 describes the causes of wrong first mowing day estimation. In section 5.3, the influences of the spatial and temporal resolution is described. Section 5.4 discusses the used validation data. The applicability of the model for deriving the first mowing days is described in section 5.5. Section 5.6 announces a new satellite system.

## 5.1 CLASSIFICATION OF INTENSIVELY AND EXTENSIVELY MANAGED GRASSLANDS

The results of the classification between the intensive and extensive managed pixels have been analysed in section 4.1. Based on the maps in appendices D and E and the bar plots in figures 11 and 12, it is not possible to classify a random pixel to one of the groups, because of overlapping data. Although statistical tests shows that there is a significant difference between the groups. This can be explained by the fact that the used statistical tests did not take data overlap into account. The used independent samples t-test (or Student's T-test) and Mann Whitney U test, are more sensitive for the equality of the means of both variables of interest. In this case the intensively and extensively mowed pixels. Both tests have been applied for detection of group differences in many fields of research (Laerd Statistics Website, Blaze Statistics Website).

There are more factors that influenced the summed EVI values. For the summed EVI of the year the mowing management led to underestimation of the total biomass, because of the removal of the grassland biomass. This may be a cause of low summed EVI year values in the group pixels with intensive management. Further improvement of this method seems possible, by taking the sums of the EVI declines which are caused by mowing. Pixels with a high sum have intensive management and the pixels with lower summed EVI are lower.

The summed EVI spring was calculated, based on the period before the mowing season started. The idea was that the summed EVI of this period performs better than the summed EVI of the whole year. But the results showed that the summed EVI spring of both groups have overlapping values as well. It is again not sure why this occurs. Effects caused by winter weather (snow, ice) in the early spring (March) or influence of high surface water levels can be an explanation for the data overlap. Thereby, the EVI value is a representation of the average EVI of the whole pixel. Other land uses within the pixel with a low EVI, for example water, bare soil or roads, cause a lower EVI even when the grasslands contain relatively high biomass what can be linked to intensive grasslands.

An alternative is to make use of the model for estimation of the first mowing days. The detection of the first mowing days performed well (section 4.2 and 5.3.2). The results of the mowing detection can be used for classification of intensive and extensive managed pixels. The extensively managed areas are covered by pixels with an average estimated mowing date of at least June 1. For calculation of an average mowing day per pixel, the years with good weather and large differences in first mowing day between intensively and extensively managed areas can be used. Then it is possible to distinguish the extensively managed parcels from the intensive ones. From the year range 2007-2010, the years 2007, 2008 and 2009 may suitable to do this. The weather in spring 2010 was cold and the results were less accurate than the other years (section 4.2.3 and 4.2.4).

## 5.2 DERIVING OF THE FIRST MOWING DATE PER PIXEL

The results of the first mowing date estimation showed that the patterns of the results are feasible. The graphs in figures 15 and 17 show, that the extensively managed pixels have later mowing dates than the intensively managed pixels and the pixels with unknown management. Also, the patterns caused by weather conditions are visible. However, there are some errors in the estimations. The caused are discussed in the next sections.

### 5.2.1 INFLUENCE OF MODIS COMPOSITING

The pixels with known management situated near Eemdijk are presented in figure 6. From four of these pixels, the estimation of the first mowing day was not correct. There are a few explanations for this.

The 16-days EVI vegetation index time series are based on the best daily MODIS sensor measurement(s) during the 16-days period. Using a compositing algorithm, a single EVI value for the 16-days interval is calculated. The composite algorithm selects the sample(s) with the best viewing angle (closest to 0 degree) and minimal atmospheric noise as possible. But the EVI values itself are not weighted in this algorithm. Therefore the used samples can be given by any day of the 16-days interval (Solano *et al.* 2010).
This compositing influences the deriving of the first mowing dates, as illustrated in figure 18. The 'real' EVI graph shows the EVI of the grassland vegetation through time, with two mowing moments around four weeks after each other. The green graph shows the MODIS EVI compositing result, with good mowing detection. The used EVI days are situated near the EVI peaks, caused by the high amount of biomass just before the mowing, and just after the drops of the EVI caused by mowing. The red graph shows an example of a wrong estimation of the first mowing detection. Because of the used EVI value of the day just before the first mowing moment and the fast regrowth of the vegetation before the used EVI of the day in the next 16-days interval, the first mowing is not detected (line is almost straight). The second mowing moment is detectable by a significant drop of the EVI and day 161 is defined as the first mowing day, instead of day 129.

The graphs in figure 18 show an extreme example of wrong first mowing date estimation. The simulated management is intensive with a mowing interval of four weeks. The simulated 16-days composted EVI values are based on the 'wrong' days for an accurate estimation of the first mowing day. It is not likely that this occurs often, but it is possible. A part of the wrong mowing estimations can be explained by this principle. For example, wrong detection 3 in appendix N.
Figure 18 gives an example of accurate mowing detection as well. The composed EVI values are representing the highest and lowest EVI values of both the composition interval and the mowing interval. With these values, the first mowing day can be estimated accurately with an uncertainty of maximum 8 days (half the composition interval). It is assumed that most first mowing days were derived based on EVI values that were composited in a way between both extremes simulated in figure 18.

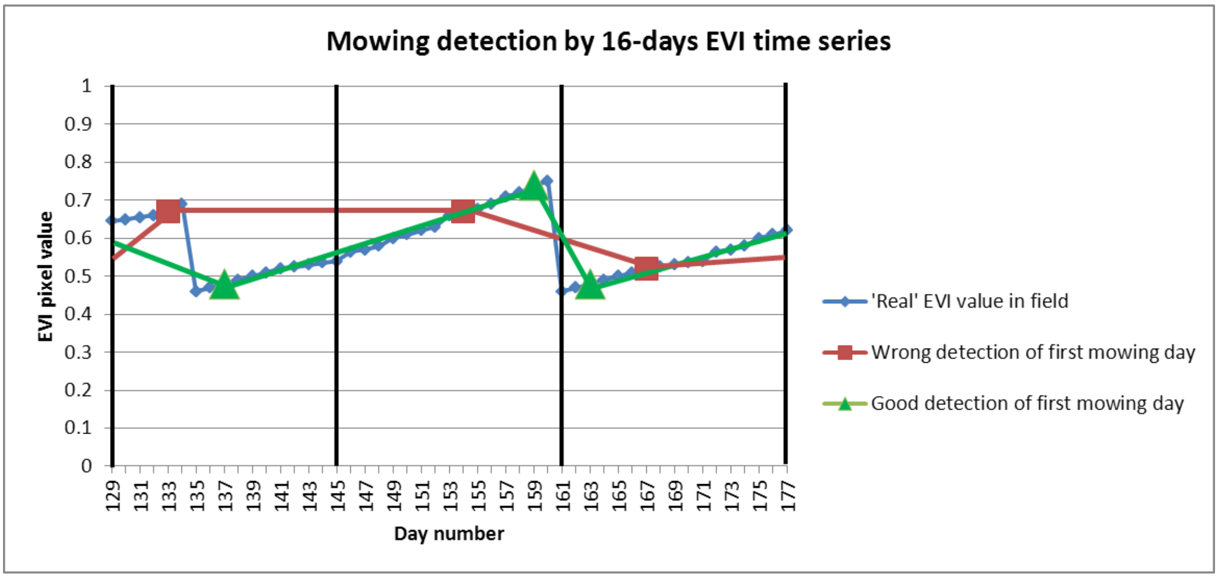



**Figure 18: Bad and good mowing detection using MODIS EVI 16-days time series. The vertical black lines indicate the 16-days compositing intervals. The 'real' EVI graph is simulated to give an impression how the 16-days compositing affects the mowing detection, but is based on a mowing interval of four weeks, what is also detected in the real management data.**

### 5.2.2 WEATHER INFLUENCE

An (interrupted) snow cover at the end of March caused an underestimation in the detection of the first mowing day in 2008 (section 4.2.3 and 4.2.4). The model should be modified to give realistic results of the first mowing dates in years with snow in the spring as well if possible. Therefore research is done to the decline of the EVI caused by snow, in relation to the decline of the EVI caused by mowing. Only the pixels were used which had a snow layer in 2008 represented by a derived mowing day of 97, and a detected mowing day of 129 in 2009. The sample size consists out of 299 pixels that fulfilled both requirements. In figure 19, the used pixels can be found.

Figure 20 shows that the decline of the EVI as reaction on a (interrupted) snow layer is almost similar as the decline of the EVI caused by mowing activity. Therefore it makes no sense to use a higher mowing threshold or to set a maximum threshold for the EVI decline that must be used for mowing detection. The only way to prevent the model from detecting a snow layer as a mowing date is to use another EVI image date as first starting date of the model. This can be solved to use not day 81, but day 97 as starting day for 2009. This has no influence on the accuracy of the mowing detection. Snow mostly falls in colder springs, when the grass grows slow and therefore the first mowing takes place later in the season in general.

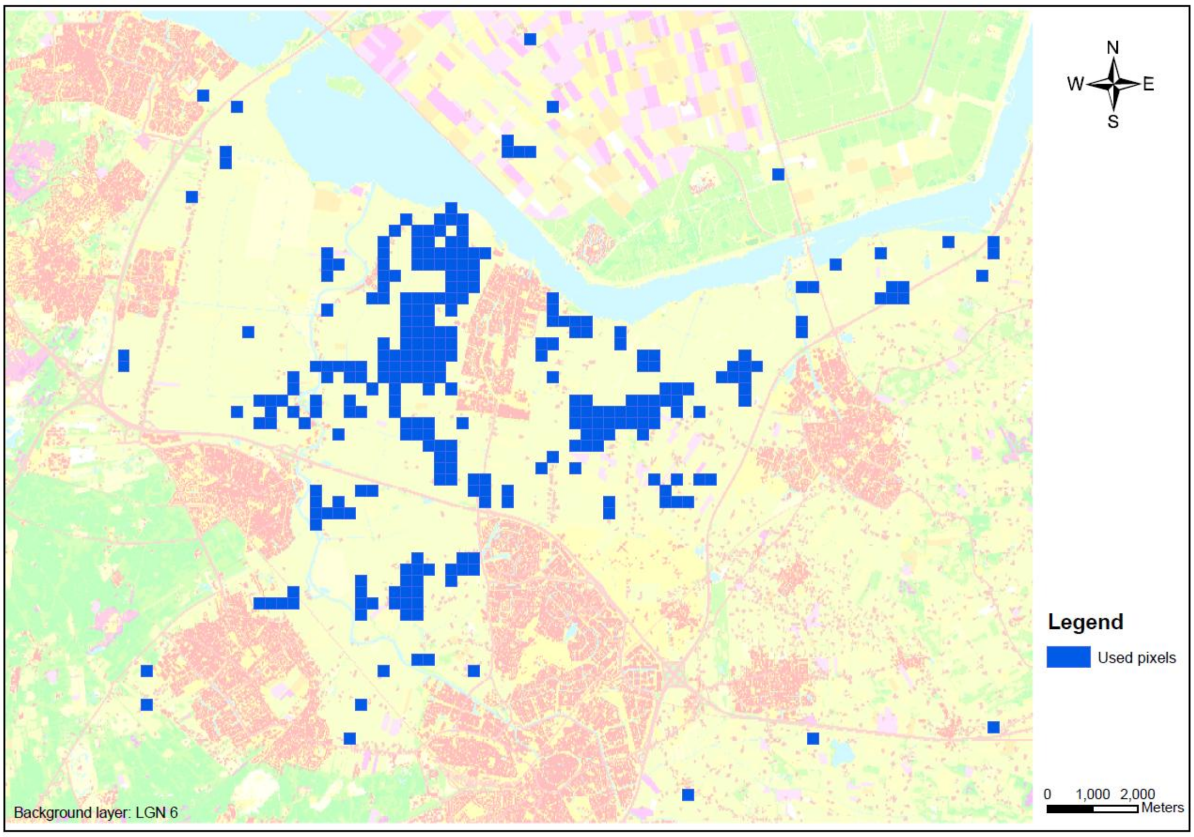



**Figure 19: Distribution of the pixels used for determining the EVI decline caused by a snow cover and mowing in spring, in the study area Arkemheen-Eemland.**

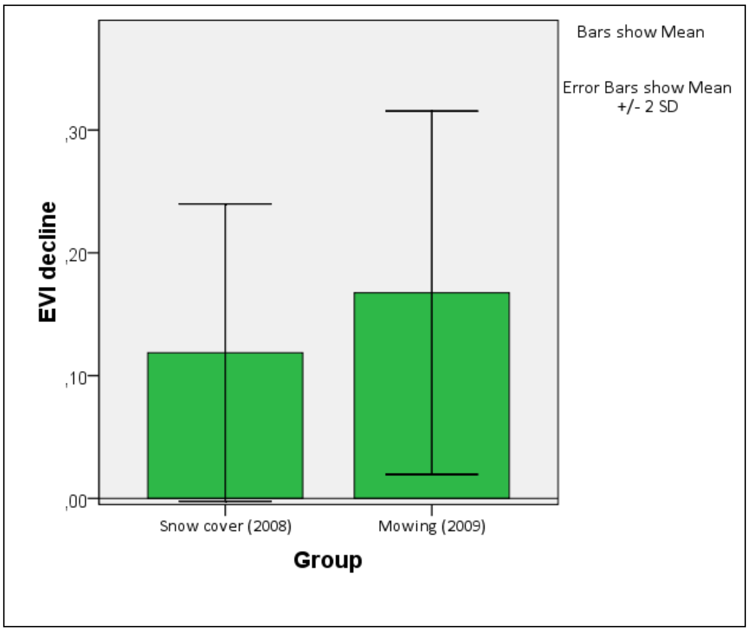



**Figure 20: Difference of the EVI decline caused by a snow cover (2008) and mowing activity (2009) for the same pixels in the study area Arkemheen-Eemland. Sample size = 299.**

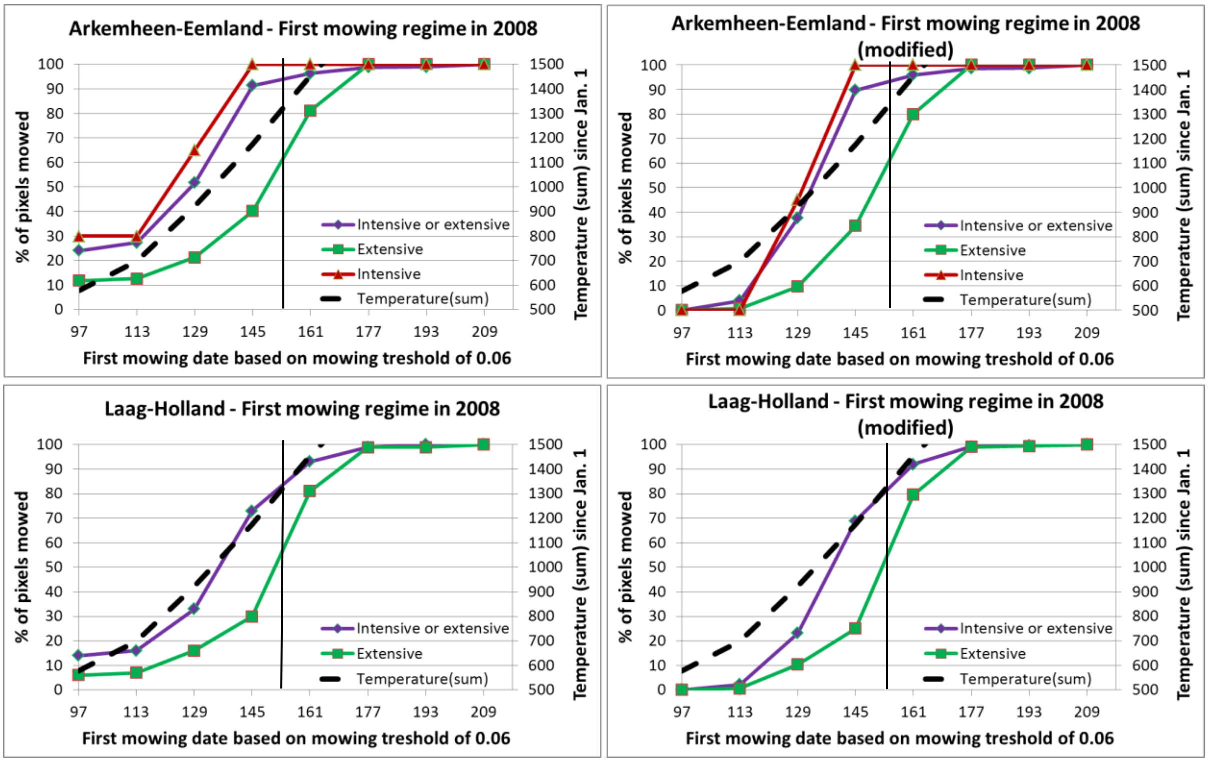



**Figure 21: First mowing detection results before and after the model modification for both study areas for the years 2007-2010. The vertical black lines indicate June 1.**

The modelling results of the old and modified model can be found in figure 21 and the belonging maps in appendices I and J. The graphs start at 0 and the maps show some differences in mowing dates. On the maps, it seems that the approximation of the mowing date is more in relation with the weather circumstances in both areas.

### 5.2.3 OTHER CAUSES OF EVI ERRORS

The graphs of the wrong estimated first mowing days of the pixels 1,2 and 4 with known management in appendix N show some strange EVI peaks and drops that are not explainable by the management or the available weather data. This could be the effect of cloud contamination in the remote sensing signal.

## 5.3 MODIS SPATIAL AND TEMPORAL RESOLUTION

The spatial resolution of 250 meter and the 16-days composition interval had influences on the results. This is discussed in the next sections for the classification of intensive and extensive management and the estimated first mowing days.

### 5.3.1 CLASSIFICATION OF INTENSIVELY AND EXTENSIVELY MANAGED GRASSLANDS

The spatial resolution of 250 meter restricts the possibility of defining the management intensity for every single parcel. The results proved that there is a significant difference between intensively and extensively managed pixels, but the range of the pixel values are overlapping (section 4.1). This means that classification of extensive and intensive managed areas is not possible. Causes of this can be the mowing management, where biomass is removed at high productive parcels more often and earlier in the season than at natural grasslands where mowing doesn’t happen before June 1. This makes the EVI values more equal between both groups.

An additional problem was that the pixels were not homogeneous in case of the land use. All pixels with at least 70% grassland coverage have been used for the classification. The EVI values are influenced by other land uses (roads, buildings, bare soil, water etc.) which lead to a lower EVI pixel value than the grasslands within the pixel. An option could be to investigate if the method can be improved using a higher minimum grassland coverage for the used pixels, or correction of the EVI based on the area of other land uses within the pixel.

The temporal resolution was less important for this classification than deriving the mowing days, what comes more precisely because of the mowing interval of four weeks (section 5.3.2). The accuracy of the EVI values of the 16-days composed time series were reliable for mowing detection. Assumed is that this was the same for the classification of the grassland management intensity.

### 5.3.2 DETECTION OF FIRST MOWING DAYS

The spatial resolution had a large influence on the detection accuracy of the first mowing date. In appendix O an overview is given of the management of the area Waterland-Oost, situated in Laag-Holland northeast of Amsterdam, including the land use (LGN 6) and the by MODIS derived first mowing days. The spatial resolution appears to be too large for a good estimation at parcel level, but roughly the extensive areas are detected. The eastern part of the area has more not-mowed parcels at the end of May and that can be found back in the management data. The northern and western part contains more parcels with intensive grazing and already mowed parcels. This is visible in the estimated mowing dates as well. However, the results are on such small-scale not usable caused by the spatial resolution.
Sometimes grazing is detected as mowing, what can be caused by the spatial and temporal resolution, and it could also be that the grazing intensity on the parcels have influence as well. The validation data lacks detailed management information about grazing for further analysis of this event. Although intensive grazing has negative influences to meadow birds as well (Terwan *et al.* 2002). For this reason, it is fine when grazing is detected as mowing. It doesn't counteract the usefulness of the results. Only the term 'first mowing day' could better changed to 'first management activities' if grazing is detected as mowing at large scale.

The temporal interval of 16 days appears to be sometimes too long for very accurate mowing detection, but it is likely that the spatial resolution gives more estimation errors. This is proven by the fact that the 16-days time series are more accurate in mowing detection than the 8-days EVI time series.
The results in section 4.2.2 showed that the 16-days composed EVI time series is more accurate than the 8-days EVI time series (manually created). The 8-days composed single band reflection values, used as input for calculation of the EVI (section 3.2) contain more noise than the 16-days composited EVI time series, because of the applied algorithms for correction of atmospheric influences (Solano *et al.* 2010) and the longer time interval. The 8-day and 16-day EVI time series of the same pixel are presented in figure 22 to give an impression. The 8-days time series have more noise (peaks and downs) than the 16-days time series. The challenge during this research was to split the EVI declines caused by noise from the EVI declines induced by mowing activity, using a so-called mowing threshold (section 3.4.2). Because of the noise in the 8-days EVI, the declines were the same and therefore not distinguishable, resulting in low accuracies (table 7). Because of the more smooth results of the 16-days EVI time series (figure 22), erroneous EVI values occur less and the mowing is better detectable. This indicates also, that a satellite has to overpass frequently (daily) to create accurate time series that are usable for mowing detection, taking into account that grassland mowing takes place every four weeks on intensively high-productive grasslands.

There are daily time series available from MODIS as well, since the Terra satellite overpasses daily. This data can also be used for detection of the first mowing dates. Even though many samples are not usable because of cloud cover or other disturbances, it is possible to filter out the noisy samples using quality control data of MODIS. These data can be downloaded together with the MODIS reflection data. During times with nice weather, the mowing detection may be more accurately detectable than with the used 16-days EVI time series. However, the data processing will take much more time than using the 16-days time series, which can be used directly after downloading.

Another option to increase the temporal resolution, is to make use of the Aqua satellite as well. Like the Terra satellite, the Aqua satellite has a MODIS sensor aboard and the same MODIS time series are available from this satellite. The 16-days EVI time series has an interval that starts 8 days later than the Terra-satellite's interval. This means, that both time series may be combinable to get accurate EVI time series with an interval of 8 days. Although some difficulties may occur when combining the data, because it is unknown which day the 16-days composed EVI value represents. Also, the overpassing time of the Aqua satellite is around 5 PM and the Terra overpasses just before midday. For the Terra satellite, the sun position is different than for the data collection of the Aqua satellite. This may give differences in EVI values between the satellites as well, as the reflection of light to the satellite is influenced by the position of the sun. Therefore this option has some drawbacks.

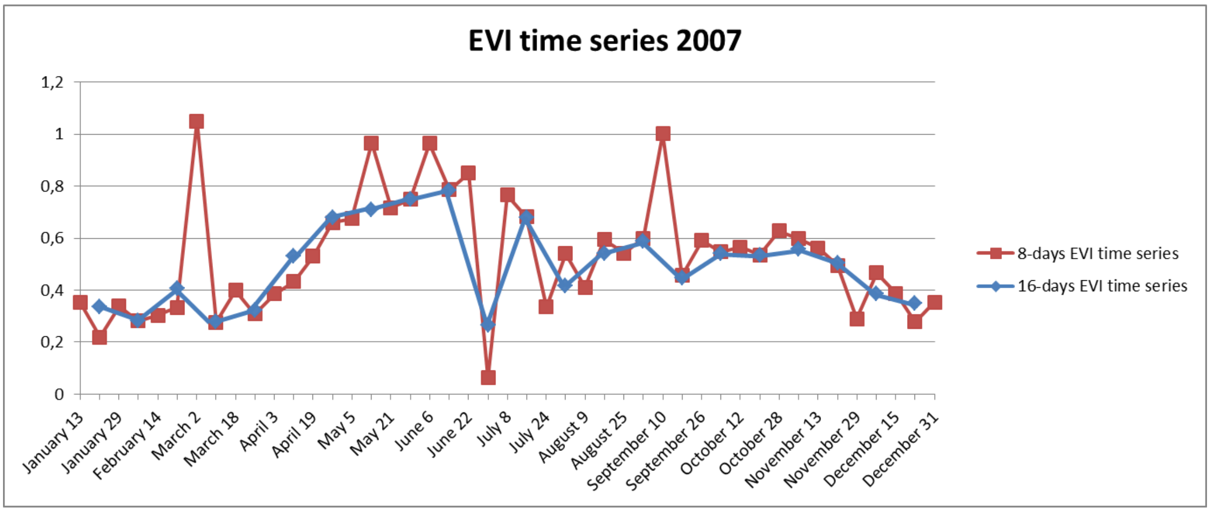



**Figure 22: Comparison between the 16-days and 8-days EVI time series of an extensively managed pixel. It is clear that the 16-days time series is more smooth, what makes it better suitable for mowing detection.**

## 5.4 VALIDATION DATA

Initially the plan was to use other validation data, that was available for a larger part of The Netherlands. This dataset, called GIAB (Geographic Information Agricultural Businesses), provides information about the amount of cattle of the farm, and the soil properties of the farm divided in grasslands and arable lands. There is experimented with this data to use it for calculation of a so-called grassland pressure. That had to be an estimation of the land use intensity of the farm and could be linked to the parcels. The next step was to use this information for validation of the summed EVI and the detected first mowing date. Unfortunately the data did not not represent the real management intensities due to a lack if information. Thereby all parcels of a farm became the same management intensity, although it is commonly known that parcels further away of the farm have a lower management intensity than the grasslands behind the stable. The quantity of used concentrates is unknown either, what could have a large impact on the real management intensity of a farm. Therefore the PSAN/SNL management data is used for validation, combined with weather descriptions for validation of inter-year differences of first mowing days. The PSAN/SNL data is available from a lower amount of parcels, but more suitable than GIAB because of the higher reliability.

The sample sizes of the validation of the methodology were very small (table 3 and table 4). In Arkemheen, the amount of extensive pixels was around 4% of the total pixels. For the pixels with intensive management, it was only 1%. In the study area Laag-Holland, extensively managed pixels cover around 10% of the total, but there are no extensively managed pixels used as for Arkemheen-Eemland. Therefore, some uncertainty about the best suitable mowing threshold remains. The methodology should be validated for the whole Netherlands to get more accurate information if the methodology is applicable to the whole Netherlands using the same mowing threshold.

Selection of the best performing mowing threshold for detection of extensive grasslands can be done by visual interpretation at local level if no validation data is available. From nature reserves it is known that the first mowing activities don't take place before June 1. The best fitting mowing threshold can be selected by eye, although it must be taken into account that the patterns of the mowing dates should reflect to the weather during spring.

In section 4.2.3, it is explained that the distribution of erroneously detected pixels in Arkemheen-Eemland appears to be located at the isolated extensively managed pixels (appendix G). This is a weakness of the validation. The use of single parcels with extensive management packages mainly performed poorly for isolated parcels, because of the spatial resolution of 250 meters. This may have influenced the estimation of the accuracy of the mowing detection negatively, what means that the model may be more accurate than the results show. This can also be explained by the fact that the MODIS EVI is very sensitive for vegetation changes, what was experienced during other studies as well (Cheng 2006, and Kawamuraa et al. 2005). The validation data contains also a few parcels with PSAN management packages 4235/4245. This are parcels which are managed in a way to increase the herbaceous species-richness, for providing herbaceous-rich vegetation for meadow birds. Around 25-30% of these pixels may have been mowed earlier than June 1. This may have affected the accuracies of the analysis negatively, although the mowing activity was detected well.

## 5.5 APPLICATION OF THE METHODOLOGY TO OTHER AREAS

The estimated first mowing days are validated for two study areas. There are two areas used for first mowing day detection. Based on the mowing detection in Arkemheen-Eemland, the best performing mowing threshold was derived based on a small test area in Eemland (section 4.2.2) and then applied to Arkemheen-Eemland (section 4.2.3). The results were analysed and compared to the weather conditions. Patterns caused by the weather were visible in the derived mowing dates. Using the same model settings, the first mowing days of Laag-Holland were derived as well (section 4.2.4). The result of this validation shows, that the first mowing date was detectable with respectable results.

The results of Laag-Holland showed that the model is valid for detection of the first mowing day in other areas than Arkemheen-Eemland. This means, that the model is applicable to other areas in The Netherlands as well. However, it is uncertain if the model gives reliable output for all areas of The Netherlands. The model was applied to whole The Netherlands, these national maps are included in appendix K. The results should be validated for other areas as well to give insights in the use of the mowing threshold. It is not unthinkable that different areas need a slightly different mowing threshold. This can only be investigated using more detailed management data, with accurate mowing dates.

## 5.6 FUTURE DEVELOPMENTS

As part of the GMES (Global Monitoring for Environment and Security) project of the ESA (European Space Agency), two Sentinel-2 satellites will be launched in 2012. The spatial resolution will be 20 meters and the revisiting time of The Netherlands is 2-3 days. Data will be collected of 13 spectral bands, covering the visible, near-infrared and short-wave infrared (443-2190 nm). These satellites will make use of 3 bands for atmospheric corrections. The satellite imagery of the Sentinel satellites will become available for free (ESA Website).

These satellites seems to be useful to improve the detection of the grassland management. Especially the spatial resolution of 20m is superior to the resolution of MODIS (250m). With a pixel size of 20 meters, it could be possible to detect the first mowing dates at parcel level. On forehand, Landsat imagery can be used to investigate if a higher resolution improves the accuracy of the first mowing day detection. Then the model can be directly applied to the Sentinel data when the data becomes available.

The Dutch government will set up a national satellite database for stimulation of the use of satellite data in 2012. In this database, satellite imagery will be stored that can freely be used for development, implementation and validation of methods using satellite imagery. For this project, the government has 4 million euro available (Ministry of EL&I Website).

# 6. CONCLUSION AND RECOMMENDATIONS

This chapter contains the conclusions and recommendations. The research questions are answered in the conclusion. The recommendations describe possibilities for further improvement of the methodology in future.

## 6.1 CONCLUSIONS

The aim of this study was to develop a remote sensing methodology for detection of the grassland management intensity and first mowing days in The Netherlands. Based on literature study (chapter 2) usable satellite imagery data products and validation data were selected. 16-days and 8-days MODIS EVI vegetation index time series with a spatial resolution of 250 meter were used. Two models were developed for detection of the grassland management. The first model was developed to classify the management intensity. Another model was developed for detection of the first mowing dates. Both models used EVI time series of the years 2007-2010. Only those pixels with at least 70% grassland coverage were used in this research. The study included two areas, Arkemheen-Eemland and Laag-Holland.

The model developed for estimation of the first mowing dates provided accurate detection of the first mowing day. The model was first calibrated for a small area covering 15 MODIS pixels. The result showed that the 8-days time series was less accurate (33,3%) than the 16-days time series (71,4%), although the sample size was very small. The model was validated for Arkemheen-Eemland and Laag-Holland thereafter. The weather differences between the years were visible in the derived mowing days for both areas. The pixels covering intensive managed parcels were mowed earlier than the pixels with extensive management. In the years with good weather, providing fast grass growth and early mowing activities, the difference between the mowing dates of both groups was larger. The spring of 2010 was cold and the grass grew very slow. The first mowing days of extensive and intensive managed pixels were more equal. There was a lack of exact mowing data for validation. The use of weather data performed well, although there still remains some uncertainty in the results.

The model for classification of intensively and extensively was applied to Arkemheen-Eemland. The summed EVI values of the years and the spring periods were calculated. Statistical tests proved, that the group differences between both groups of pixels were significant ($p<0.005$) for all years. However, the summed EVI values of both groups had overlapping values. Therefore it was not possible to classify the management intensity based on the summed EVI values. The model for estimation of the first mowing dates performed well. Classification can be done using the estimated first mowing dates. Extensively managed areas are detectable using the first mowing days of the years with a larger management difference between intensively and extensively managed areas. This means, that only the data of the years with high grass productivity is usable. For the years 2007-2010, only the year of 2010 is not suitable because of the cold spring period and therefore small differences in management intensity. Calculation of the average mowing day per pixel gives an idea which areas were mowed later than others. These areas are more suitable for meadow birds. This method should be validated in future.

Validation of the derived first mowing dates for Arkemheen-Eemland and Laag-Holland indicated that the model is applicable to other areas. The results were comparable. However, this doesn’t guarantee that the method is usable for accurate detection of the first mowing dates for whole The Netherlands. Validation of other areas using exact mowing data should estimate if the model is applicable on large scale without adjustments.

## 6.2 RECOMMENDATIONS

- The model should be validated using mowing data with exact mowing dates for other areas to estimate if the model has the same accuracy for different areas;

- Identify the extensively managed areas using the estimated first mowing days. This can be done by calculation of the average mowing day per pixel for the years 2007-2010. Validation is possible using exact mowing dates or meadow bird data;

- Test if the accuracy of the model for detection of the first mowing day can be improved by using daily observation data of MODIS;

- Make use of Landsat data to estimate if a higher spatial resolution leads to a better estimation of the first mowing day at parcel level;

- Improve the model for detection of the first mowing day so that it can be applied to the data of Sentinel 2. This satellite will be launched by the ESA in 2013 and will have a spatial resolution of 20 meter.

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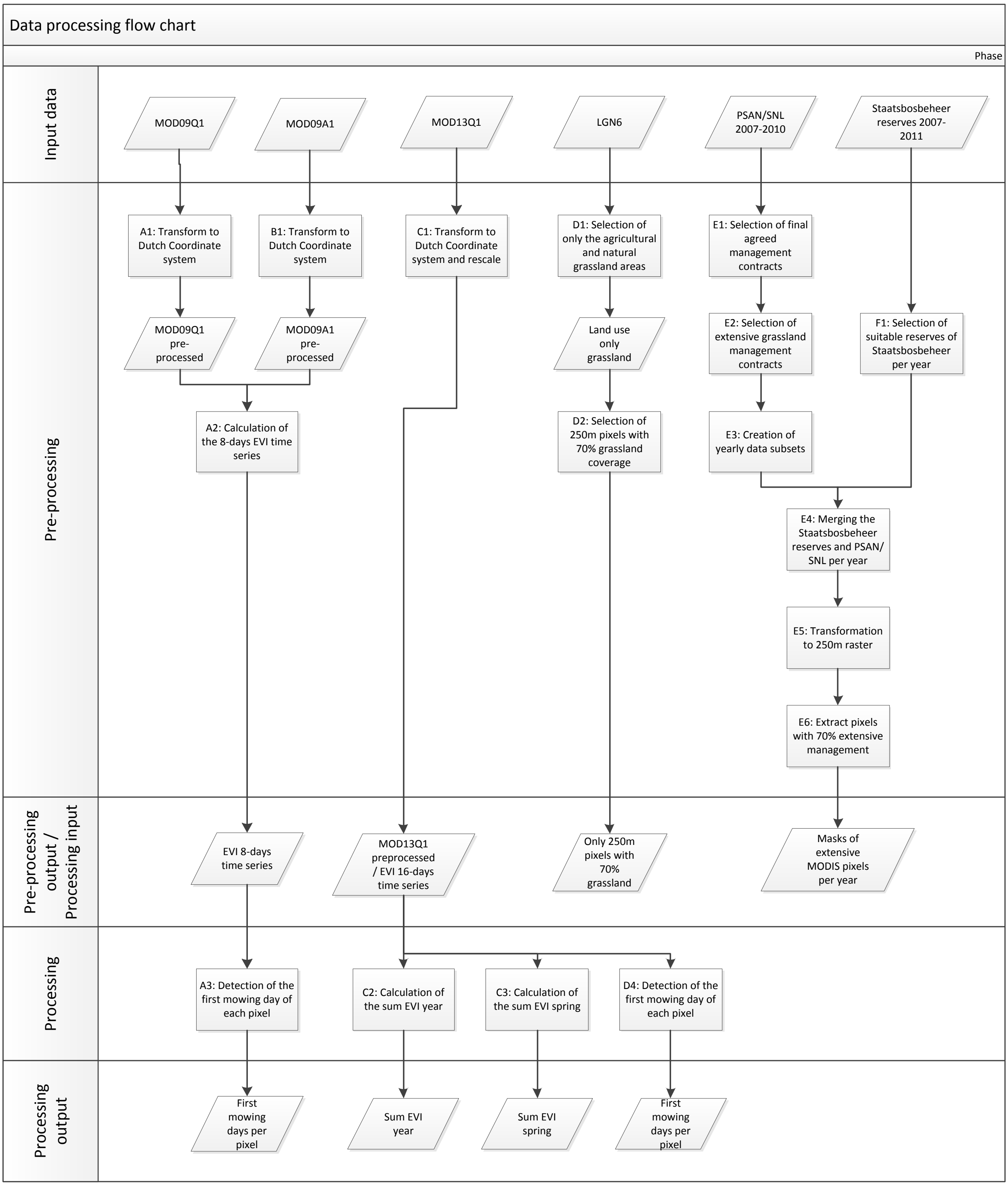
# APPENDIX A: FLOW CHART OF THE METHODOLOGY



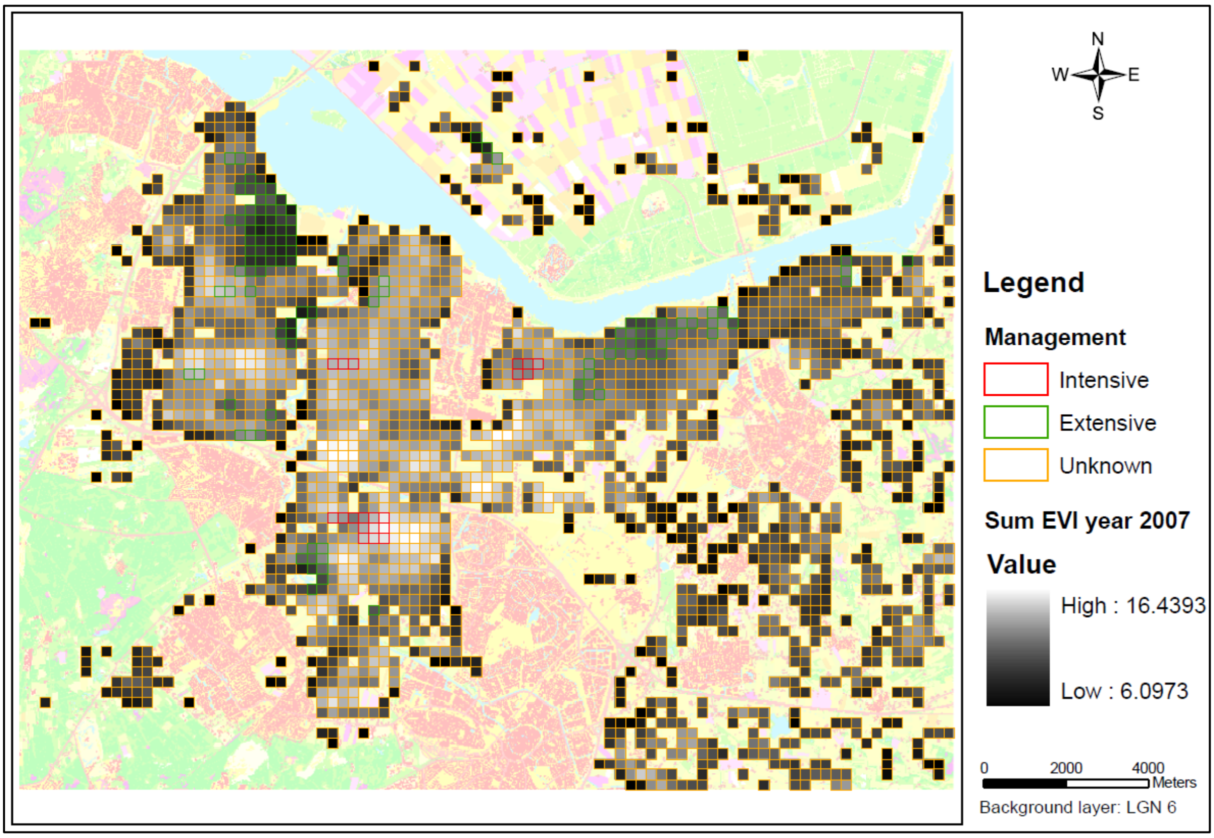
## APPENDIX B: TABLE WITH RESULTS OF THE SUMEVI YEAR ARKEMHEEN

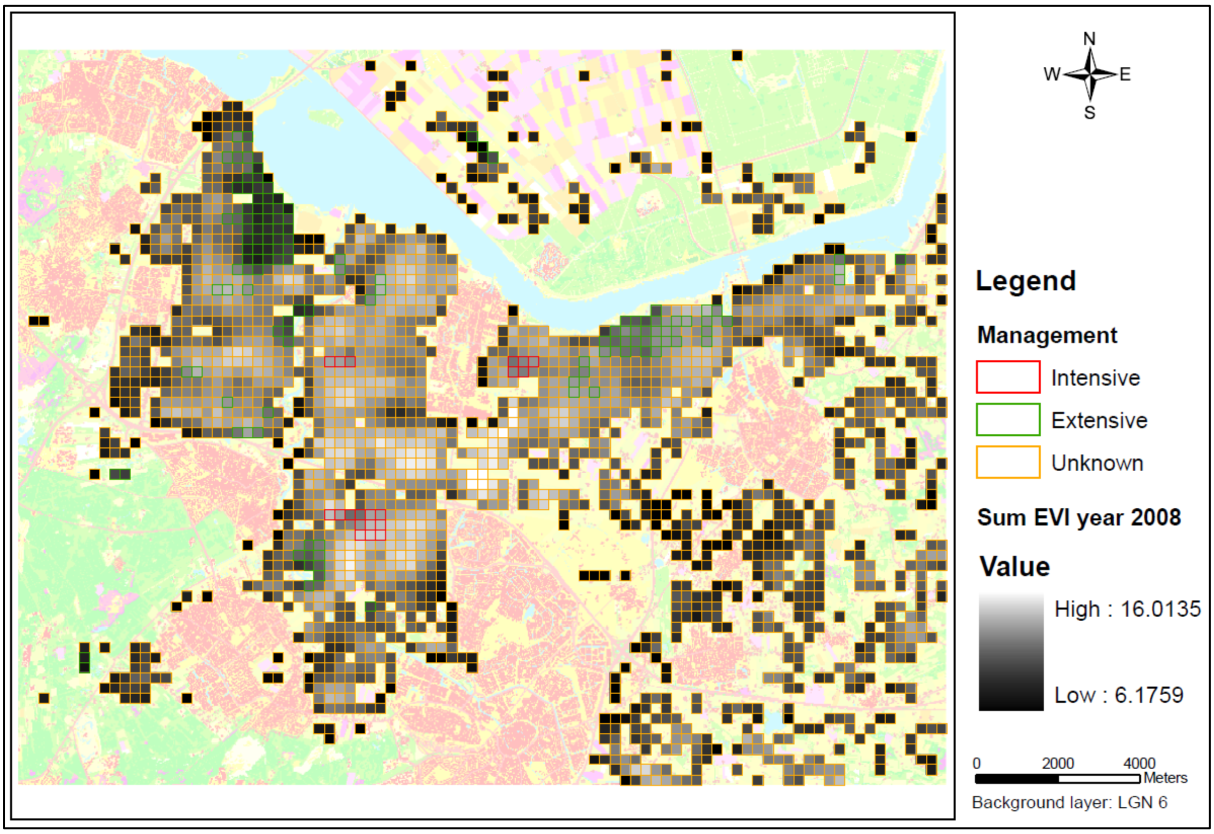
| | | Early mowed | Late mowed | Early or late mowed |
|---|---|---|---|---|
| 2007 | min | 13.3306 | 10.7687 | 6.0973 |
| | max | 15.7789 | 14.9842 | 16.4393 |
| | mean | 14.5338 | 12.6176 | 13.0165 |
| | stdev | 0.7348 | 0.969 | 1.4512 |
| | | | | |
| 2008 | min | 12.8763 | 9.729 | 6.1759 |
| | max | 14.7768 | 14.4219 | 16.0135 |
| | mean | 13.8598 | 12.4115 | 12.6774 |
| | stdev | 0.6133 | 1.1055 | 1.4714 |
| | | | | |
| 2009 | min | 11.6403 | 10.0178 | 3.6312 |
| | max | 14.1597 | 13.966 | 14.8655 |
| | mean | 12.7775 | 11.8279 | 11.7308 |
| | stdev | 0.8111 | 0.9344 | 1.4206 |
| | | | | |
| 2010 | min | 11.3283 | 8.7342 | 3.4624 |
| | max | 14.0392 | 13.2256 | 14.794 |
| | mean | 12.4551 | 11.0064 | 11.2772 |
| | stdev | 0.8501 | 0.9344 | 1.4093 |

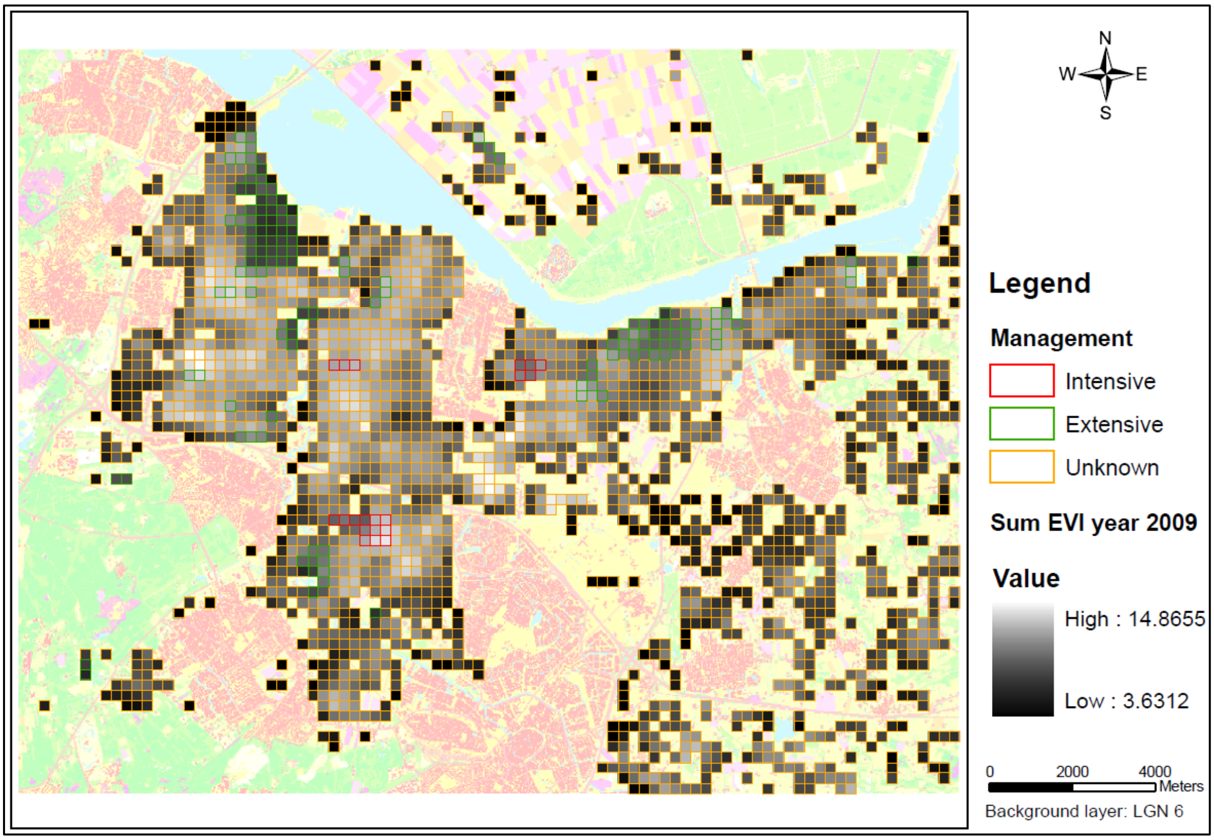
## APPENDIX C: TABLE WITH RESULTS OF THE SUMEVI SPRING ARKEMHEEN

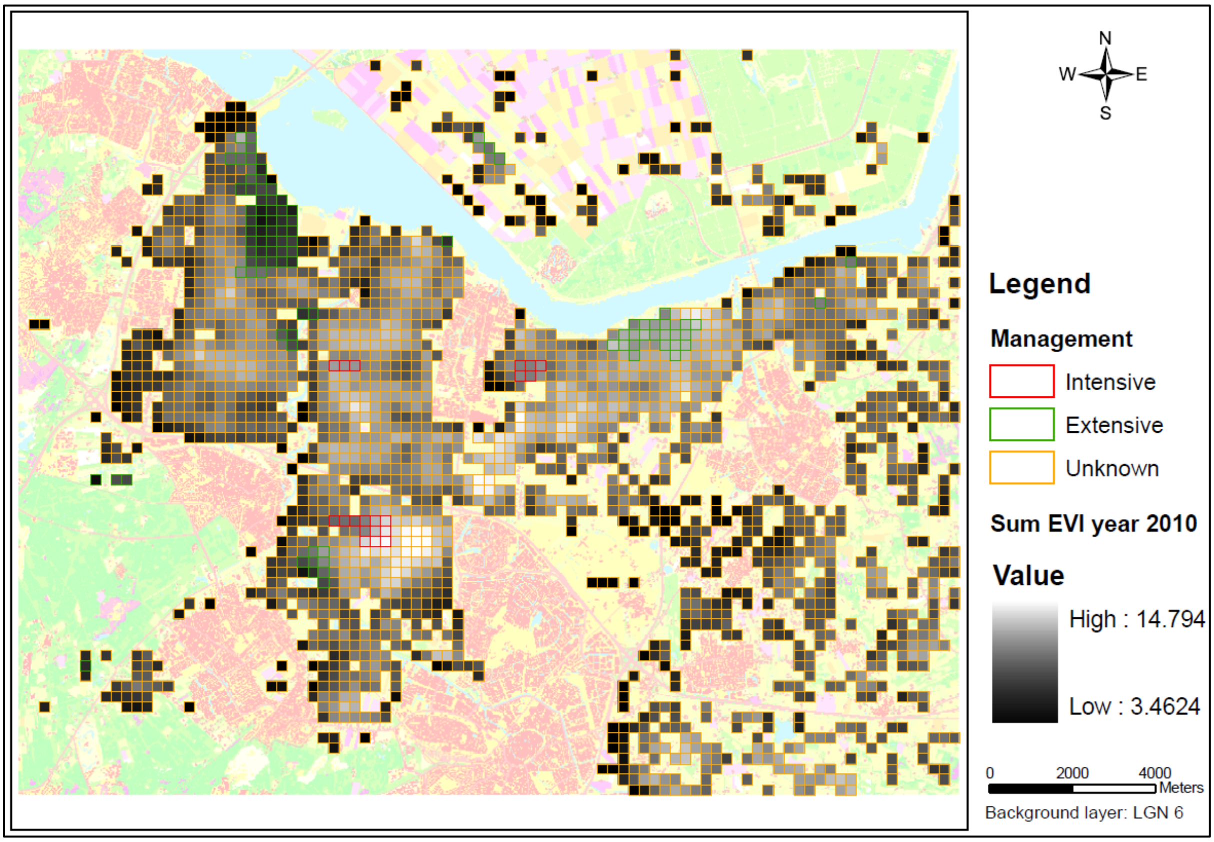
| | | Early mowed | Late mowed | Early or late mowed |
|---|---|---|---|---|
| 2007 | min | 1.7108 | 1.2703 | 0.4256 |
| | max | 2.2826 | 2.1243 | 2.3731 |
| | mean | 2.0279 | 1.7286 | 1.8106 |
| | stdev | 0.1572 | 0.2051 | 0.2489 |
| | | | | |
| 2008 | min | 1.878 | 1.2275 | 0.8347 |
| | max | 2.2799 | 2.1383 | 2.5497 |
| | mean | 2.0915 | 1.633 | 1.8005 |
| | stdev | 0.1209 | 0.2442 | 0.2984 |
| | | | | |
| 2009 | min | 1.8058 | 1.2817 | 0.3893 |
| | max | 2.2285 | 2.2347 | 2.4024 |
| | mean | 2.02 | 1.7655 | 1.7572 |
| | stdev | 0.1366 | 0.2403 | 0.2892 |
| | | | | |
| 2010 | min | 1.4706 | 0.7811 | 0.4148 |
| | max | 1.8992 | 2.0627 | 2.1998 |
| | mean | 1.6289 | 1.3764 | 1.4992 |
| | stdev | 0.1489 | 0.3458 | 0.2417 |

## APPENDIX D: MAPS OF ARKEMHEEN-EEMLAND WITH THE SUMMED EVI FOR THE YEARS 2007-2010

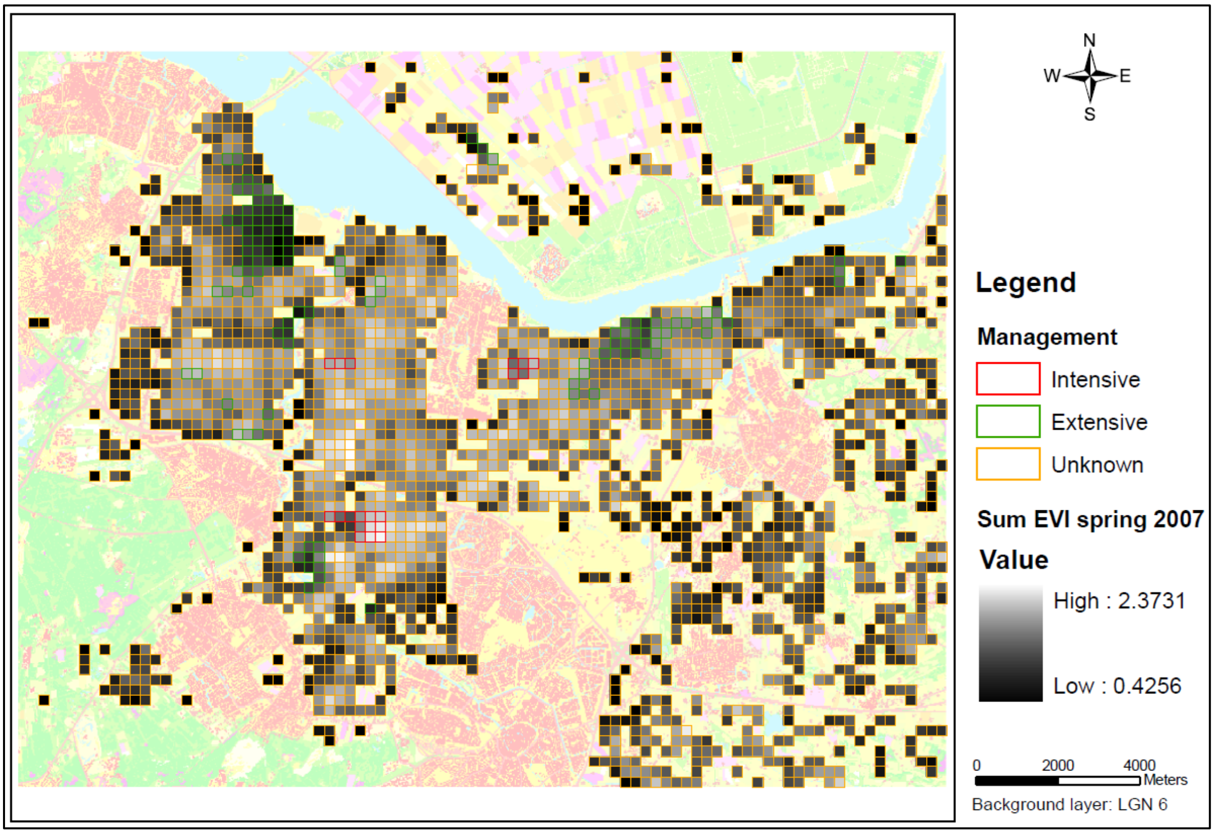


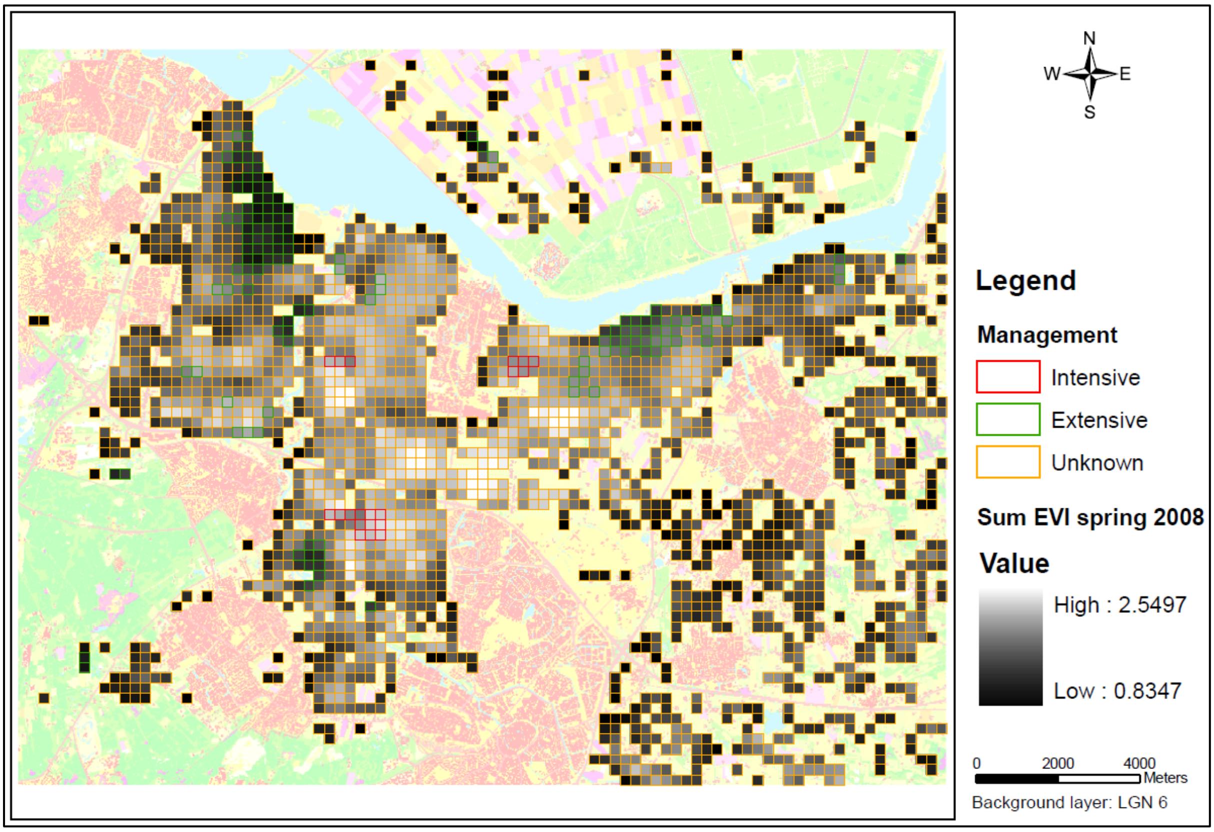



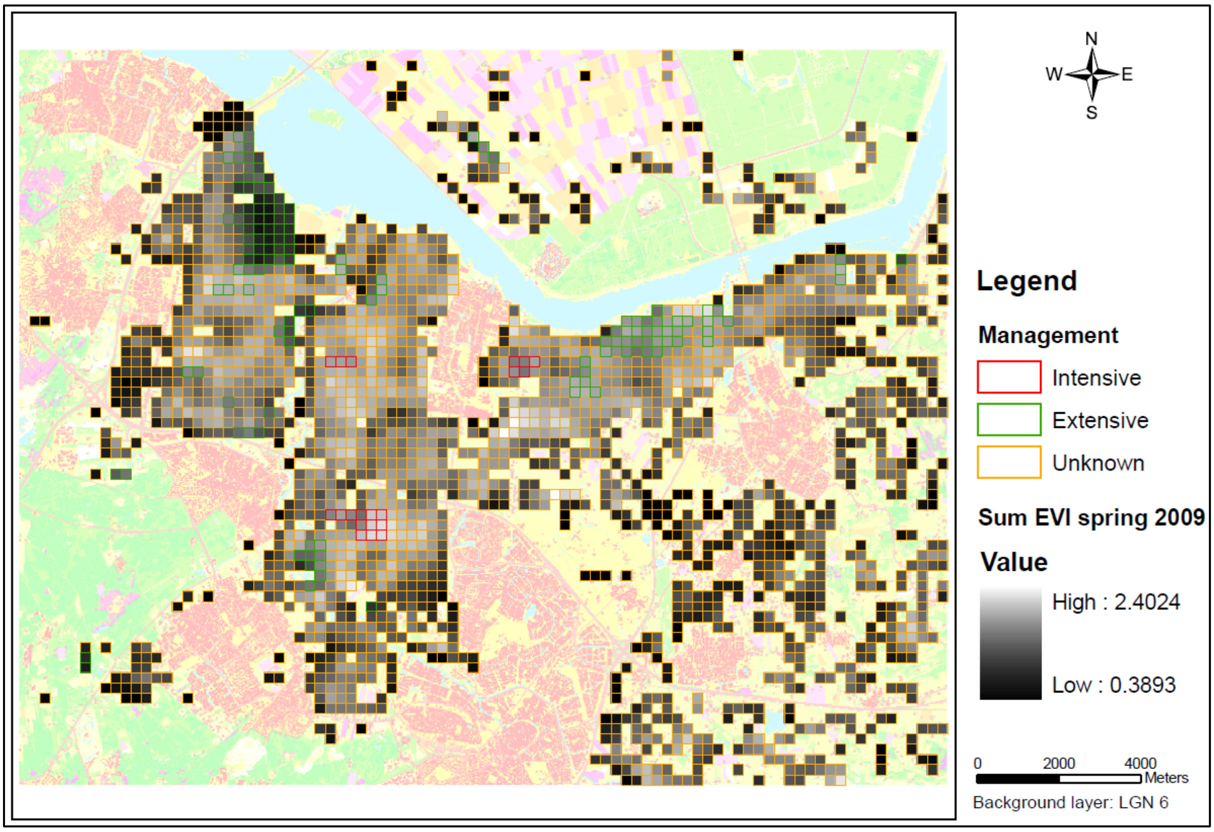

N
W
E
S
Legend
Management
Intensive
Extensive
Unknown
Sum EVI year 2009
Value
High : 14.8655
Low : 3.6312
0
2000
4000
Meters
Background layer: LGN 6

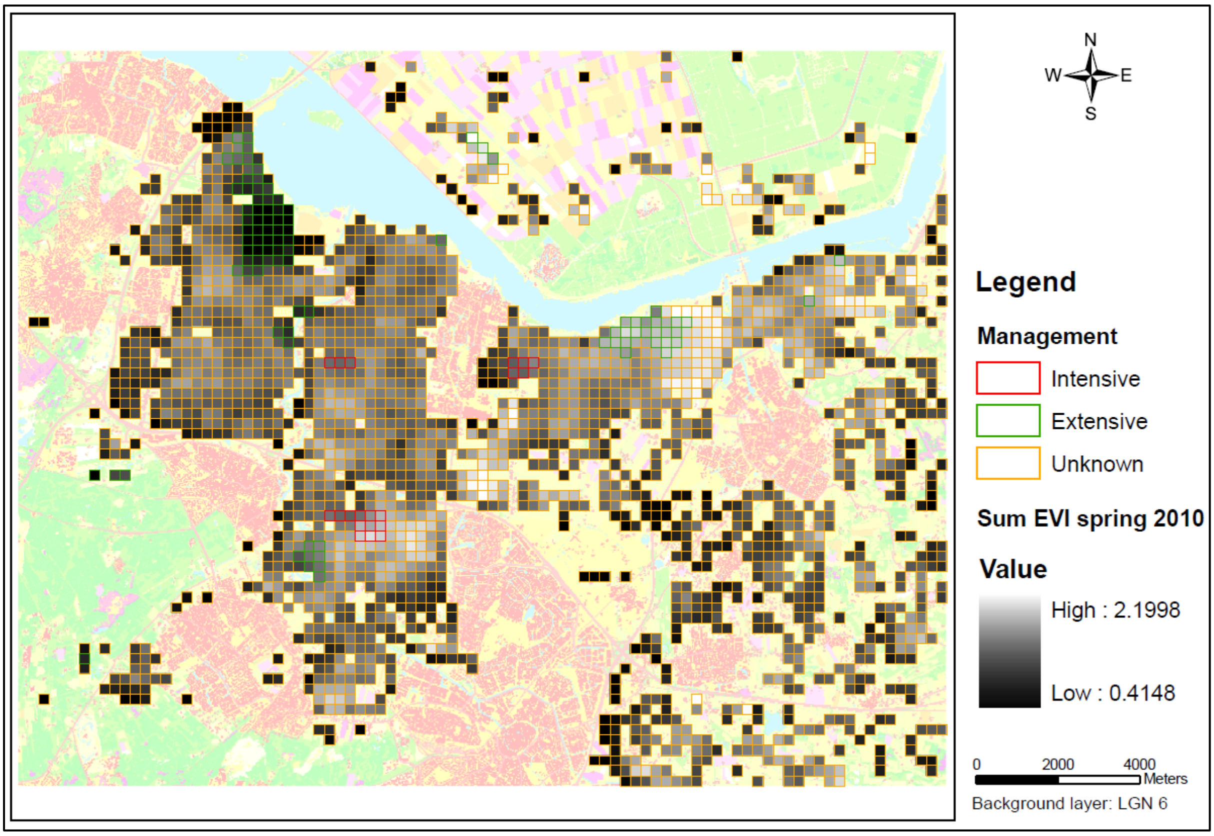

N
W
E
S
Legend
Management
Intensive
Extensive
Unknown
Sum EVI year 2010
Value
High : 14.794
Low : 3.4624
0
2000
4000
Meters
Background layer: LGN 6

## APPENDIX E: MAPS OF ARKEMHEEN-EEMLAND WITH THE SUMMED EVI FOR THE SPRINGS 2007-2010



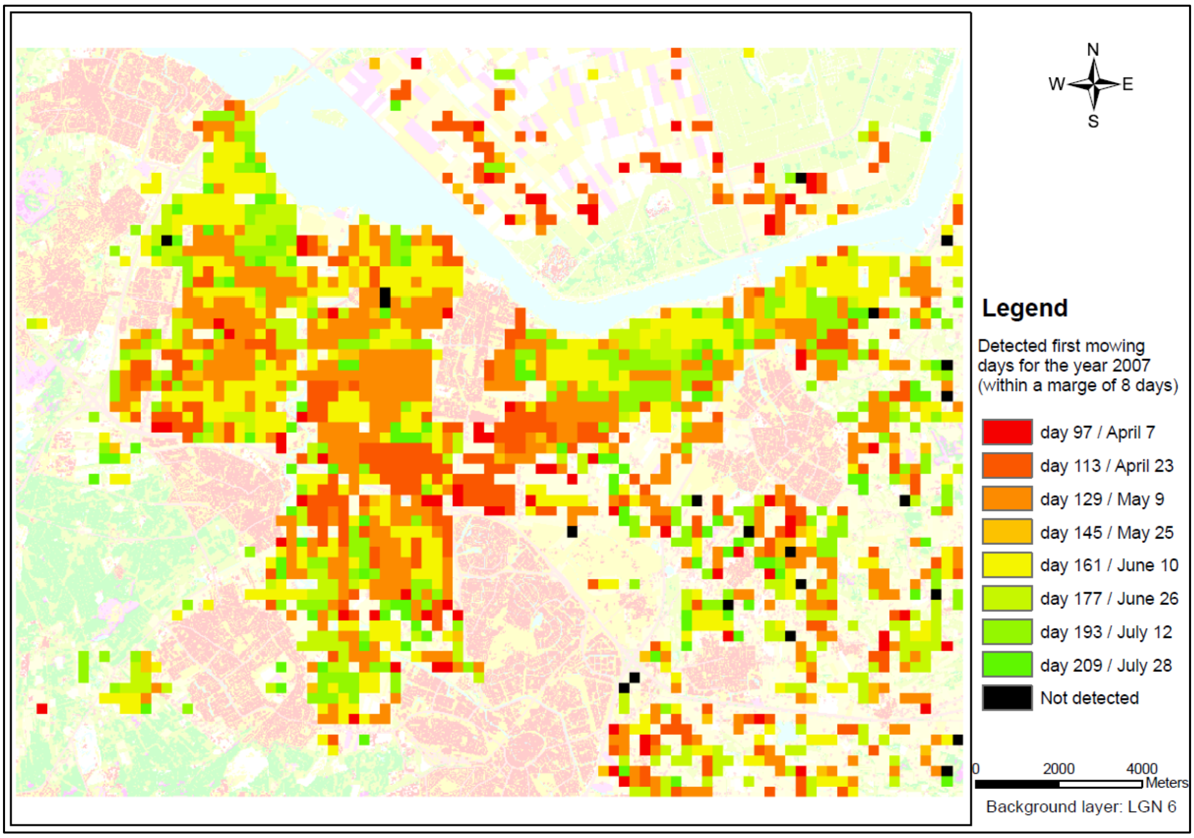



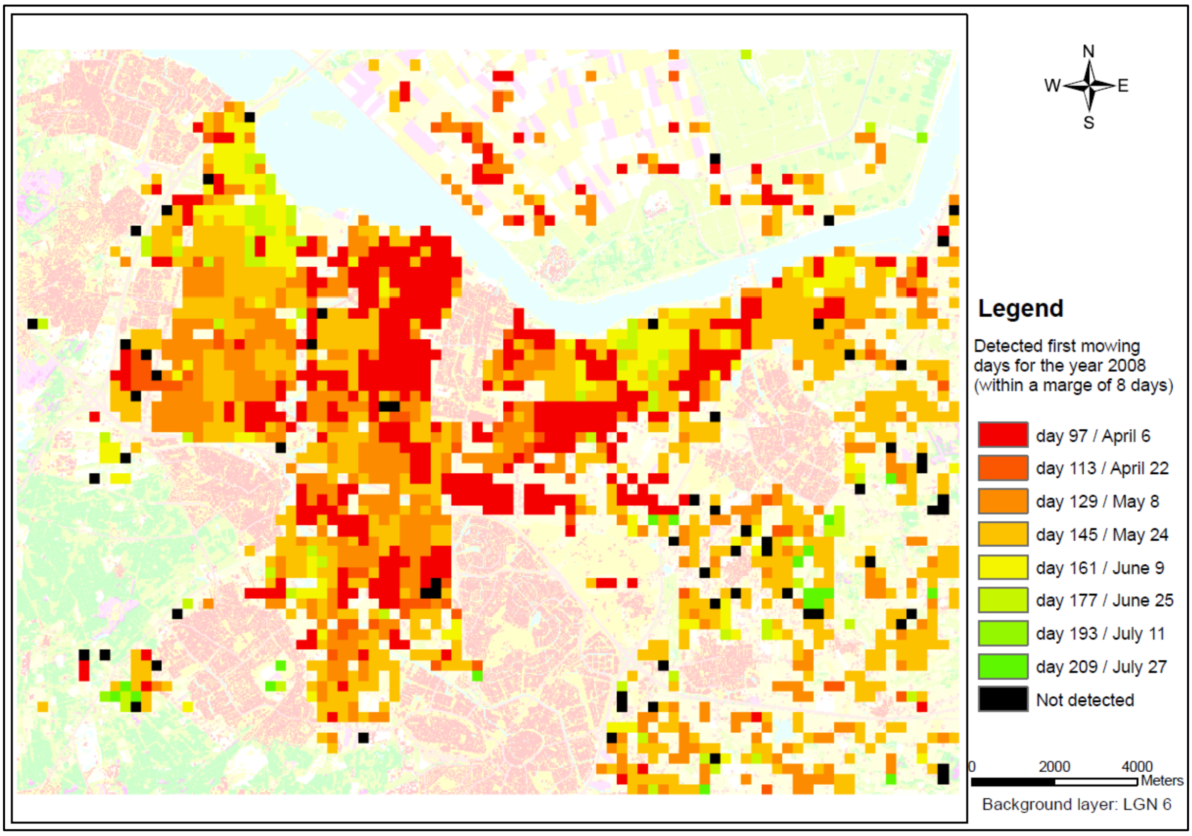

N
W
E
S
Legend
Management
Intensive
Extensive
Unknown
Sum EVI spring 2009
Value
High : 2.4024
Low : 0.3893
0
2000
4000
Meters
Background layer: LGN 6

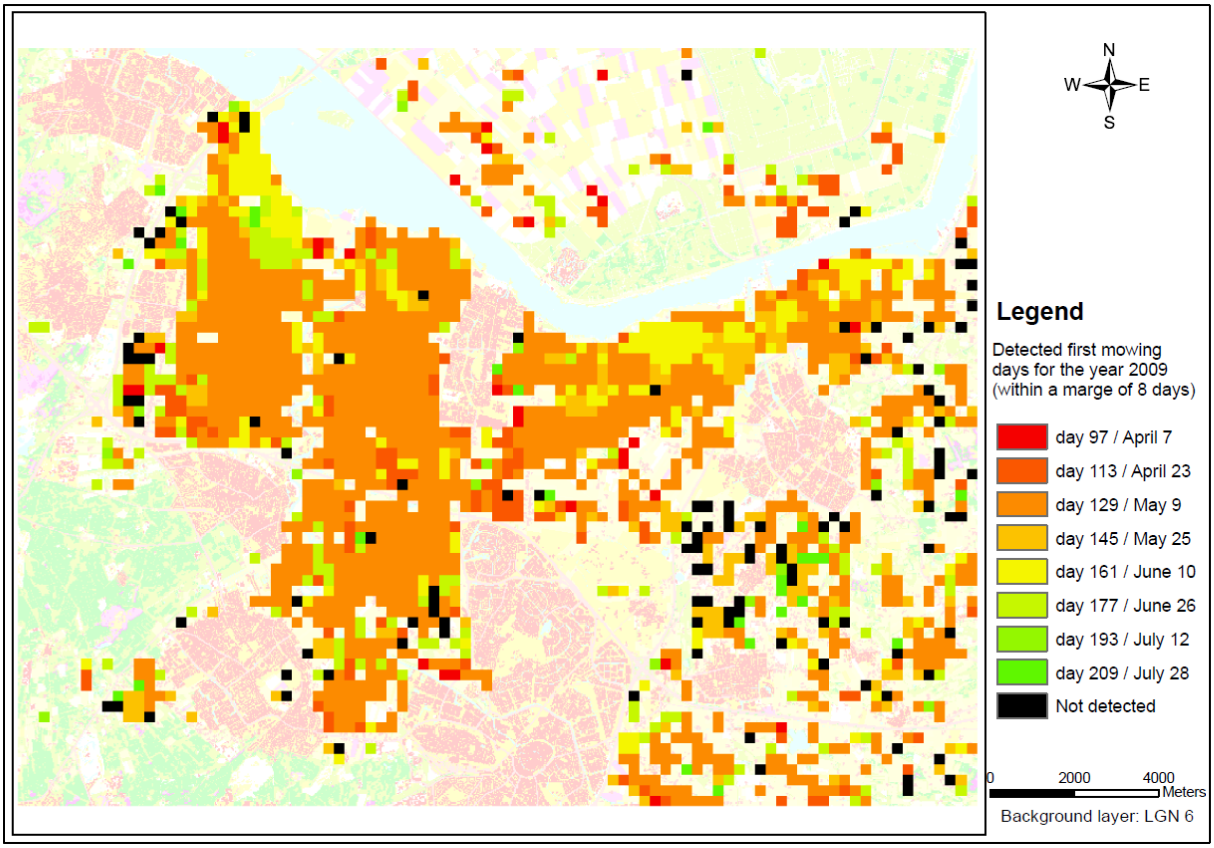

N
W
E
S
Legend
Management
Intensive
Extensive
Unknown
Sum EVI spring 2010
Value
High : 2.1998
Low : 0.4148
0
2000
4000
Meters
Background layer: LGN 6

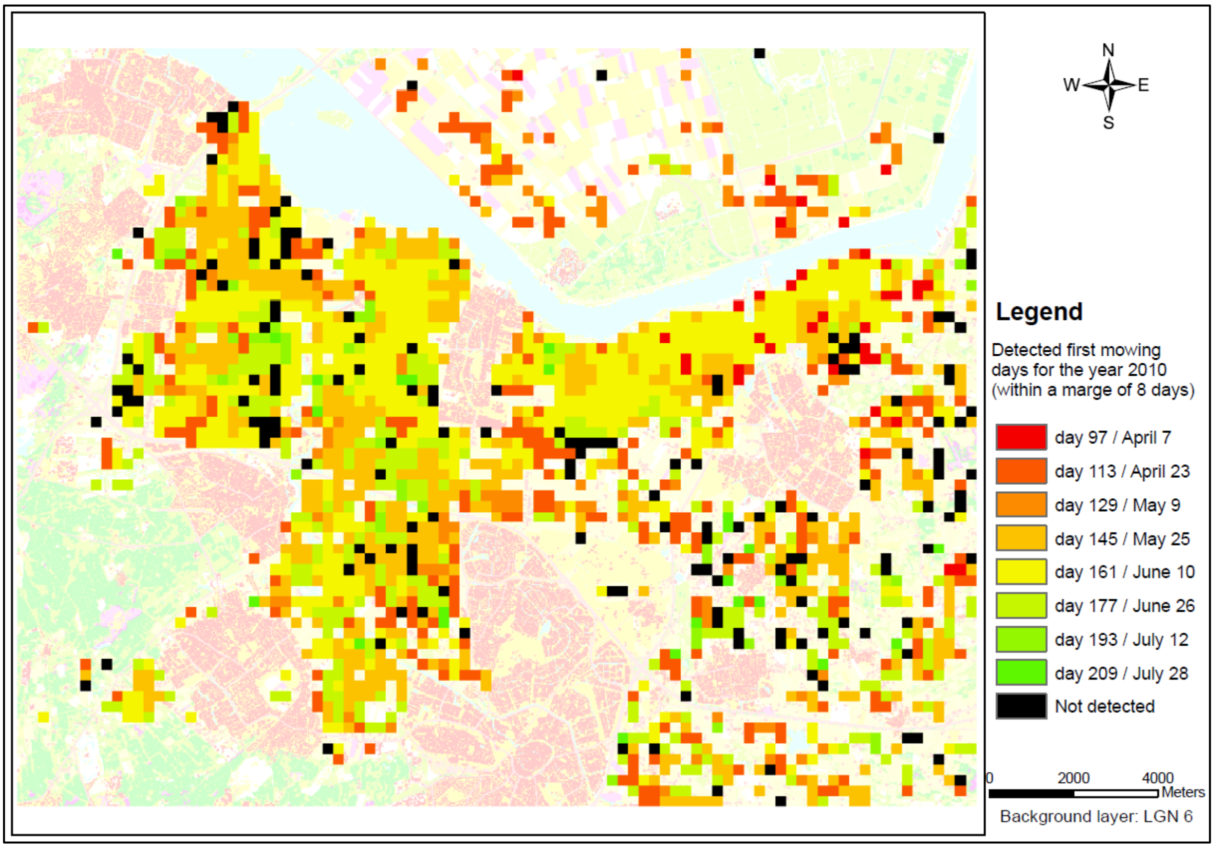
## APPENDIX F: MAPS WITH BY MODIS DERIVED FIRST MOWING DAYS ARKEMHEEN-EEMLAND 2007-2010

Maps with estimated mowing dates for Arkemheen-Eemland for the years 2007-2010. Based on the MODIS 16-days EVI time series with a mowing threshold of 0.06.

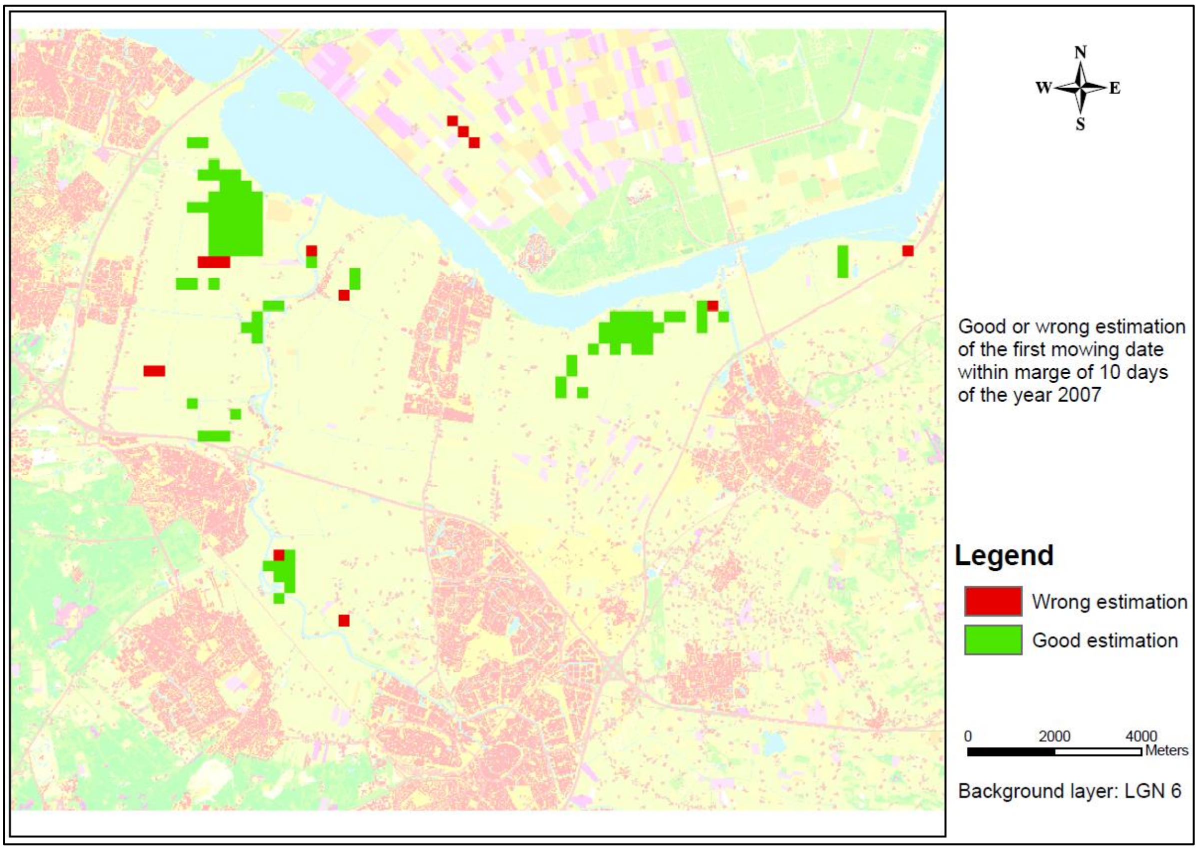


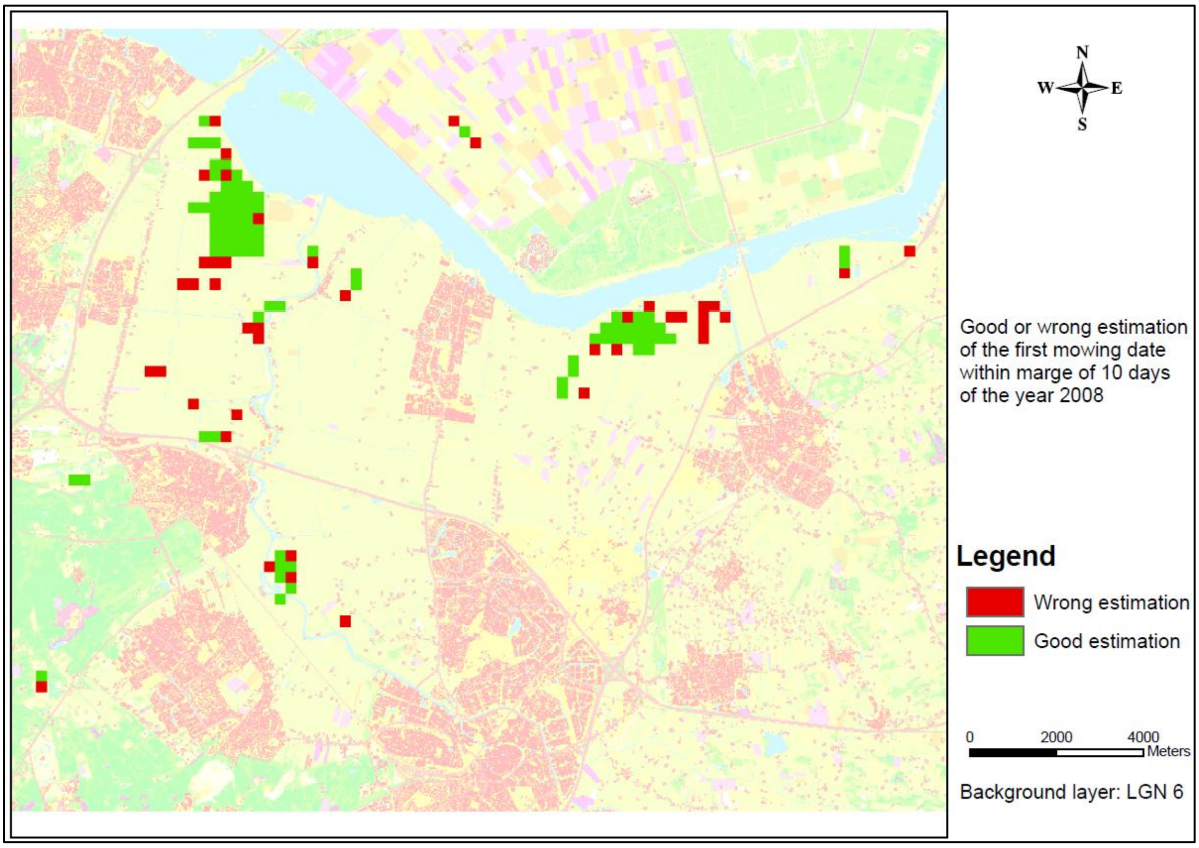



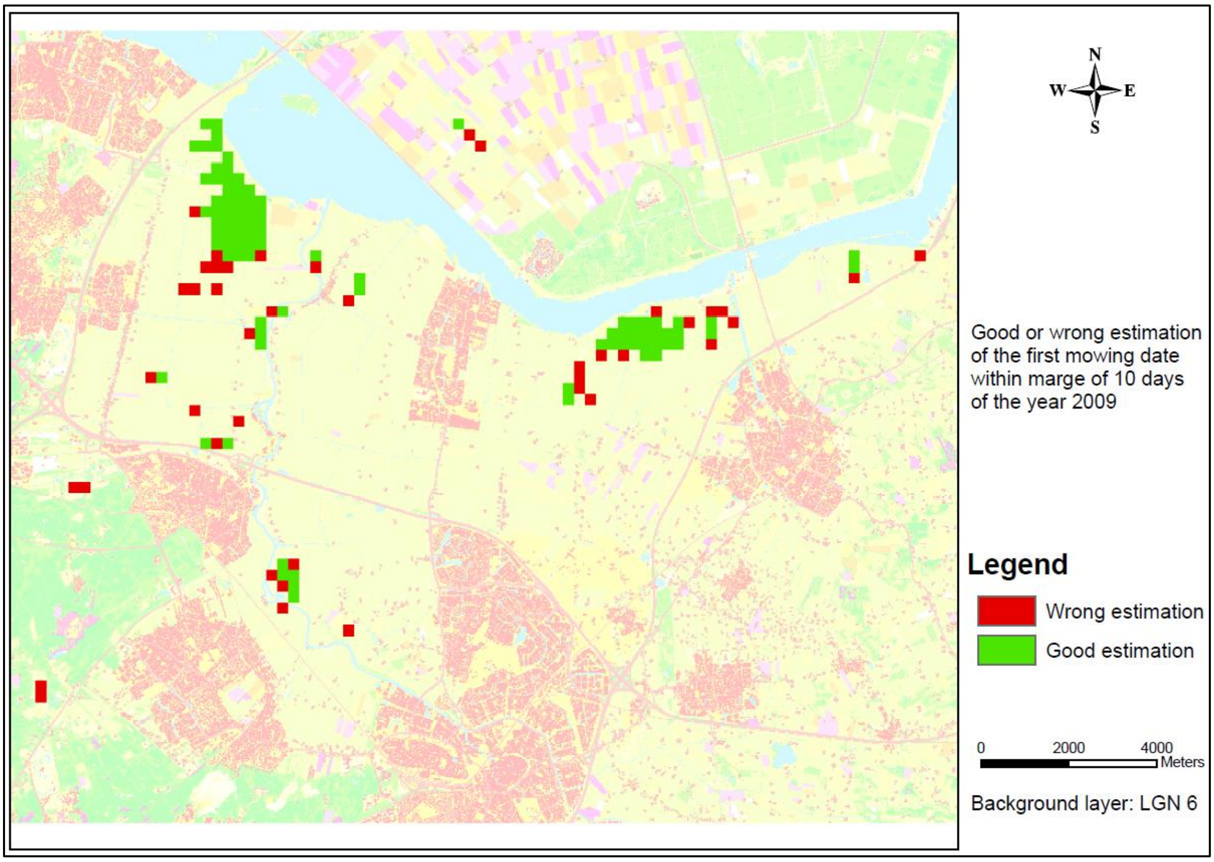

N
W
E
S
Legend
Detected first mowing days for the year 2009 (within a marge of 8 days)
day 97 / April 7
day 113 / April 23
day 129 / May 9
day 145 / May 25
day 161 / June 10
day 177 / June 26
day 193 / July 12
day 209 / July 28
Not detected
0
2000
4000
Meters
Background layer: LGN 6

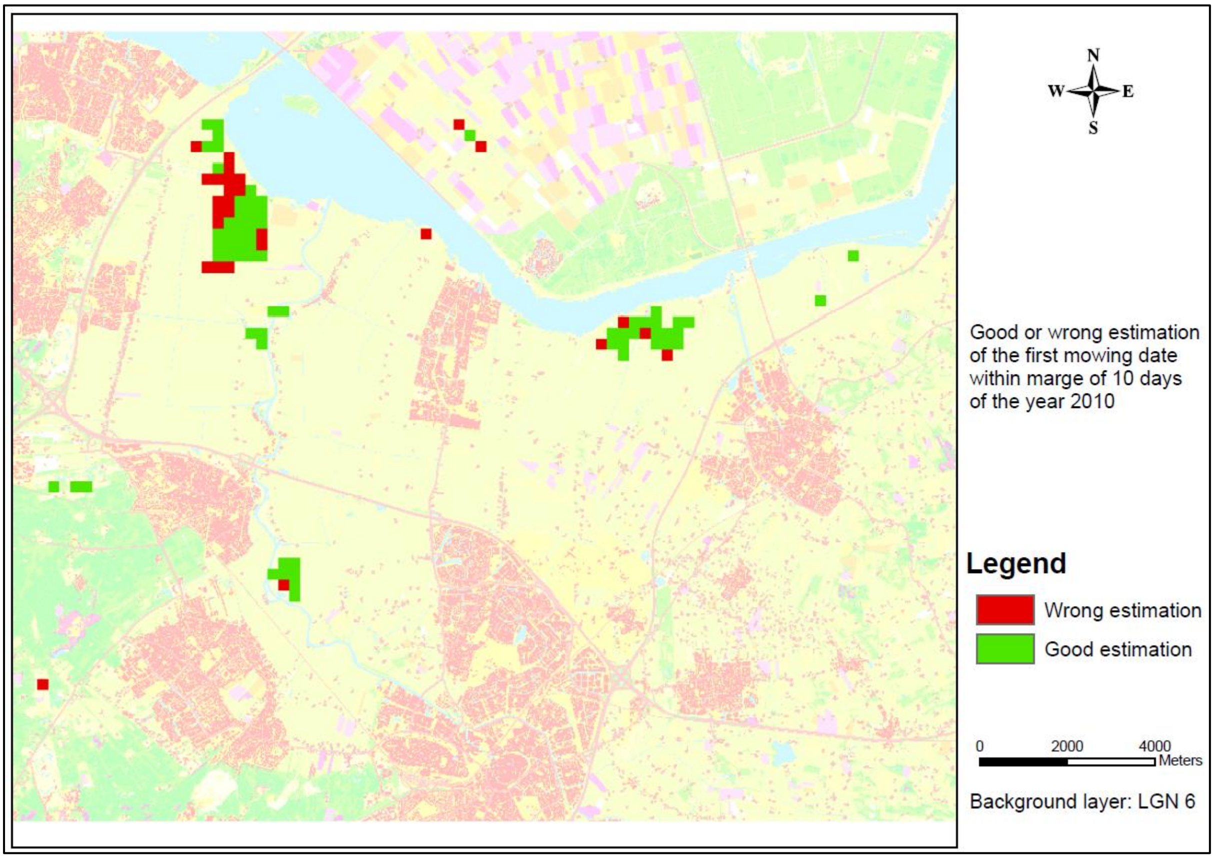

N
W
E
S
Legend
Detected first mowing days for the year 2010 (within a marge of 8 days)
day 97 / April 7
day 113 / April 23
day 129 / May 9
day 145 / May 25
day 161 / June 10
day 177 / June 26
day 193 / July 12
day 209 / July 28
Not detected
0
2000
4000
Meters
Background layer: LGN 6

## APPENDIX G: DISTRIBUTION OF PIXELS WITH WRONG ESTIMATED FIRST MOWING DATES IN ARKEMHEEN-EEMLAND 2007-2010



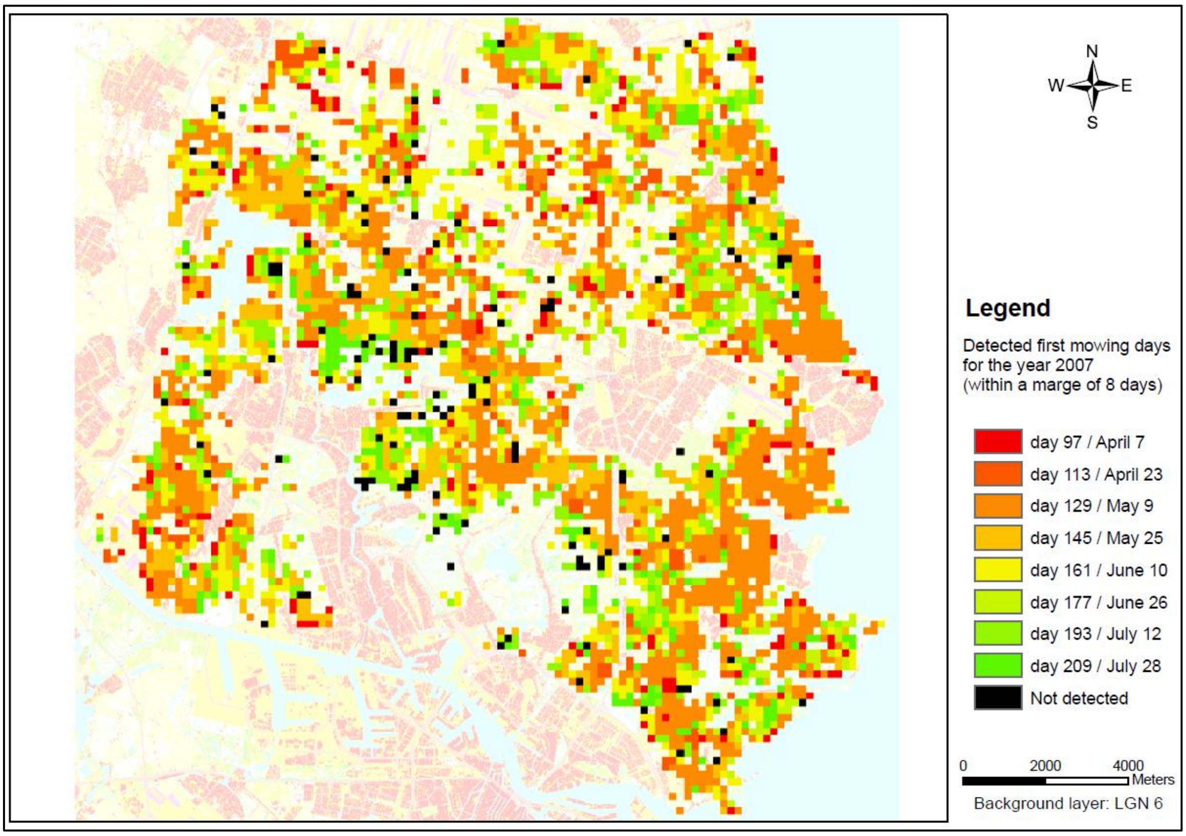



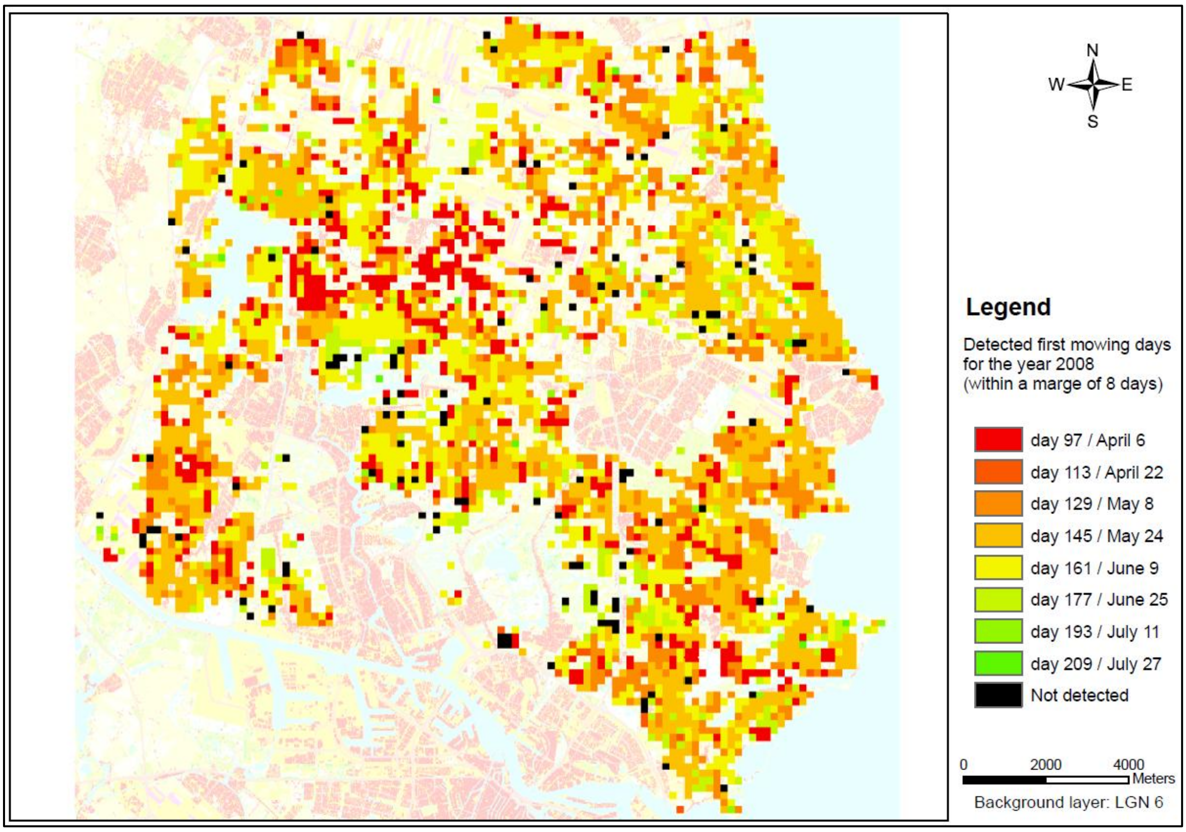

N
W
E
S
Good or wrong estimation of the first mowing date within marge of 10 days of the year 2009
Legend
Wrong estimation
Good estimation
0
2000
4000
Meters
Background layer: LGN 6

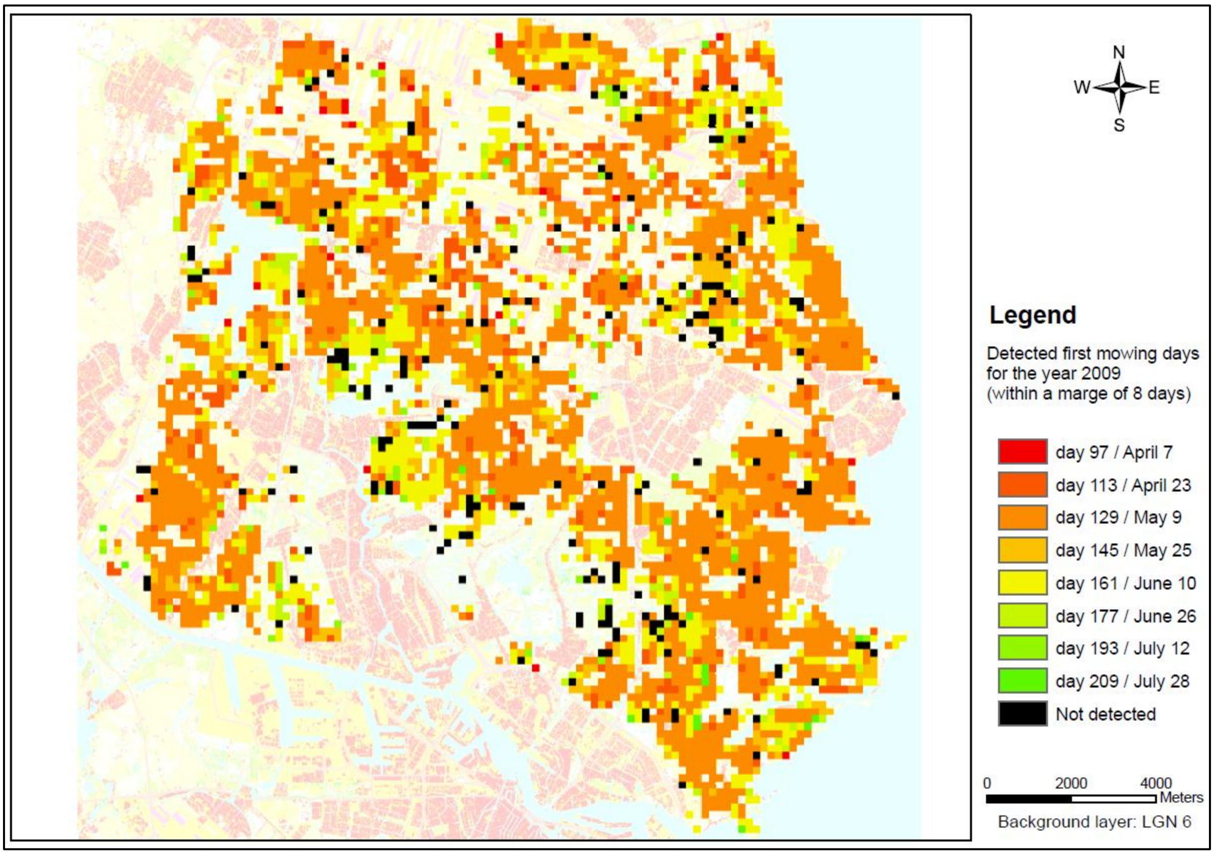

N
W
E
S
Good or wrong estimation of the first mowing date within marge of 10 days of the year 2010
Legend
Wrong estimation
Good estimation
0
2000
4000
Meters
Background layer: LGN 6

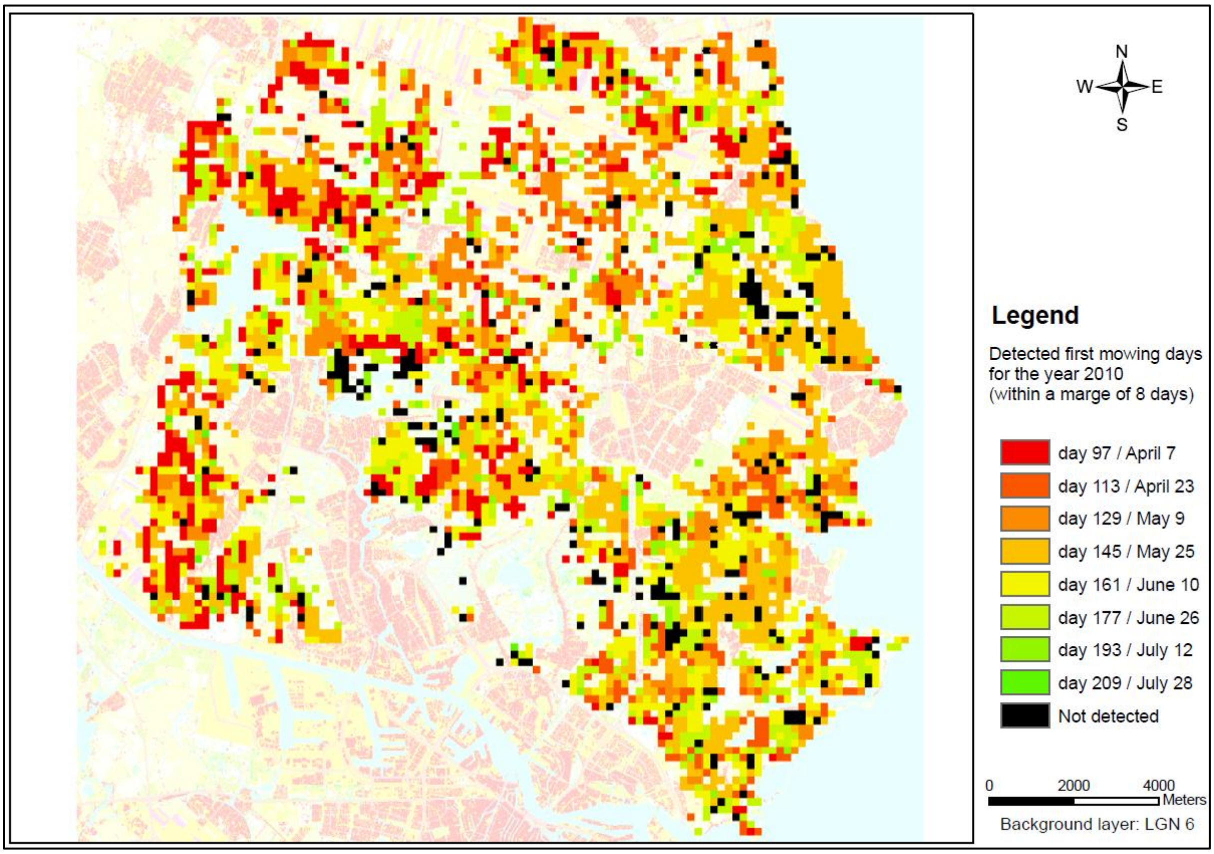
## APPENDIX H: MAPS WITH BY MODIS DERIVED FIRST MOWING DAYS LAAG-HOLLAND 2007-2010

Maps with estimated mowing dates for Laag-Holland for the years 2007-2010. Based on the MODIS 16-days EVI time series with a mowing threshold of 0.06.

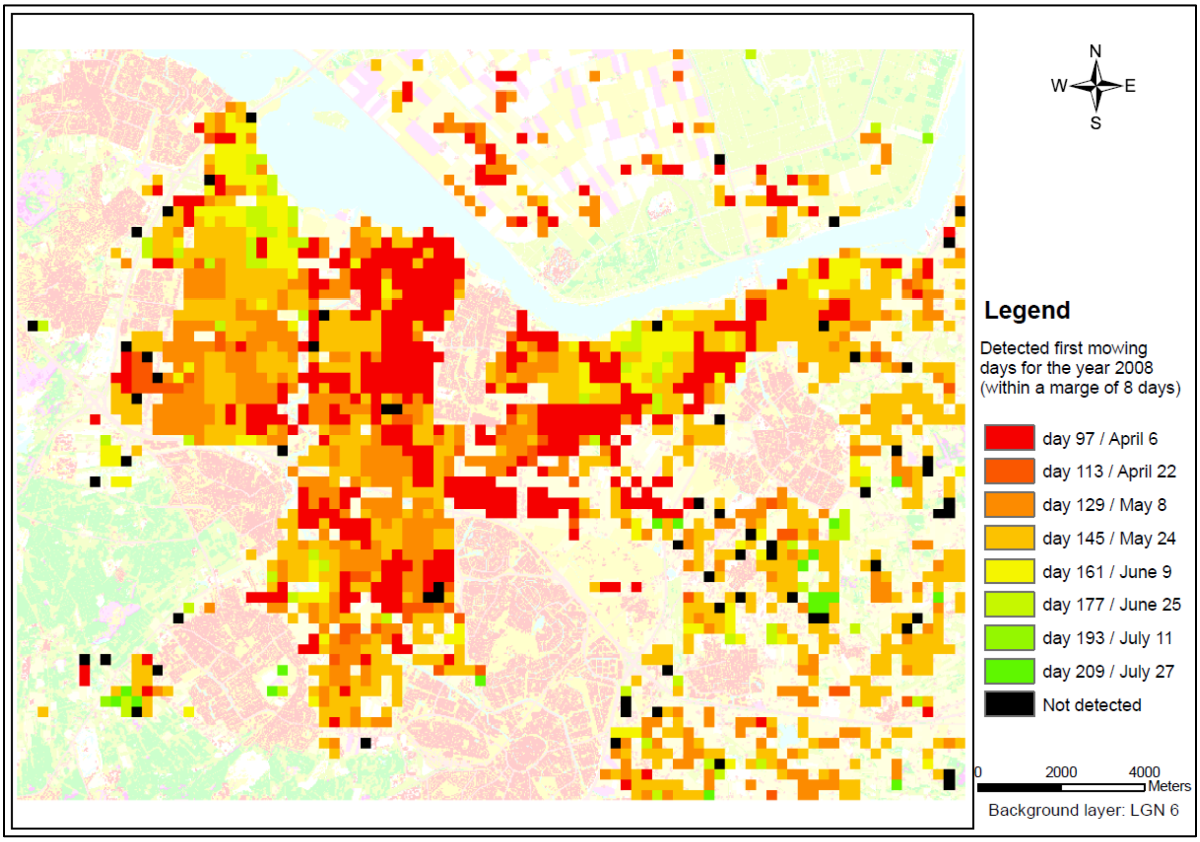


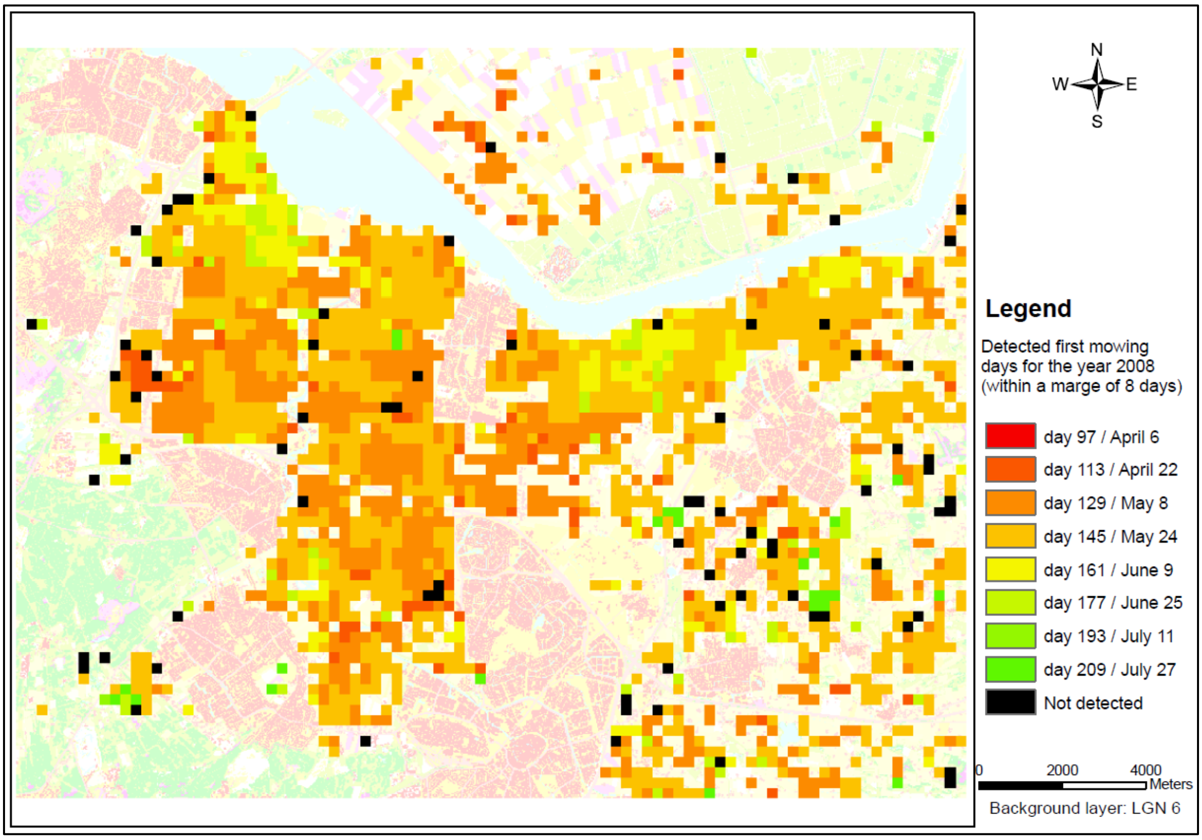




N
W
E
S
Legend
Detected first mowing days for the year 2009 (within a marge of 8 days)
day 97 / April 7
day 113 / April 23
day 129 / May 9
day 145 / May 25
day 161 / June 10
day 177 / June 26
day 193 / July 12
day 209 / July 28
Not detected
0
2000
4000
Meters
Background layer: LGN 6

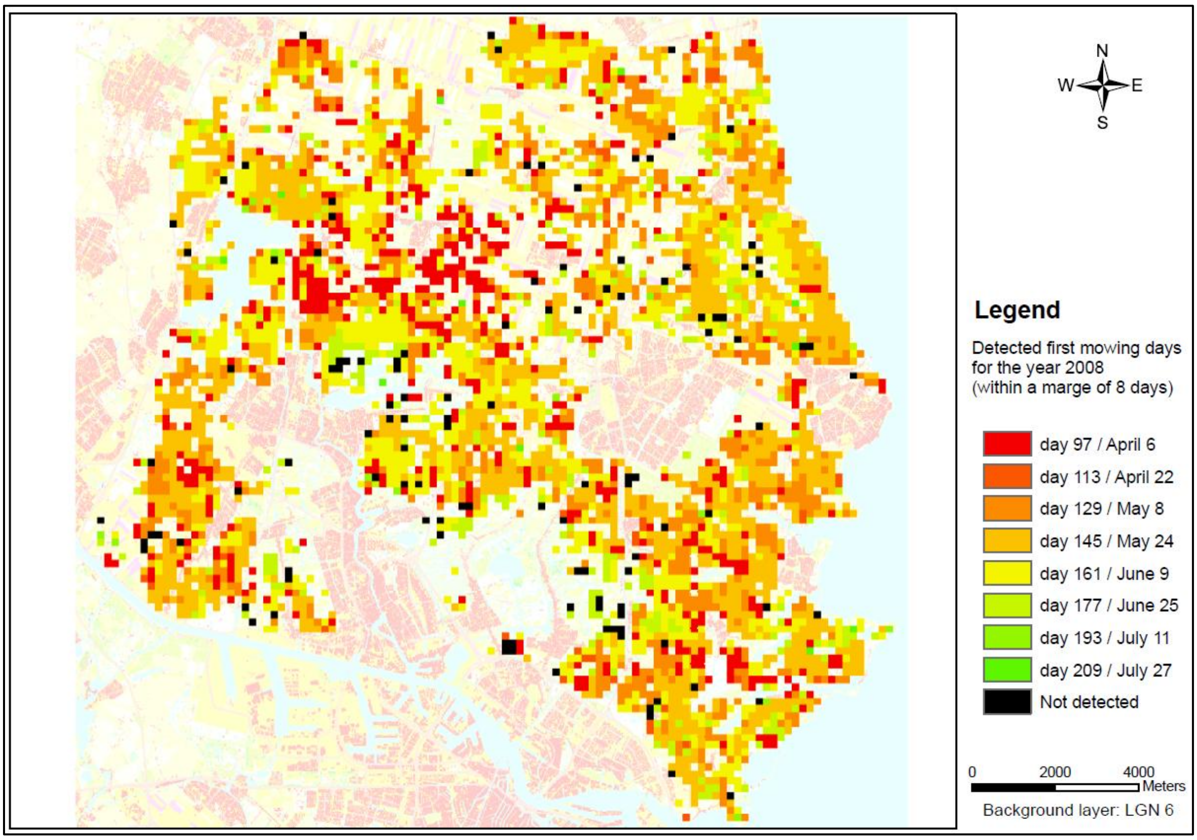

N
W
E
S
Legend
Detected first mowing days for the year 2010 (within a marge of 8 days)
day 97 / April 7
day 113 / April 23
day 129 / May 9
day 145 / May 25
day 161 / June 10
day 177 / June 26
day 193 / July 12
day 209 / July 28
Not detected
0
2000
4000
Meters
Background layer: LGN 6

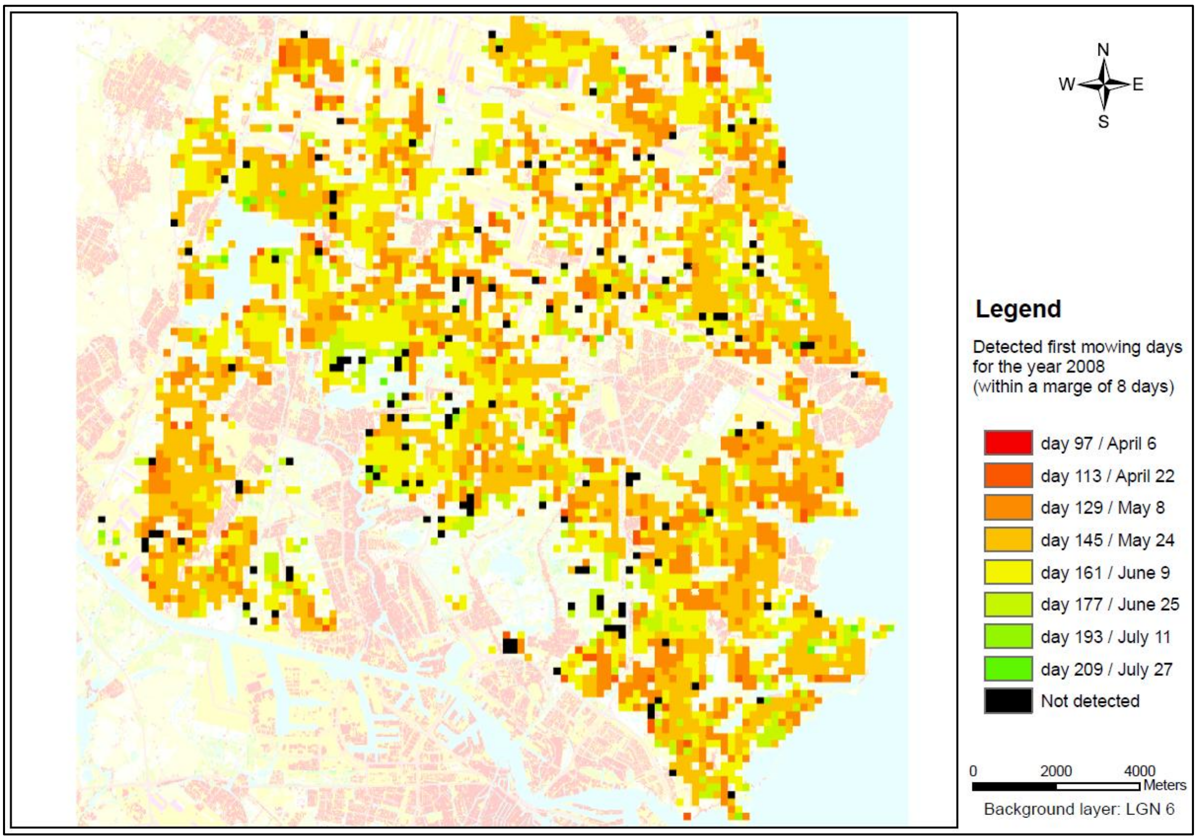
# APPENDIX I: MAPS WITH BY MODIS DERIVED FIRST MOWING DAYS ARKEMHEEN-EEMLAND 2008, BASIC AND MODIFIED VERSION



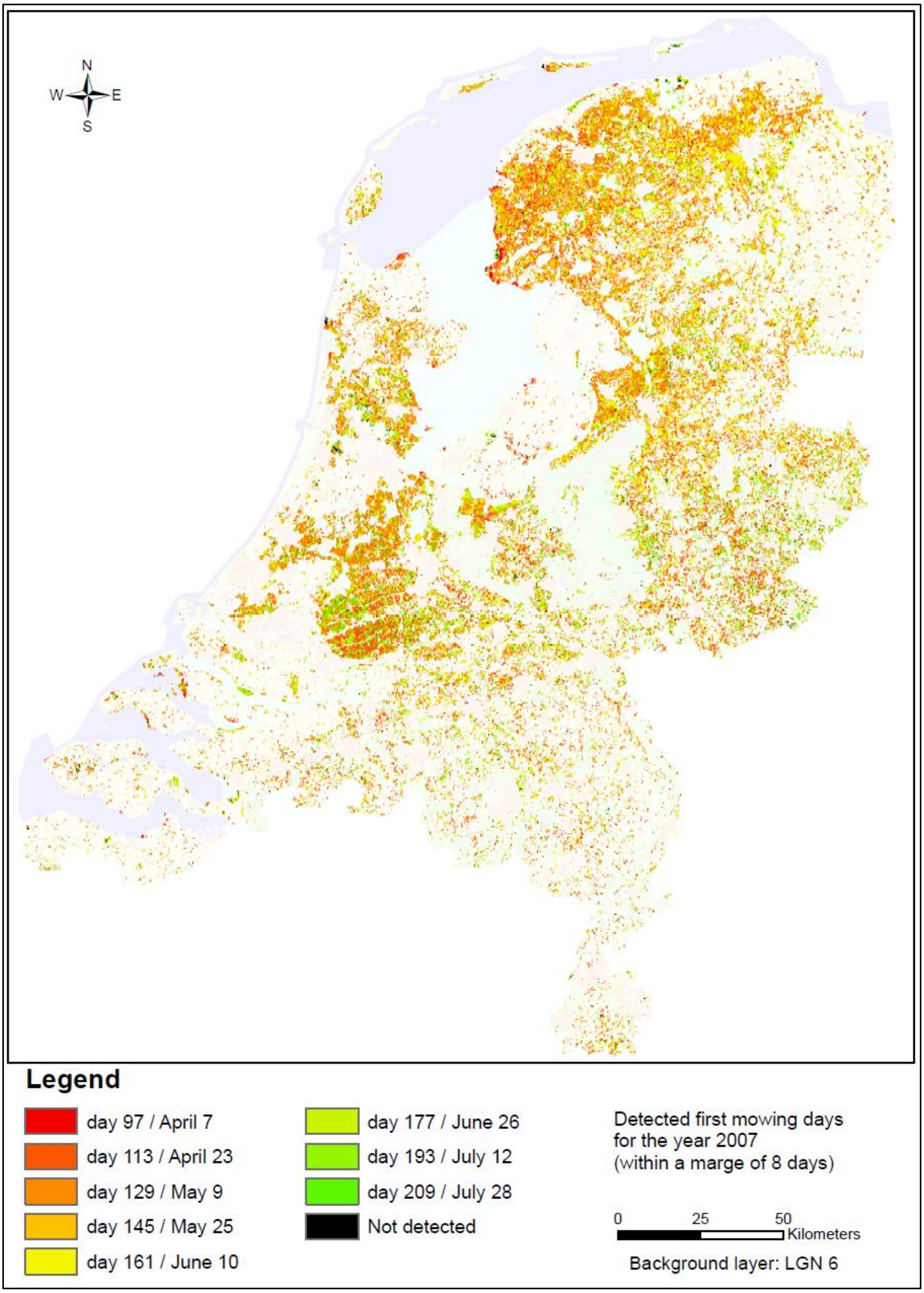



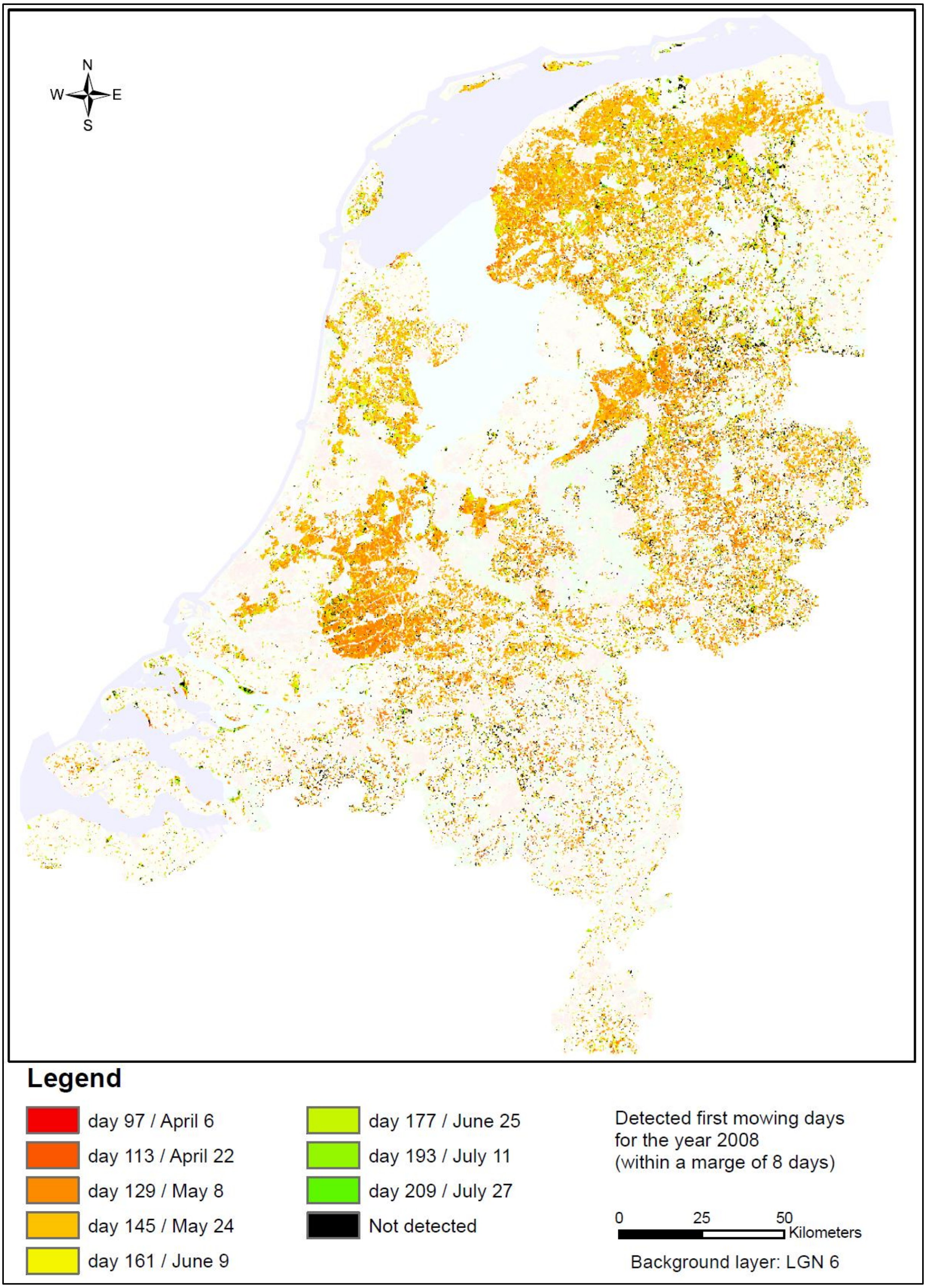
## APPENDIX J: MAPS WITH BY MODIS DERIVED FIRST MOWING DAYS LAAG-HOLLAND 2008, BASIC AND MODIFIED VERSION

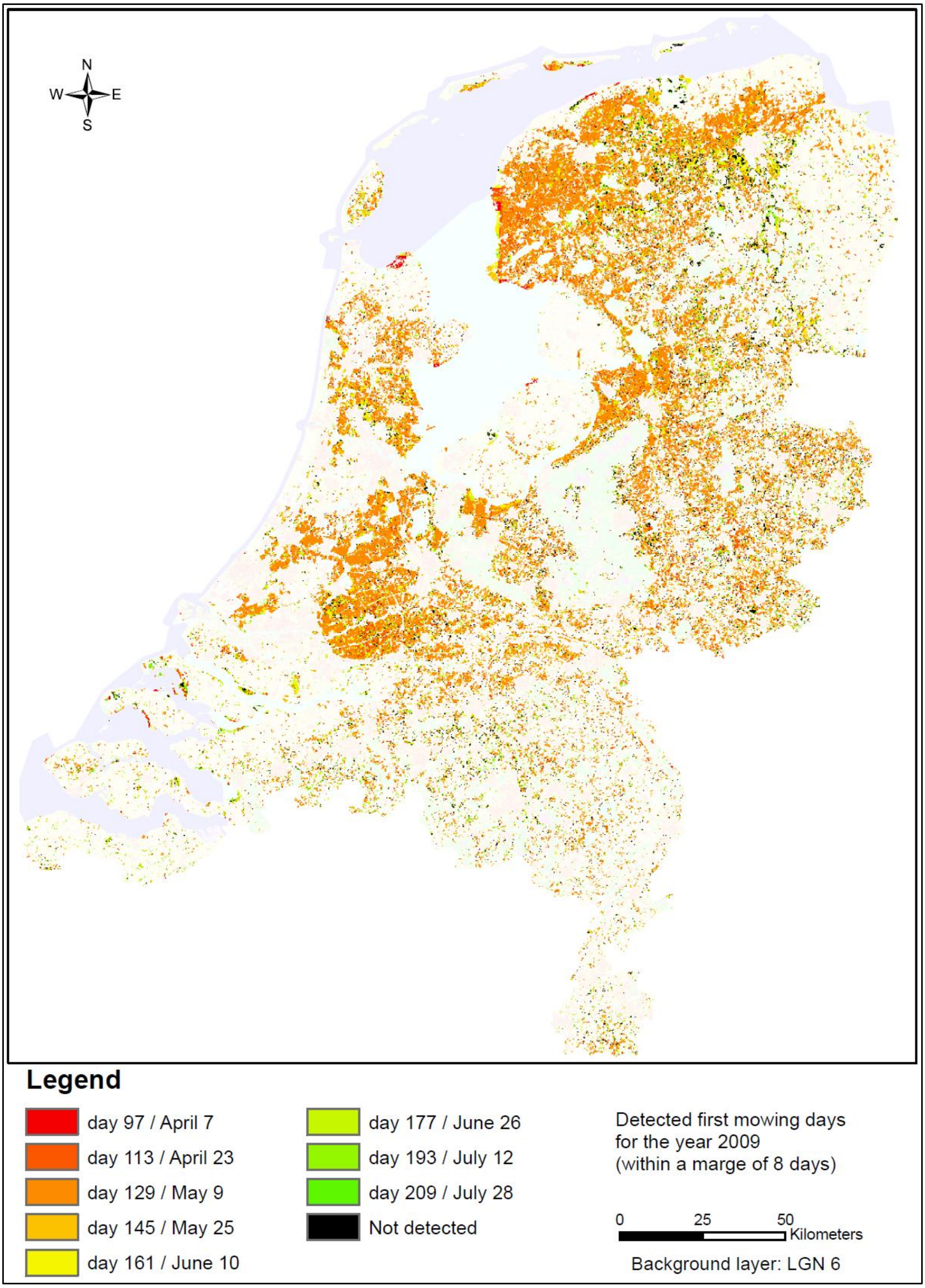


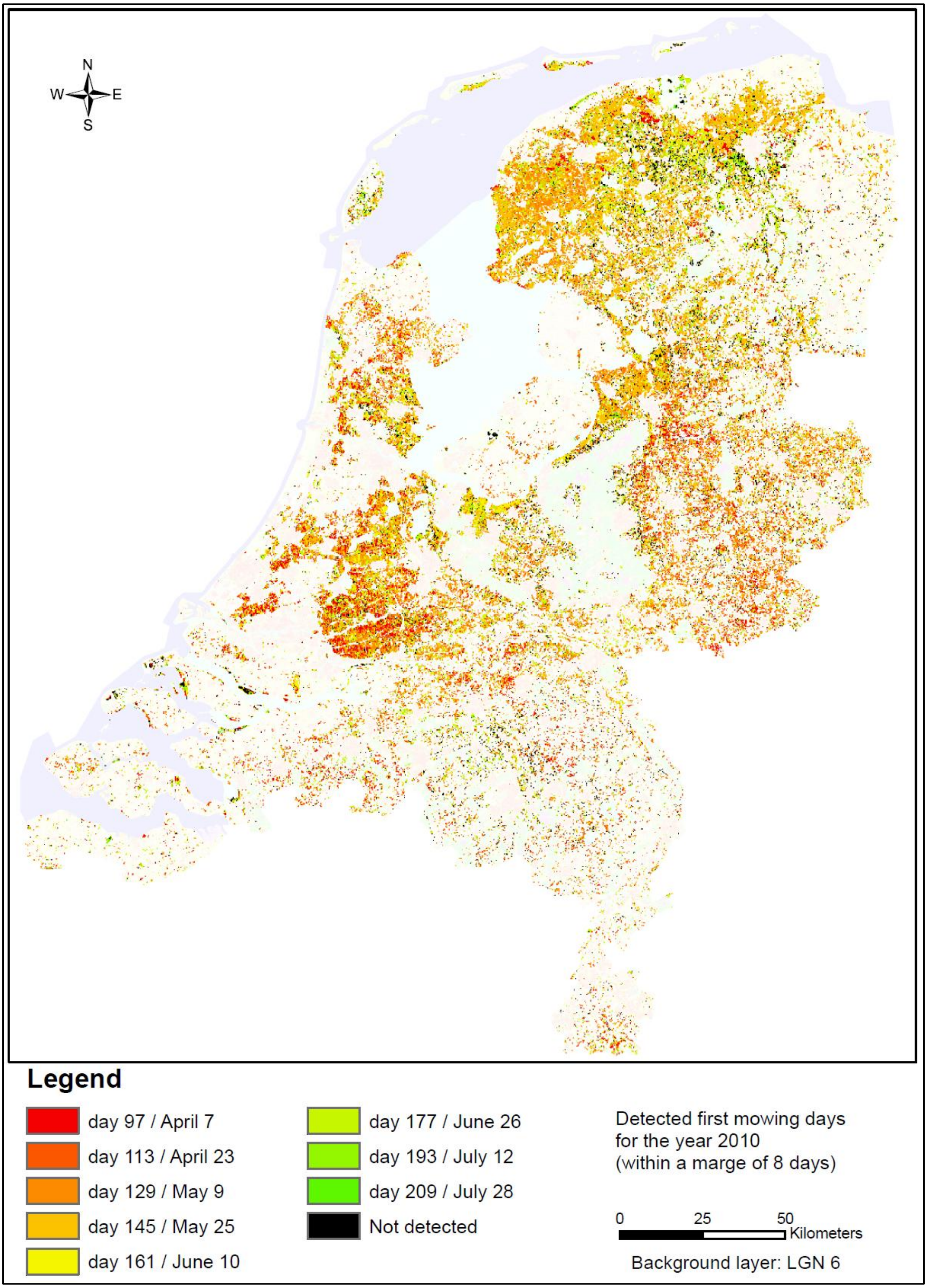



# APPENDIX K: MAPS WITH BY MODIS DERIVED FIRST MOWING DAYS THE NETHERLANDS 2007-2010

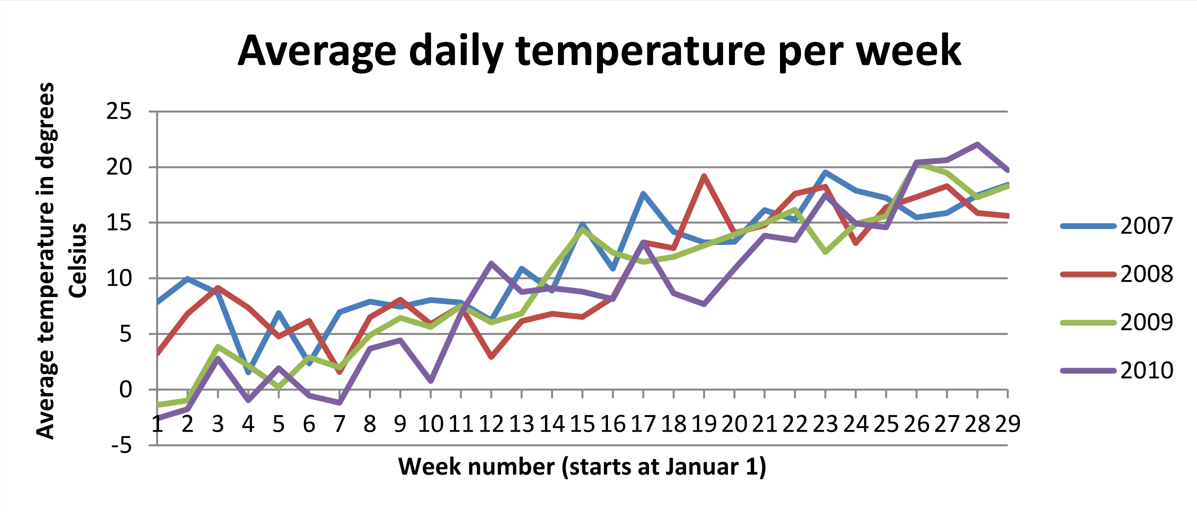


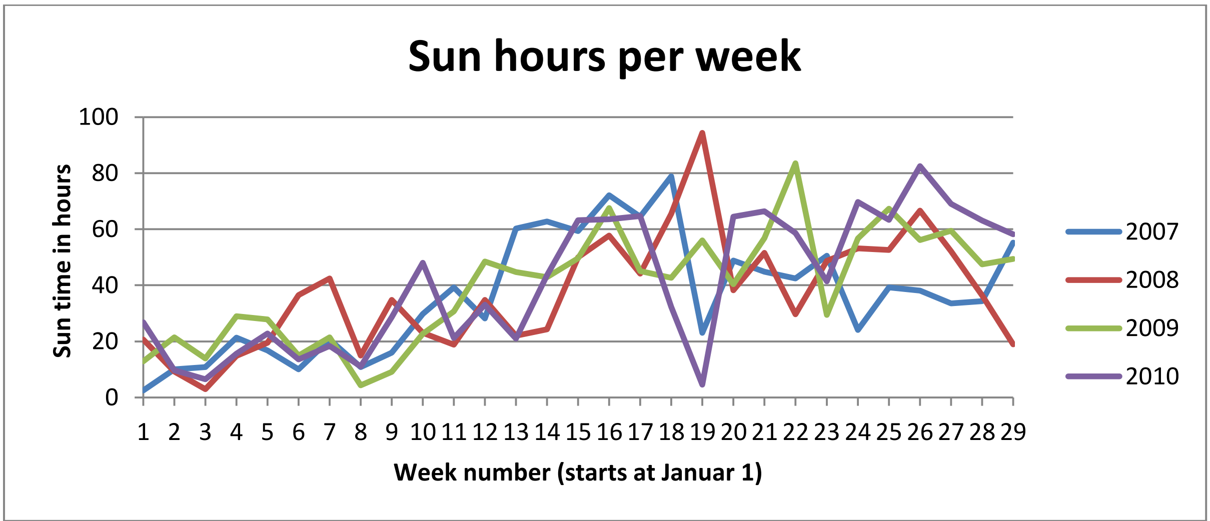

N
W
E
S
Legend
day 97 / April 6
day 113 / April 22
day 129 / May 8
day 145 / May 24
day 161 / June 9
day 177 / June 25
day 193 / July 11
day 209 / July 27
Not detected
Detected first mowing days
for the year 2008
(within a marge of 8 days)
0
25
50
Kilometers
Background layer: LGN 6

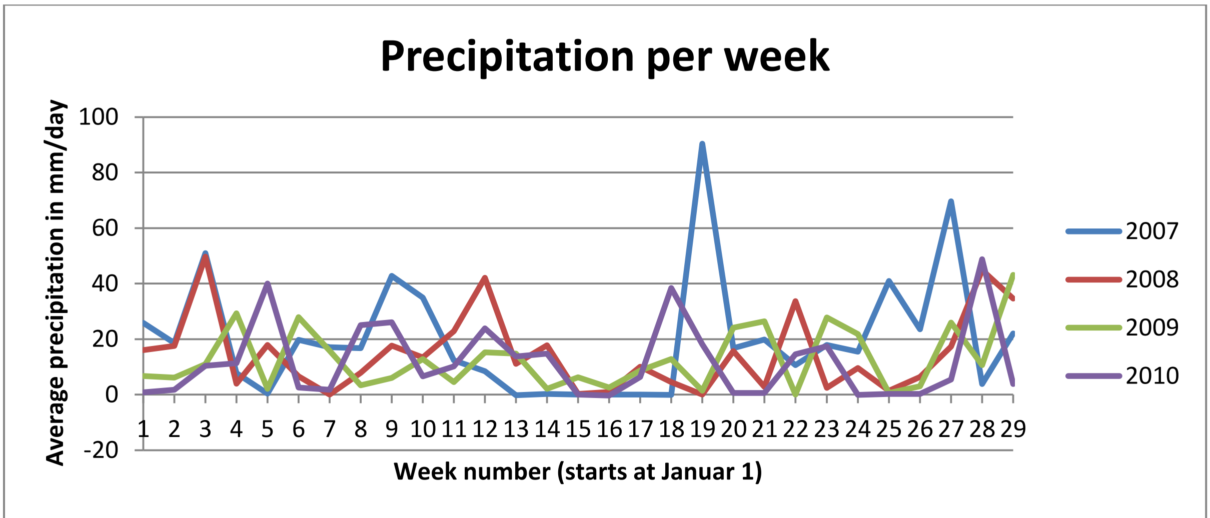

N
W
E
S
Legend
day 97 / April 7
day 113 / April 23
day 129 / May 9
day 145 / May 25
day 161 / June 10
day 177 / June 26
day 193 / July 12
day 209 / July 28
Not detected
Detected first mowing days
for the year 2009
(within a marge of 8 days)
0
25
50
Kilometers
Background layer: LGN 6


N
W
E
S
Legend
day 97 / April 7
day 113 / April 23
day 129 / May 9
day 145 / May 25
day 161 / June 10
day 177 / June 26
day 193 / July 12
day 209 / July 28
Not detected
Detected first mowing days
for the year 2010
(within a marge of 8 days)
0
25
50
Kilometers
Background layer: LGN 6

## APPENDIX L: GRAPHS OF THE WEATHER IN THE YEARS 2007-2010




Source: KNMI, weather station of De Bilt

## APPENDIX M: DESCRIPTIONS OF THE SPRING WEATHER IN THE YEARS 2007-2010

| **2007** | |
|---|---|
| **February** | Mild, wet and dark weather |
| **March** | Very mild, sunny and wet |
| **April** | Very sunny, very dry and very mild |
| **May** | After May 6, relatively hot and changeable weather |
| **June** | Hot, very wet and dark |
| **Influence on agriculture** | Farmers were able to mow early in spring before May 6, because of the mild weather and many sun hours, and thus fast growing grass. After this date, the precipitation avoided the farmers from mowing. The parcels that were not mown before May 6, could not be mowed before June. |

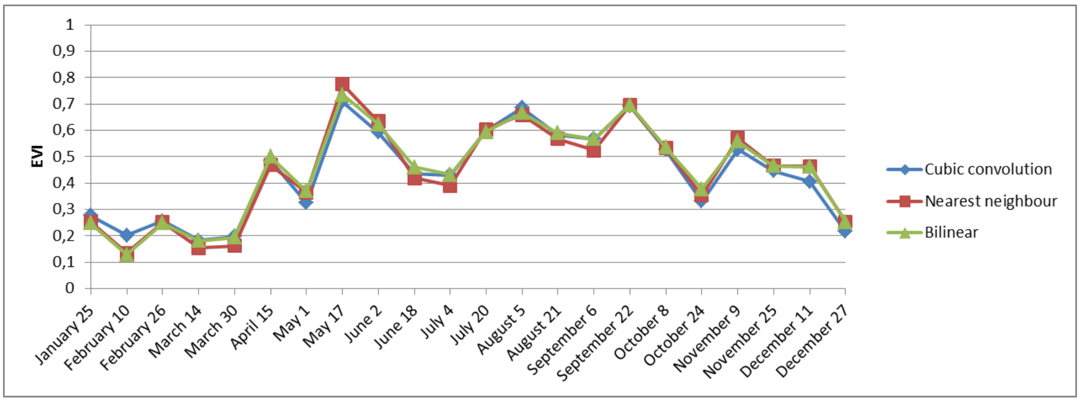
| **2008** | |
|---|---|
| **February** | Sunny and relatively dry |
| **March** | First half changeable weather and relatively mild, second half cold, changeable weather with snow. At the end of March milder weather, very wet and sunny. |
| **April** | In April, it was for a long time too cold. Not so many precipitation and sunny. |
| **May** | Very hot, little rain and many sun hours. |
| **June** | In the beginning of June a lot of rain, and hot. Later cooler, but wet. |
| **Influence on agriculture** | The first mowing activities took place a bit later than in 2007, around the beginning of May. This is a bit on the early, in comparison to yearly averages (De Natuurkalender) |

| **2009** | |
|---|---|
| **February** | Severe winter, ends relatively mild and dark |
| **March** | Severe winter, ends relatively mild and dark |
| **April** | Very hot |
| **May** | - |
| **June** | - |
| **Influence on agriculture** | Farmers were able to mow early in spring (April) |

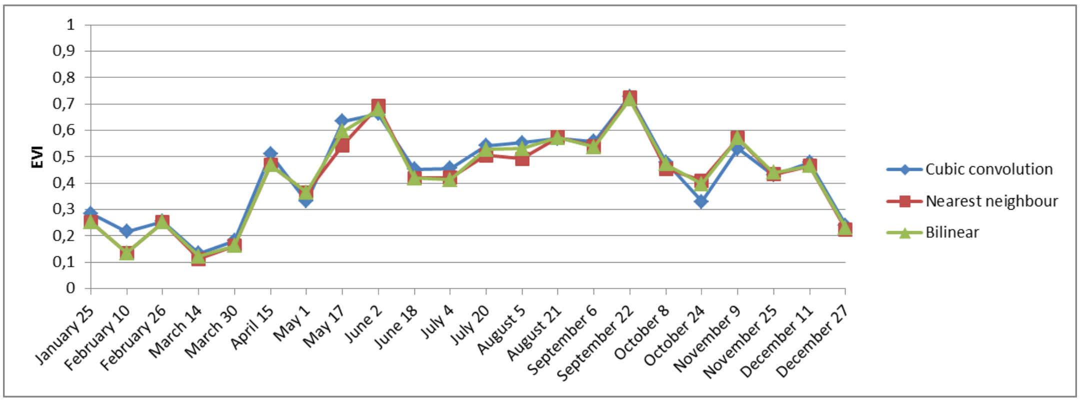
| **2010** | |
|---|---|
| **February** | Cold weather |
| **March** | Up to half March, it was still cold. Later, some days with precipitation and milder. |
| **April** | Till the end of April, relatively normal weather, a bit on the cold side. |
| **May** | May was cold. |
| **Influence on agriculture** | The grass grew very slow, most parcels have mowed in June for first time |

(Van Vliet 2010, Buissink *et al.* 2008, Van 't Veer *et al.* 2009, Van 't Veer *et al.* 2010, Van 't veer *et al.* 2011)

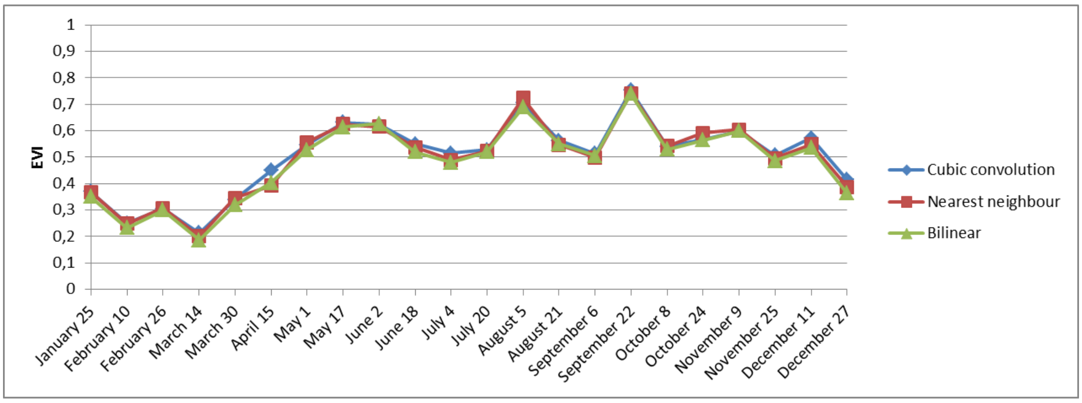
## APPENDIX N: WRONG MOWING DETECTION IN THE SMALL AREA OF EEMLAND



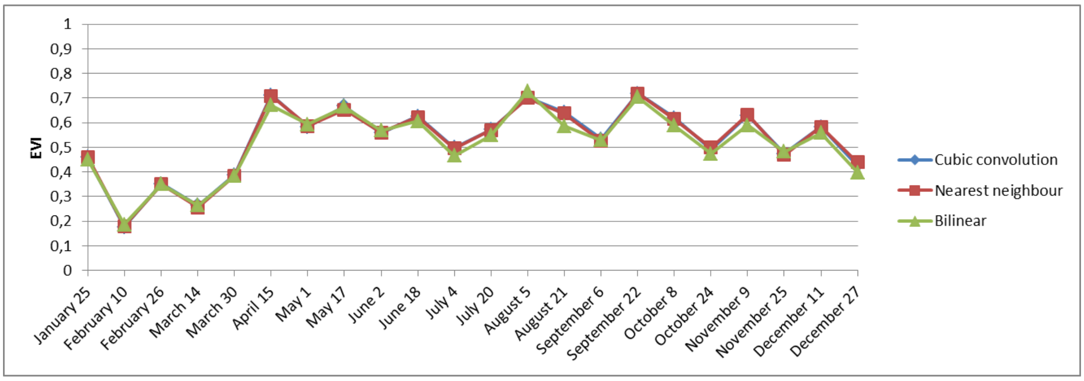

Wrong estimation 1 (real day June 15, but estimation around April 23 by MODIS)




Wrong estimation 2 (real day June 15, but estimation around April 23 by MODIS)

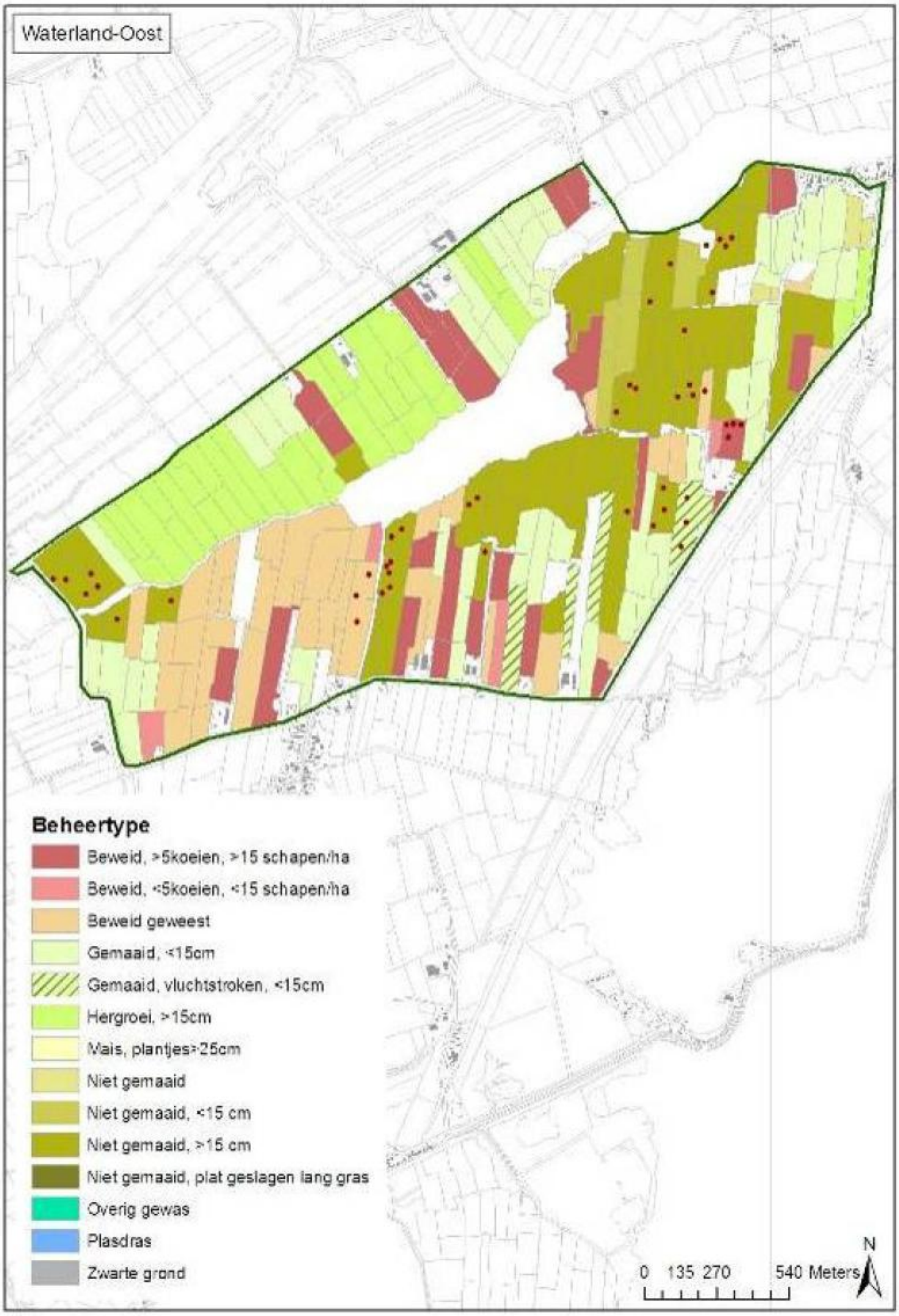



Wrong estimation 3 (real day May 12, but estimation around June 10 by MODIS)

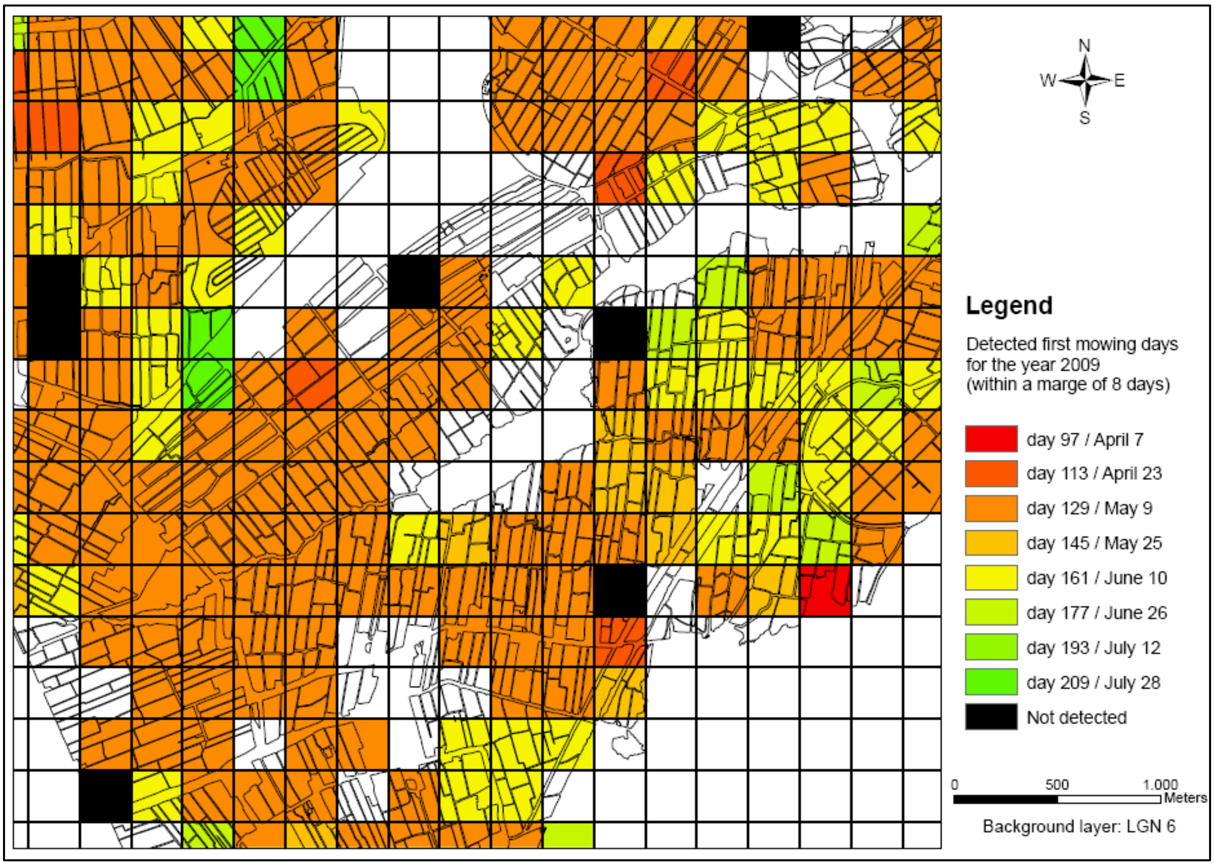



Wrong estimation 4 (real day May 19, but around April 23 by MODIS)

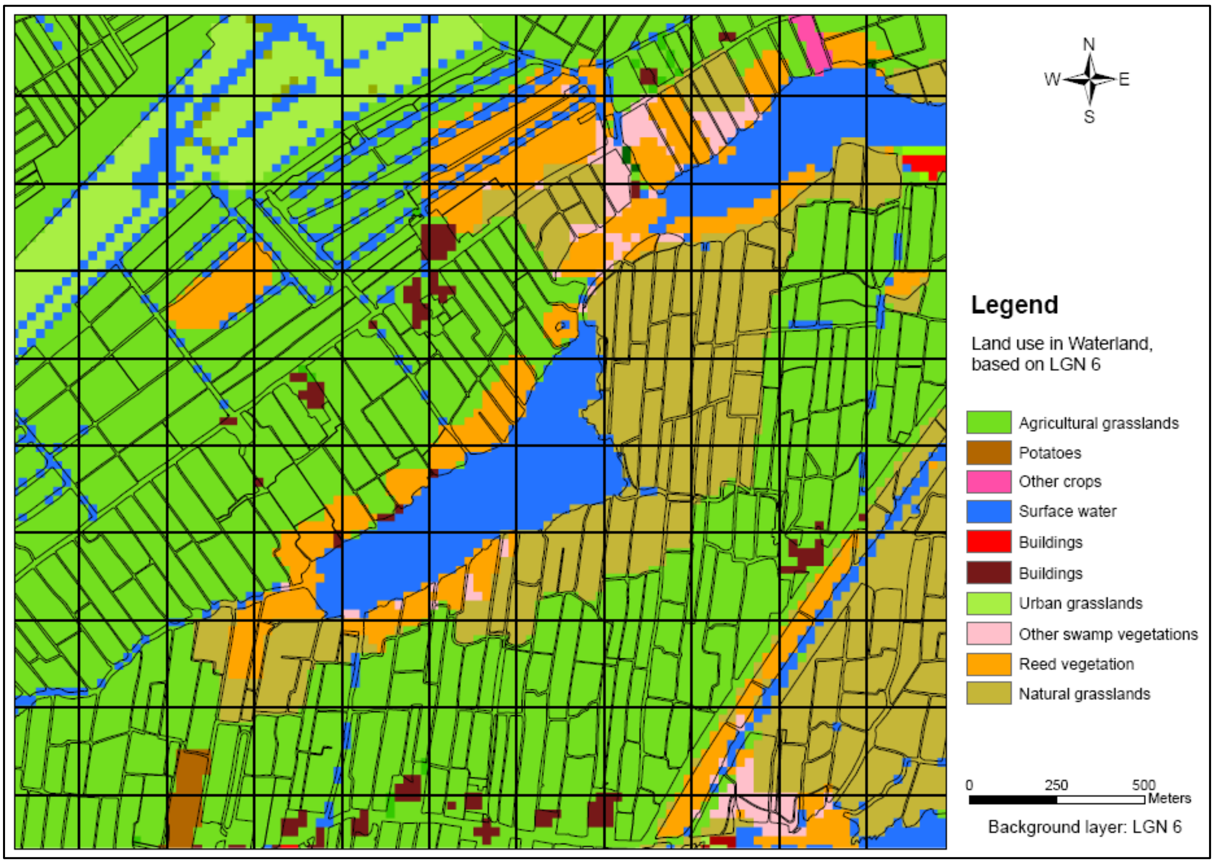
## APPENDIX O: FIRST MOWING DAY DETECTION IN WATERLAND




Management types, classified based on a field visit at May 25, 2009 (Raes *et al.* 2010).




First mowing days in Waterland, 2009




Land use in Waterland (LGN 6)

## APPENDIX P: A1 – TRANSFORMATION OF MOD09Q1 TO RD COORDINATES

```
# ---------------------------------------------------------------------------
# Transformation of MOD09Q1 from WGS84 to RD coordinates
# Created on: Wed Mar 02 2011 11:53:54 AM
# Author: Martin Lips
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create(9.3)
gp.OverwriteOutput = 1

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

# Set up workspace (create folders and create list of tif-images)
root = 'D:\\MartinLips\\MODISdata'
fl_org = 'BronData\\2010MOD09Q1JanDec' # This dir will be read for creating a list of tif files
fl_scr = 'scratch'
fl_finMOD09Q1 = 'GebruiksData\\Ark2010MOD09Q1JanDec' # this is the output folder
gp.CreateFolder_management(root, fl_finMOD09Q1)
gp.workspace = root + "\\" + fl_org
li_org = gp.ListRasters("" , "TIF")

print li_org
print len(li_org)

# Set counter
i = 0

while i < len(li_org):

   # Define variables
   vr_org = root + "\\" + fl_org + "\\" + li_org[i] # actueel ingelezen bronbestand
   vr_part = li_org[i].split(".") # only file name without extention
   vr_reprojectVI = root + "\\" + fl_scr + "\\" + "vr_reprojectVI.img"
   vr_reprojectbnd1and2 = root + "\\" + fl_scr + "\\" + "vr_reprojectbnd1and2"
   vr_reprojectbnd3blue = root + "\\" + fl_scr + "\\" + "vr_reprojectbnd3blue.img"
   vr_clipbnd1 = root + "\\" + fl_scr + "\\" + "vr_clipbnd1.img"
   vr_clipbnd2 = root + "\\" + fl_scr + "\\" + "vr_clipbnd2.img"
   vr_blckbnd1 = root + "\\" + fl_scr + "\\" + "vr_blckbnd1.img"
   vr_blckbnd2 = root + "\\" + fl_scr + "\\" + "vr_blckbnd2.img"
   vr_finMOD09Q1 = root + "\\" + fl_finMOD09Q1 + "\\" +  vr_part[0] + vr_part[2] + vr_part[4] + ".img"

   # Set the Geoprocessing environment...
   gp.newPrecision = "DOUBLE"
   gp.XYResolution = "0.001 Meters"
   gp.scratchWorkspace = ""
   gp.MTolerance = ""
   gp.compression = "LZ77"
   gp.randomGenerator = "0 ACM599"
```

```
    gp.outputCoordinateSystem =
"PROJCS['RD_New',GEOGCS['GCS_Amersfoort',DATUM['D_Amersfoort',SPHEROID['Bessel_1841',6377397.155,299.152812
8]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Double_Stereographic'],PARAMETER['Fal
se_Easting',155000.0],PARAMETER['False_Northing',463000.0],PARAMETER['Central_Meridian',5.38763888888889],PARA
METER['Scale_Factor',0.9999079],PARAMETER['Latitude_Of_Origin',52.15616055555555],UNIT['Meter',1.0]],VERTCS['NAP',
VDATUM['Normaal_Amsterdams_Peil'],PARAMETER['Vertical_Shift',0.0],PARAMETER['Direction',1.0],UNIT['Meter',1.0]]"
    gp.rasterStatistics = "STATISTICS 1 1"
    gp.snapRaster = ""
    gp.projectCompare = "FULL"
    gp.outputZFlag = "Disabled"
    gp.qualifiedFieldNames = "true"
    gp.tileSize = "128 128"
    gp.pyramid = "PYRAMIDS -1 CUBIC"
    gp.extent = "143000 462000 165500 480000"
    gp.XYTolerance = "0.001 Meters"
    gp.cellSize = "MINOF"
    gp.outputZValue = ""
    gp.outputMFlag = "Disabled"
    gp.geographicTransformations = ""
    gp.ZResolution = ""
    gp.mask = ""
    gp.workspace = ""
    gp.MResolution = ""
    gp.derivedPrecision = "DOUBLE"
    gp.ZTolerance = ""

    # Process: Project Raster...
    gp.ProjectRaster_management(vr_org , vr_finMOD09Q1,
"PROJCS['RD_New',GEOGCS['GCS_Amersfoort',DATUM['D_Amersfoort',SPHEROID['Bessel_1841',6377397.155,299.152812
8]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Double_Stereographic'],PARAMETER['Fal
se_Easting',155000.0],PARAMETER['False_Northing',463000.0],PARAMETER['Central_Meridian',5.38763888888889],PARA
METER['Scale_Factor',0.9999079],PARAMETER['Latitude_Of_Origin',52.15616055555555],UNIT['Meter',1.0]]", "CUBIC",
"250", "Amersfoort_To_WGS_1984_2", "",
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwi
ch',0.0],UNIT['Degree',0.0174532925199433]]")



    print li_org[i] + " done"

    i += 1

print "End of script"
```

## APPENDIX Q: B1 – TRANSFORMATION OF MOD09A1 TO RD COORDINATES

```
# ---------------------------------------------------------------------------
# Transformation of MOD09A1 from WGS84 to RD coordinates
# Created on: Wed Mar 02 2011 11:53:54 AM
# Author: Martin Lips
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create(9.3)
gp.OverwriteOutput = 1

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

# Set up workspace (create folders and create list of tif-images)
root = 'D:\\MartinLips\\MODISdata'
fl_org = 'BronData\\2010MOD09A1JanDec' # This dir will be read for creating a list of tif files
fl_scr = 'scratch'
fl_finMOD09A1 = 'GebruiksData\\Ark2010MOD09A1JanDec' # this is the output folder
gp.CreateFolder_management(root, fl_finMOD09A1)
gp.workspace = root + "\\" + fl_org
li_org = gp.ListRasters("" , "TIF")

# Set counter
i = 0

while i < len(li_org):

    # Define variables
    vr_org = root + "\\" + fl_org + "\\" + li_org[i] # actueel ingelezen bronbestand
    vr_part = li_org[i].split(".") # only file name without extention
    vr_finMOD09A1 = root + "\\" + fl_finMOD09A1 + "\\" +  vr_part[0] + vr_part[2] + vr_part[4] + ".img"

    # Set the Geoprocessing environment...
    gp.newPrecision = "DOUBLE"
    gp.XYResolution = "0.001 Meters"
    gp.scratchWorkspace = ""
    gp.MTolerance = ""
    gp.compression = "LZ77"
    gp.randomGenerator = "0 ACM599"
    gp.outputCoordinateSystem =
"PROJCS['RD_New',GEOGCS['GCS_Amersfoort',DATUM['D_Amersfoort',SPHEROID['Bessel_1841',6377397.155,299.152812
8]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Double_Stereographic'],PARAMETER['Fal
se_Easting',155000.0],PARAMETER['False_Northing',463000.0],PARAMETER['Central_Meridian',5.38763888888889],PARA
METER['Scale_Factor',0.9999079],PARAMETER['Latitude_Of_Origin',52.15616055555555],UNIT['Meter',1.0]],VERTCS['NAP',
VDATUM['Normaal_Amsterdams_Peil'],PARAMETER['Vertical_Shift',0.0],PARAMETER['Direction',1.0],UNIT['Meter',1.0]]"
    gp.rasterStatistics = "STATISTICS 1 1"
    gp.snapRaster = ""
    gp.projectCompare = "FULL"
    gp.outputZFlag = "Disabled"
```

```
    gp.qualifiedFieldNames = "true"
    gp.tileSize = "128 128"
    gp.pyramid = "PYRAMIDS -1 CUBIC"
    gp.extent = "143000 462000 165500 480000"
    gp.XYTolerance = "0.001 Meters"
    gp.cellSize = "MINOF"
    gp.outputZValue = ""
    gp.outputMFlag = "Disabled"
    gp.geographicTransformations = ""
    gp.ZResolution = ""
    gp.mask = ""
    gp.workspace = ""
    gp.MResolution = ""
    gp.derivedPrecision = "DOUBLE"
    gp.ZTolerance = ""

    # Process: Project Raster...
    gp.ProjectRaster_management(vr_org , vr_finMOD09A1,
"PROJCS['RD_New',GEOGCS['GCS_Amersfoort',DATUM['D_Amersfoort',SPHEROID['Bessel_1841',6377397.155,299.152812
8]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Double_Stereographic'],PARAMETER['Fal
se_Easting',155000.0],PARAMETER['False_Northing',463000.0],PARAMETER['Central_Meridian',5.38763888888889],PARA
METER['Scale_Factor',0.9999079],PARAMETER['Latitude_Of_Origin',52.15616055555555],UNIT['Meter',1.0]]", "CUBIC",
"250", "Amersfoort_To_WGS_1984_2", "",
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwi
ch',0.0],UNIT['Degree',0.0174532925199433]]")

    print li_org[i] + " done"
    print i
    i += 1

print "End of script"
```

## APPENDIX R: A2 – PROCESSING OF THE 8-DAYS EVI TIME SERIES

```
# ---------------------------------------------------------------------------
# Processing of the EVI 8-days vegetation index time series
# Created on: Wed May 26 2011 1:13:14 PM
# Author: Martin Lips
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create(9.3)
gp.OverwriteOutput = 1

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

# Set up workspace
root = 'D:\\MartinLips\\MODISdata\\GebruiksData'
fl_bnd1 = 'NL2007MOD09Q1JanDec'
fl_bnd2 = 'NL2007MOD09Q1JanDec'
fl_bnd3 = 'NL2007MOD09A1JanDec'
fl_scr = 'scratch'
fl_EVI = 'NL2007EVI_8days'
gp.CreateFolder_management(root, fl_scr)
gp.CreateFolder_management(root, fl_EVI)
gp.workspace = root + "\\" + fl_bnd1
li_bnd1 = gp.ListRasters("*b01.img", "IMG")
li_bnd2 = gp.ListRasters("*b02.img", "IMG")
gp.workspace = root + "\\" + fl_bnd3
li_bnd3 = gp.ListRasters("*b03.img", "IMG")

if len(li_bnd1) == len(li_bnd2) == len(li_bnd3):
    print li_bnd1
    print li_bnd2
    print li_bnd3

    # Set counter
    i = 0
    j = 0
    k = 0

    while i < len(li_bnd1):

        # Define variables
        vr_bnd1 = root + "\\" + fl_bnd1 + "\\" + li_bnd1[i] # red
        vr_bnd2 = root + "\\" + fl_bnd2 + "\\" + li_bnd2[j] # NIR
        vr_bnd3 = root + "\\" + fl_bnd3 + "\\" + li_bnd3[k] # blue
        vr_bnd1float = root + "\\" + fl_scr + "\\" + "bnd1float.img"
        vr_bnd2float = root + "\\" + fl_scr + "\\" + "bnd2float.img"
```

```
vr_bnd3float = root + "\\" + fl_scr + "\\" + "bnd3float.img"
vr_bnd1rescaled = root + "\\" + fl_scr + "\\" + "bnd1rescaled.img"
vr_bnd2rescaled = root + "\\" + fl_scr + "\\" + "bnd2rescaled.img"
vr_bnd3rescaled = root + "\\" + fl_scr + "\\" + "bnd3rescaled.img"
vr_num = root + "\\" + fl_scr + "\\" + "numerator.img"
vr_denpart1 = root + "\\" + fl_scr + "\\" + "denpart1.img"
vr_denpart2 = root + "\\" + fl_scr + "\\" + "denpart2.img"
vr_denpart1minus2 = root + "\\" + fl_scr + "\\" + "denpart1minus2.img"
vr_denpart3 = root + "\\" + fl_scr + "\\" + "denpart3.img"
vr_denom = root + "\\" + fl_scr + "\\" + "denominator.img"
vr_numdenom = root + "\\" + fl_scr + "\\" + "numdenom.img"
filenamepart = li_bnd1[i]
vr_EVI = root + "\\" + fl_EVI + "\\" + filenamepart[8:15] + "_8daysEVI.img"

# Transfer integers to floats band1
gp.Float_sa(vr_bnd1, vr_bnd1float)

# Transfer integers to floats band2
gp.Float_sa(vr_bnd2, vr_bnd2float)

# Transfer integers to floats band3
gp.Float_sa(vr_bnd3, vr_bnd3float)

# Rescale bnd1(red), devide by 10000
gp.Divide_sa(vr_bnd1float, 10000, vr_bnd1rescaled)

# rescale bnd1(NIR): devide by 10000
gp.Divide_sa(vr_bnd2float, 10000, vr_bnd2rescaled)

# rescale bnd1(blue): devide by 10000
gp.Divide_sa(vr_bnd3float, 10000, vr_bnd3rescaled)

# process numerator: NIR - RED (numerator)
gp.Minus_sa(vr_bnd2rescaled, vr_bnd1rescaled, vr_num)

# Process denominator part 1: C1 * RED
gp.Times_sa(6.0, vr_bnd1rescaled, vr_denpart1)

# process denominator part 2: C2 * BLUE
gp.Times_sa(vr_bnd3rescaled, 7.5, vr_denpart2)

# process denominator part1minus2: denpart 1 - denpart 2
gp.Minus_sa(vr_denpart1, vr_denpart2, vr_denpart1minus2)

# process denominator part 1 * 2: denpart1minus2 +  NIR
gp.Plus_sa(vr_denpart1minus2, vr_bnd2rescaled, vr_denpart3)

# process denominator final: denpart1plus2 * denpart3
gp.Plus_sa(1.0, vr_denpart3, vr_denom)

# process num/denom
gp.Divide_sa(vr_num, vr_denom, vr_numdenom)

# process final EVI number
gp.Times_sa(2.5, vr_numdenom, vr_EVI)
```

```
        print li_bnd1[i] + " done"

        i += 1
        j += 1
        k += 1

else:
    print "Wrong inputdata, lists have no equal length"

print "End of script"
```

## APPENDIX S: A3 – DETECTION OF THE FIRST MOWING DAY PER PIXEL (8-DAYS TIME SERIES)

```
# ---------------------------------------------------------------------------
# Deriving the first mowing day out of the 8-days EVI time series
# Created on: May 26 2011 2:16:37 PM
# Author: Martin Lips
# ---------------------------------------------------------------------------


def runner(): # load complete file in IDLE, then run it with the command "runner()"
    for i in range(4,12,1):
        i=i/100.0
        tester(i)
    print tester

def tester(var):

    # Import system modules
    import sys, string, os, arcgisscripting

    # Create the Geoprocessor object
    gp = arcgisscripting.create(9.3)
    gp.OverwriteOutput = 1

    # Check out any necessary licenses
    gp.CheckOutExtension("spatial")

    # Load required toolboxes...
    gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

    # Set up workspace (create folders and create list of tif-images)
    root = 'D:\\MartinLips\\MODISdata\\Gebruiksdata'
    fl_org = 'NL2008EVI8days' # This dir will be read for creating a list of tif files
    fl_scr = 'scratch'
    fl_mowdate2010 = 'MowDate8days2008_later'
    gp.CreateFolder_management(root, fl_scr)
    gp.CreateFolder_management(root, fl_mowdate2010)
    gp.workspace = root + "\\" + fl_org
    li_org = gp.ListRasters("*EVI.img" , "IMG")


    # Set counter and create empty list whereto the
    # MODIS spring time serie must be added

    i = 10 # means starting date equal to day 81 = March 22
    li_springtimeserie = []
    while i < 27: # last date of the spring data is day 209 July 28
        li_springtimeserie.append(li_org[i]) # adds the data file names to the list
        i = i + 1 # counter

    print li_springtimeserie
```

```
    # create a new raster layer with only the grassland pixels
    # and with a constant value of 9999

    try:
        # Set the output raster name
        vr_emptyras = root + "\\" + fl_mowdate2010 + "\\" + "MowDate0.img"
        outRaster = vr_emptyras

        # Check out Spatial Analyst extension license
        gp.CheckOutExtension("Spatial")

        # Process: Create Constant Raster
        constantValue = 9999
        cellSize = 250
        rasterExtent = root + "\\" + fl_org + "\\" + li_springtimeserie[0]
        gp.CreateConstantRaster_sa(outRaster, constantValue, "INTEGER", cellSize, rasterExtent)

    except:
        # If an error occurred while running a tool, then print the messages
        print gp.GetMessages()


    j = 0
    daydate1 = 81
    mowedpixelperiods = ""

    while j < (len(li_springtimeserie) - 1):
        daydate2 = daydate1 + 8
        date1 = j
        date2 = j + 1
        meanday = daydate2
        treshold = str(var) # difference parameter for standard EVI fluctuations between 0.09-0.17. Interpret only differences
below treshold as mowing.


        # create raster with difference between evi (date1-date2)

        vr_date1 = root + "\\" + fl_org + "\\" + li_springtimeserie[date1]
        vr_date2 = root + "\\" + fl_org + "\\" + li_springtimeserie[date2]
        vr_date1mindate2 = root + "\\" + fl_mowdate2010 + "\\" + "difEVIday" + str(daydate1) + "and" + str(daydate2) +
".img"
        vr_conmowresult = root + "\\" + fl_mowdate2010 + "\\" + "conmowday" + str(daydate1) + "and" + str(daydate2) +
".img"

        gp.Minus_sa(vr_date2, vr_date1, vr_date1mindate2)

        print vr_date1mindate2 + " done"

        # Process: Con
        gp.Con_sa(vr_date1mindate2, meanday, vr_conmowresult, 9999, ("VALUE <= -" + treshold + " AND VALUE > -0.30"))

        daydate1 += 8
        mowedpixelperiods += vr_conmowresult
```

```
        if j < (len(li_springtimeserie) - 2):
            semicolon = u':'
            mowedpixelperiods += ";"

        j += 1

        print "mowedpixelperiods:"
        print mowedpixelperiods

    # Process: Cell Statistics...
    vr_lowestmowingdayperpixel = root + "\\" + fl_mowdate2010 + "\\" + "lowestmowingday_8days_2008_later_" +
treshold + ".img"
    gp.CellStatistics_sa(mowedpixelperiods, vr_lowestmowingdayperpixel, "MINIMUM")

    print str(var) + " script finished"
```

# APPENDIX T: C1 – TRANSFORMATION OF MOD13Q1 TO RD COORDINATES

```
# ---------------------------------------------------------------------------
# Reprojection of the 16-days time series from UTM to RD coordinates
# Created on: Wed Mar 03 2011 1:43:05 PM
# Author: Martin Lips
# ---------------------------------------------------------------------------

# Import system modules
import sys, string, os, arcgisscripting

# Create the Geoprocessor object
gp = arcgisscripting.create(9.3)
gp.OverwriteOutput = 1

# Check out any necessary licenses
gp.CheckOutExtension("spatial")

# Load required toolboxes...
gp.AddToolbox("C:/Program Files/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

# Set up workspace (create folders and create list of tif-images)
root = 'D:\\MartinLips\\MODISdata'
fl_org = 'BronData\\2007NDVI250JanDec' # This dir will be read for creating a list of tif files
fl_scr = 'scratch'
fl_finVIrescaled = 'GebruiksData\\Ark2007NDVI250JanDec' # this is the output folder
gp.CreateFolder_management(root, fl_scr)
gp.CreateFolder_management(root, fl_finVIrescaled)
gp.workspace = root + "\\" + fl_org
li_org = gp.ListRasters("" , "TIF")

# Set counter
i = 0

while i < len(li_org):

   # Define variables
   vr_org = root + "\\" + fl_org + "\\" + li_org[i] # actueel ingelezen bronbestand
   vr_part = li_org[i].split(".") # alleen de filenaam zonder extentie
   vr_finVI = root + "\\" + fl_scr + "\\" +  vr_part[0] + vr_part[2] + vr_part[4] + ".img"
   vr_finVIrescaled = root + "\\" + fl_finVIrescaled + "\\" +  vr_part[0] + vr_part[2] + vr_part[4] + ".img"

   # Set the Geoprocessing environment...
   gp.newPrecision = "DOUBLE"
   gp.XYResolution = "0.001 Meters"
   gp.scratchWorkspace = ""
   gp.MTolerance = ""
   gp.compression = "LZ77"
   gp.randomGenerator = "0 ACM599"
   gp.outputCoordinateSystem =
"PROJCS['RD_New',GEOGCS['GCS_Amersfoort',DATUM['D_Amersfoort',SPHEROID['Bessel_1841',6377397.155,299.152812
8]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Double_Stereographic'],PARAMETER['Fal
se_Easting',155000.0],PARAMETER['False_Northing',463000.0],PARAMETER['Central_Meridian',5.38763888888889],PARA
```

```
METER['Scale_Factor',0.9999079],PARAMETER['Latitude_Of_Origin',52.15616055555555],UNIT['Meter',1.0]],VERTCS['NAP',
VDATUM['Normaal_Amsterdams_Peil'],PARAMETER['Vertical_Shift',0.0],PARAMETER['Direction',1.0],UNIT['Meter',1.0]]"
    gp.rasterStatistics = "STATISTICS 1 1"
    gp.snapRaster = ""
    gp.projectCompare = "FULL"
    gp.outputZFlag = "Disabled"
    gp.qualifiedFieldNames = "true"
    gp.tileSize = "128 128"
    gp.pyramid = "PYRAMIDS -1 CUBIC"
    gp.extent = "143000 462000 165500 480000"
    gp.XYTolerance = "0.001 Meters"
    gp.cellSize = "MINOF"
    gp.outputZValue = ""
    gp.outputMFlag = "Disabled"
    gp.geographicTransformations = ""
    gp.ZResolution = ""
    gp.mask = ""
    gp.workspace = ""
    gp.MResolution = ""
    gp.derivedPrecision = "DOUBLE"
    gp.ZTolerance = ""

        # Process: Reproject Raster to RDnew by Amersfoort_to_wgs_2 using CUBIC and clip study area (Arkemheen)
    gp.ProjectRaster_management(vr_org , vr_finVI,
"PROJCS['RD_New',GEOGCS['GCS_Amersfoort',DATUM['D_Amersfoort',SPHEROID['Bessel_1841',6377397.155,299.152812
8]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.0174532925199433]],PROJECTION['Double_Stereographic'],PARAMETER['Fal
se_Easting',155000.0],PARAMETER['False_Northing',463000.0],PARAMETER['Central_Meridian',5.38763888888889],PARA
METER['Scale_Factor',0.9999079],PARAMETER['Latitude_Of_Origin',52.15616055555555],UNIT['Meter',1.0]]", "CUBIC",
"250", "Amersfoort_To_WGS_1984_2", "",
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',6378137.0,298.257223563]],PRIMEM['Greenwi
ch',0.0],UNIT['Degree',0.0174532925199433]]")

    # Porcess: Multiply by 0.0001 to remove scale factor
    gp.Times_sa(vr_finVI, 0.0001, vr_finVIrescaled)

        print li_org[i] + " done"
    #print i

    i += 1

# Process: Delete intermediate files
gp.Delete_management(vr_finVI, "")
print "End of script"
```

## APPENDIX U: D4 – DETECTION OF THE FIRST MOWING DAY PER PIXEL (16-DAYS TIME SERIES)

```
# ---------------------------------------------------------------------------
# Detection of mowing days based on the 16-days time series
# Created on: Mon May 30 2011 11:24:23 AM
# Author: Martin Lips
# ---------------------------------------------------------------------------

def runner(): # load complete file in Python, then run it with the command "runner()"
    for i in range(2,13,1):
        i=i/100.0
        tester(i)

def tester(var):

    # Import system modules
    import sys, string, os, arcgisscripting

    # Create the Geoprocessor object
    gp = arcgisscripting.create(9.3)
    gp.OverwriteOutput = 1

    # Check out any necessary licenses
    gp.CheckOutExtension("spatial")

    # Load required toolboxes...
    gp.AddToolbox("C:/Program Files (x86)/ArcGIS/ArcToolbox/Toolboxes/Data Management Tools.tbx")

    # Set up workspace (create folders and create list of tif-images)
    root = 'L:\\MartinLips\\MODISdata\\Gebruiksdata'
    fl_org = 'NL2010NDVI250JanDec' # This dir will be read for creating a list of tif files
    fl_scr = 'scratch'
    fl_mowdate2010 = 'MowDate16days2010later'
    gp.CreateFolder_management(root, fl_scr)
    gp.CreateFolder_management(root, fl_mowdate2010)
    gp.workspace = root + "\\" + fl_org
    li_org = gp.ListRasters("*EVI.img" , "IMG")


    #print li_org
    #print len(li_org)

    print li_org[4]

    # Set counter and create empty list whereto the
    # MODIS spring time serie must be added

    i = 4 # means starting date equal to day 81 March 22
    li_springtimeserie = []
    while i < 13: # last date of the spring data is day 209 July 28
        li_springtimeserie.append(li_org[i]) # adds the data file names to the list
        i = i + 1 # counter
```

```
    print li_springtimeserie

    # create a new raster layer with only the grassland pixels
    # and with a constant value of 9999

    try:
        # Set the output raster name
        vr_emptyras = root + "\\" + fl_mowdate2010 + "\\" + "MowDate0.img"
        outRaster = vr_emptyras

        # Check out Spatial Analyst extension license
        # gp.CheckOutExtension("Spatial")

        # Process: Create Constant Raster
        constantValue = 9999
        cellSize = 250
        rasterExtent = root + "\\" + fl_org + "\\" + li_springtimeserie[0]
        gp.CreateConstantRaster_sa(outRaster, constantValue, "INTEGER", cellSize, rasterExtent)

    except:
        # If an error occurred while running a tool, then print the messages
        print gp.GetMessages()

    j = 0
    daydate1 = 81
    mowedpixelperiods = ""


    while j < (len(li_springtimeserie) - 1):
        daydate2 = daydate1 + 16
        date1 = j
        date2 = j + 1
        meanday = daydate2
        treshold = str(var) # difference parameter for standard EVI fluctuations. Interpret only differences below treshold as
mowing.

        # create raster with difference between evi (date1-date2)

        vr_date1 = root + "\\" + fl_org + "\\" + li_springtimeserie[date1]
        vr_date2 = root + "\\" + fl_org + "\\" + li_springtimeserie[date2]
        vr_date1mindate2 = root + "\\" + fl_mowdate2010 + "\\" + "difEVIday" + str(daydate1) + "and" + str(daydate2) +
".img"
        vr_conmowresult = root + "\\" + fl_mowdate2010 + "\\" + "conmowday" + str(daydate1) + "and" + str(daydate2) +
".img"

        gp.Minus_sa(vr_date2, vr_date1, vr_date1mindate2)

        print vr_date1mindate2 + " done"

        # Process: Con
        gp.Con_sa(vr_date1mindate2, meanday, vr_conmowresult, 9999, ("VALUE <= -" + treshold))

        daydate1 += 16
        mowedpixelperiods += vr_conmowresult
```

```
      if j < (len(li_springtimeserie) - 2):
        semicolon = u':'
        mowedpixelperiods += ";"

      j += 1

      print "mowedpixelperiods:"
      print mowedpixelperiods


    #Process: Cell Statistics...
    vr_lowestmowingdayperpixel = root + "\\" + fl_mowdate2010 + "\\" + "lowestmowingday_16days_2010_" + treshold +
  ".img"
    gp.CellStatistics_sa(mowedpixelperiods, vr_lowestmowingdayperpixel, "MINIMUM")

    print str(var) + " script finished"
```