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Land Surface Phenology as an indicator of performance of conservation policies like Natura2000

Gunjan Sharma

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Department of
Physical Geography and Ecosystem Science
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

LUND UNIVERSITY

ITC UNIVERSITY OF TWENTE.
FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

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Gunjan Sharma

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Supervisor

Lars Eklundh (Lund University)

Exam committee:

Examiner 1: Cecilia Akselsson (Lund University)

Examiner 2: Zhanzhang Cai (Lund University)

ABSTRACT

Considering the growing pressure on various ecosystems all around the world, the development of ecological indicators for assessing the health and condition of the ecosystems has become an integral part of environmental management and policy making efforts. Such indicators do not only simplify the complex ecosystem processes but can also act as a measure of performance of a conservation policy. The use of remote sensing in developing these indicators has been very limited due to a gap that exists between nature conservation agencies and remote sensing communities. The present research is an attempt at bridging this gap by testing the potential of land surface phenology (LSP) in developing indicators which can illustrate the performance of conservation policies like Natura2000.

A total of 60 sites were selected across five largest biogeographical regions of Europe, out of which 30 sites were within the Natura2000 protected network while 30 sites were outside the protected network. Moderate Resolution Imaging Spectroradiometer (MODIS) Normalised Difference Vegetation Index **(**NDVI) data was used to derive phenological metrics for land cover class pastures, for within and outside the Natura2000 protection network for a time period between 2001-2015. Eight phenological parameters namely seasonal amplitude, peak value, large integral, small integral, start of growing season, end of growing season, length of growing season and peak of season were generated using the TIMESAT software and were compared for differences within and outside protected areas. A change in management practices after the establishment of Natura2000 was assumed to have an impact on the vegetation vigour of the pastures, thereby confirming the implementation of Natura2000.

The results showed a consistent significant difference in phenological parameters such as start of growing season, length of growing season and large integral (integrated NDVI values), between sites within and outside Natura2000 network, across majority of the biogeographical regions. These differences in phenological parameters emerged as a result of differences in management practices within and outside protected areas because of their conservation status, thus confirming the effectiveness of Natura2000. Additionally, a trend analysis was performed on all the sites using the Mann-Kendall test to detect the presence of monotonic trends. Only 10% significant trends were observed for different parameters. Although a majority of the sites displayed a tendency for negative trends, not enough evidence was found to confirm that the protected and unprotected sites differed consistently in trends for any given phenological metric. A plausible reason for this could be the short time series and single pixel representation of each study site. The SPEI (Standardised Precipitation-Evapotranspiration Index) and FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) drought indicator data was analysed to see if the 10% significant trends were drought-induced. However, only two sites in the Mediterranean region with significant trends were observed to coincide with the significant drought-indicator values suggesting that the sites were not largely influenced by drought. For related future studies, use of time series data for a longer period of time and study sites represented by more than a single pixel have been recommended in order to achieve better results from trend analysis.

Keywords: Land Surface Phenology (LSP), ecological indicators, Natura2000, MODIS NDVI, TIMESAT, trend analysis.

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Gunjan

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ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer
CORINE	Coordinate Information on the Environment
EC	European Commission
EEA	European Environmental Agency
EIA	Environmental Impact Assessment
EM	Electromagnetic
ESRI	Environmental Systems Research Institute
EU	European Union
EVI	Enhanced Vegetation Index
FAO	Food and Agricultural Organization of the United Nations
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GIS	Geographic Information System
LAI	Leaf Area Index
LSP	Land Surface Phenology
MK	Mann-Kendall
MODIS	Moderate Resolution Imaging Spectro-radiometer
MVC	Maximum Value Composite
NDVI	Normalised Difference Vegetation Index
NIR	Near Infrared
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Cente
PPI	Plant Phenology Index
RED	Renewable Energy Directive
SACs	Special Areas of Conservation
SPAs	Special Protection Areas
SPEI	Standardised Precipitation-Evapotranspiration Index
SPOT	Satellite Pour l’Observation de la Terre
SWIR	Short Wave Near Infrared
VI	Vegetation Indices

1 INTRODUCTION

1.1 Background

Human beings, just like many other species of organisms that populate the earth, benefit from different ecosystem products and services provided by various ecosystems. The fact that a number of ecosystems are currently experiencing immense pressure due to anthropogenic and climatic factors, results in the need for development of ecological indicators to assess the state and health of ecosystems. The development of these ecological indicators has become an integral part of policy making and planning for a sustainable development. They not only serve the function of illustrating environmental trends but also are measures of how well/poorly the policies are working (Hammond et al. 1995). Furthermore a qualitative or quantitative analysis can be done to evaluate ecosystem health using these indicators, depending on the ecosystem structure, ecosystem function and the aim of assessment (Lu et al. 2015). Constanza (1992), as cited in Lu et al. (2015), proposed that ‘‘ecosystem health is closely linked to the idea of sustainability, which is seen to be a comprehensive, multi-scale, dynamic measure of system resilience, organization, and vigour’’. This idea led to the development of three groups of indicators, vigour, organization and resilience (VOR) describing the aggregate condition of the ecosystem, where for example vigour could be represented by productivity, organization by biodiversity indexes and resilience by recovery time after damage. In this regard, although ecological indicators are widely being used by policy makers in environmental management, yet many data deficiencies and a lack of time series data, restrict the ability to pursue many environmental issues (Esty et al. 2008). Satellite based remote sensing has the potential to fill this gap with the global coverage and wide range of tools it offers.

Technologies like remote sensing and Geographic Information System (GIS) play a vital role in the development of environmental indicators to evaluate the successful implementation and observations about the surface of the Earth from the satellites. Where on one hand the satellite observed data in digital form makes computer based trend analysis easy to perform, while on the other hand GIS makes use of attribute data to analyse ecosystem condition and change, creating a connection between change and possible impact (Revenga 2005). Remote sensing aids in the development of ecological indicators that can be applied on a wide range of scales. On the global scale indicators are mainly appropriate for monitoring and scenario development for assessing policy options while on the regional and local scale they can offer themselves as an essential tool for natural resource management and pollution control (Revenga 2005). This satellite based remote sensing can enhance our understanding and capacity to maintain and manage ecosystems in a sustainable way.

Ecosystem health and dynamics can be characterized by vegetation phenology and productivity, acquired through remote sensing. This satellite observed phenology is generally known as Land Surface Phenology (LSP) and is defined as the seasonal pattern of variation in vegetated land surfaces observed from remote sensing (“Land Surface Phenology and Remote Sensing (LSP/RS) | USA National Phenology Network,” 2016). LSP is an important indicator of ecosystem dynamics under a changing environment at different temporal scales, whether the change is slow and gradual due to climate, medium paced due to change in management practices or an abrupt change due to sudden disturbances like fire. Additionally, LSP cannot merely detect changes in the vegetal cover but it can also provide a deeper understanding of biophysical characteristics of vegetation cover through the use of vegetation indices. Spectral vegetation indices are a mathematical combination of visible and near-infrared reflectance bands of the electromagnetic spectrum, which are semi-analytical measures of vegetation activity displaying spatio-temporal variability of green cover (Viña 2011). Tucker & Sellers (1986) proposed that there is a strong and positive relationship between vegetation indices and primary productivity. Similarly Higginbottom & Symeonakis (2014) suggested that multi temporal analysis of vegetation indices can provide a sophisticated measure of ecosystem health and condition. Therefore, vegetation indices can provide a deep insight into the health and condition of an ecosystem, for example, the most widely used vegetation index Normalised Differential Vegetation Index (NDVI) ("Remote Sensing Phenology" 2015). NDVI bears a strong correlation with the aboveground primary productivity and thus serves as an index of ecosystem function (Kerr and Ostrovsky 2003).

Different studies have focused on the use of remote sensing for assessing different ecosystems. For example for biodiversity assessment in tropical forests and wetlands (Fuller et al. 1998), for urban ecosystems (Wilson et al. 2003), for health assessment of grassland ecosystems (Chena and Wang 2005), for river ecosystem (Wu et al. 2007) etc. Grasslands ecosystems out of all seem to be an interesting target for research because they are the world’s largest biomes harbouring a wide variety of biodiversity but at the same time they are highly dynamic ecosystems. They serve the function of supplying forage to livestock, soil protection against erosion, carbon storage and also provide great landscape views. However, in the present scenario, it becomes important to assess the health of grassland ecosystems because under the pressure of human activities, climate change and invasive species, grasslands are degrading or have a potential to do so (Xu and Guo 2015). For example, according to Food and Agricultural Organization (FAO) (2006) as cited in Collins & Beaufoy (2012) the area of grasslands in the European Union (EU) has declined by 12.8% between 1990 and 2003, and further losses have occurred since 2003. Similarly, the European Environmental Agency (EEA) (1999) as cited in LIFE (2008) listed that there has been an increasing pressure on the grassland habitats, and about 60% of the newly afforested area in the EU was formerly permanent pasture or meadows, 37% was arable land and only 3% was permanent cropland. This pressure has been on account of factors like change in land use, afforestation, change in livestock density and intensification of grassland management.

Europe has various types of grasslands ecosystems, but since most of them have been created and maintained by agricultural activities like grazing and/or mowing, they could be defined as “semi-natural grasslands” (LIFE 2008). These semi-natural grasslands of Europe have a considerable cultural, aesthetical, economical, ecological as well as agricultural value. Despite the fact that the semi-natural grasslands of Europe support a large part of the European biodiversity and serve as an important source of ecosystem services, they have continued to decline in extent and quality due to intensification of agricultural practices (King 2010). A threat to these grassland habitats poses a threat to the several plant and animal species that they harbour. For example Gärdenfors (2005) as cited in Öster (2006) enumerate that 46% of all 3653 Red listed species in Sweden are associated with the agricultural landscape, and these semi-natural grasslands constitute the main habitat of a number of these species.

A number of EU initiatives aim to protect semi-natural grasslands. To name a few, the EU Environmental Impact Assessment (EIA) Directive (1985) for protection of grasslands from conversion and agricultural intensification, the Renewable Energy Directive (RED) which aimed at preventing conversion of highly biodiverse grasslands to cultivation for biofuels, EU 2020 Biodiversity Strategy which was adopted to cease the loss of biodiversity and ecosystem services in EU by 2020 etc. (Collins & Beaufoy, 2012). Similarly, Natura2000, although not completely dedicated to grasslands, is another network of protected areas stretching across 28 EU countries, for the conservation of Europe’s most valuable species and habitats. The Natura2000 protected network has been proposed under the Birds Directive and the Habitats directive where the Habitats Directive requires the member states to establish a network of Special Areas of Conservation (SACs) along with the Special Protection Areas (SPAs) designated under the Birds Directive (79/409/EEC), creating the Natura2000 network (LIFE 2008). It does not prevent human activity in the protected network, but rather promotes the establishment and conservation of these threatened species by helping them to co-exist in a symbiotic way with the human activities. This for example is demonstrated by the fact that the farmlands make up around 40% of the total area included in Natura2000 (European Commission 2014). Furthermore, high biodiversity is associated with low agricultural productivity, therefore, most of the farmlands inside Natura2000 are located in less productive land such as wet grasslands and peatlands, on the other hand some species listed in the Natura2000 are also found on intensively managed and highly productive agricultural land. The management practices on these farmlands is associated with the objective of conservation, whether the aim is to conserve farmland habitat or to conserve farmland species.

Where on one hand conservation of vulnerable ecosystems is an essential step, on the other hand evaluation of the conservation performance becomes an equally important task. The European Environmental Agency (EEA) plays a crucial role in this dual context. EEA works to help the member countries in making decisions on improving the environment, integrating environmental considerations into economic policies for sustainable development and to coordinate the European environment information and observation network ("Who we are— European Environment Agency" 2016). For instance EEA highlights the status of Natura2000 network and its possible contribution to the plight of species and habitat (EEA 2015), it describes the state of deteriorating grassland biodiversity observed by a decline in butterfly population, using the European Grassland Butterfly Indicator based on Butterfly Monitoring Schemes in 19 countries across Europe (Van Swaay et al. 2013), in another report EEA provides an overview of the current state of ecosystems in Europe and the human pressures they are being exposed to (European Environment Agency 2016). In this manner EEA provides a sound and independent information for the development, implementation and evaluation of environmental policies ("Who we are— European Environment Agency" 2016).

1.2 Research Problem

As mentioned earlier grassland ecosystem are under a major threat compared to other habitats in Europe. Analysis by EEA based on detailed reports from EU member states shows that agricultural ecosystems, particularly grasslands in the Natura2000 network, are in a very poor state with 76% of Natura2000 grasslands being in an unfavourable i.e. inadequate or bad status; and the condition of the remaining 17% is unassessed or unknown (Collins & Beaufoy 2012). A report by The Grasslands Trust commissioned by the European Forum on Nature Conservation and Pastoralism states that anecdotal evidence point out at the inadequacy of integration between different polices and directives on grassland management and the difficulty to find data to show this lack of integration (King 2010). Collins & Beaufoy (2012) in their report highlight the poor ecological condition of semi-natural grasslands across Europe and recommend innovations in data systems, monitoring and reporting which will help to improve the effectiveness of current policies. Against that background, the need to assess the effectiveness of conservation policies like Natura2000 is extremely relevant but at the same time a highly complex task. Remote sensing confronts the issue of scale, spatially and temporally for assisting in monitoring and reporting of environmental policies like Natura2000. Borre et al. (2011) suggest that although remote sensing is an extremely powerful tool for acquiring details on multiple aspects of habitats at various spatial scales, its use in case of Natura2000 monitoring and reporting has been very restricted. They attribute this drawback to the knowledge gap that exists between the nature conservation agencies and the remote sensing community. An integration between the two disciplines is essential for the benefit of both. Moreover, the role of Natura2000 in conservation status of birds adhering to the Birds Directive, has been better known but there are no similar studies focussed on Habitats Directive for habitats assessment or species other than birds (EEA 2015).

This research aims at bridging the gap between conservation efforts and the use of remote sensing methods to evaluate the status of these conservation efforts by focussing on the habitat assessment. The use of phenological metrics derived from remotely sensed NDVI time series to approximate ecosystem health and dynamics is expected to give an insight into the performance and effectiveness of conservation policies like Natura2000, which will consequently, provide a feedback to the policy planners and decision makers.

The focus of this research is on pastures, which is a representation of ecosystem type grassland in spatial dimension (Egoh et al. 2008). The Coordinate Information on the Environment (CORINE) land cover level 2 class, pastures, falls under the level 1 class Agriculture (EEA 1994). The land cover class pastures, has been chosen for this study because it is assumed that after being incorporated in the Natura2000 protection network, a change in management practices from intensive to extensive management will be followed by a change in vegetation vigour. Additionally, in cases where those sites were incorporated in Natura2000 which were already under low intensity of farming it will be interesting to see whether their condition has maintained or undergone any change. This research will try to answer questions pertaining to the potential of LSP in detecting changes in vegetation vigour in areas inside and outside the Natura2000 protection network. This information on vegetation vigour will subsequently supply information on the health of the ecosystem, thereby indicating the conservation status of Natura2000.

1.3 Research Aim and Objectives

The overall aim of this research is to explore the potential of phenological metrics derived from remotely sensed NDVI, as robust indicators for assessing the effectiveness of Natura2000 protection network.

The aim of this research will be addressed through the following objectives:

1. To compute the phenological metrics for sites inside and outside Natura2000 protected network, from remotely sensed NDVI data.

2. To analyse and compare the variation in phenological variables inside and outside the protected network.

3. To estimate the trends in vegetation vigour using phenological metrics derived from NDVI time series and analyse them for differences within and outside Natura2000 protection network.

1.4 Outline of the thesis

The structure of the thesis has been outlined below (Fig. 1) to depict the steps taken to address the research objectives.

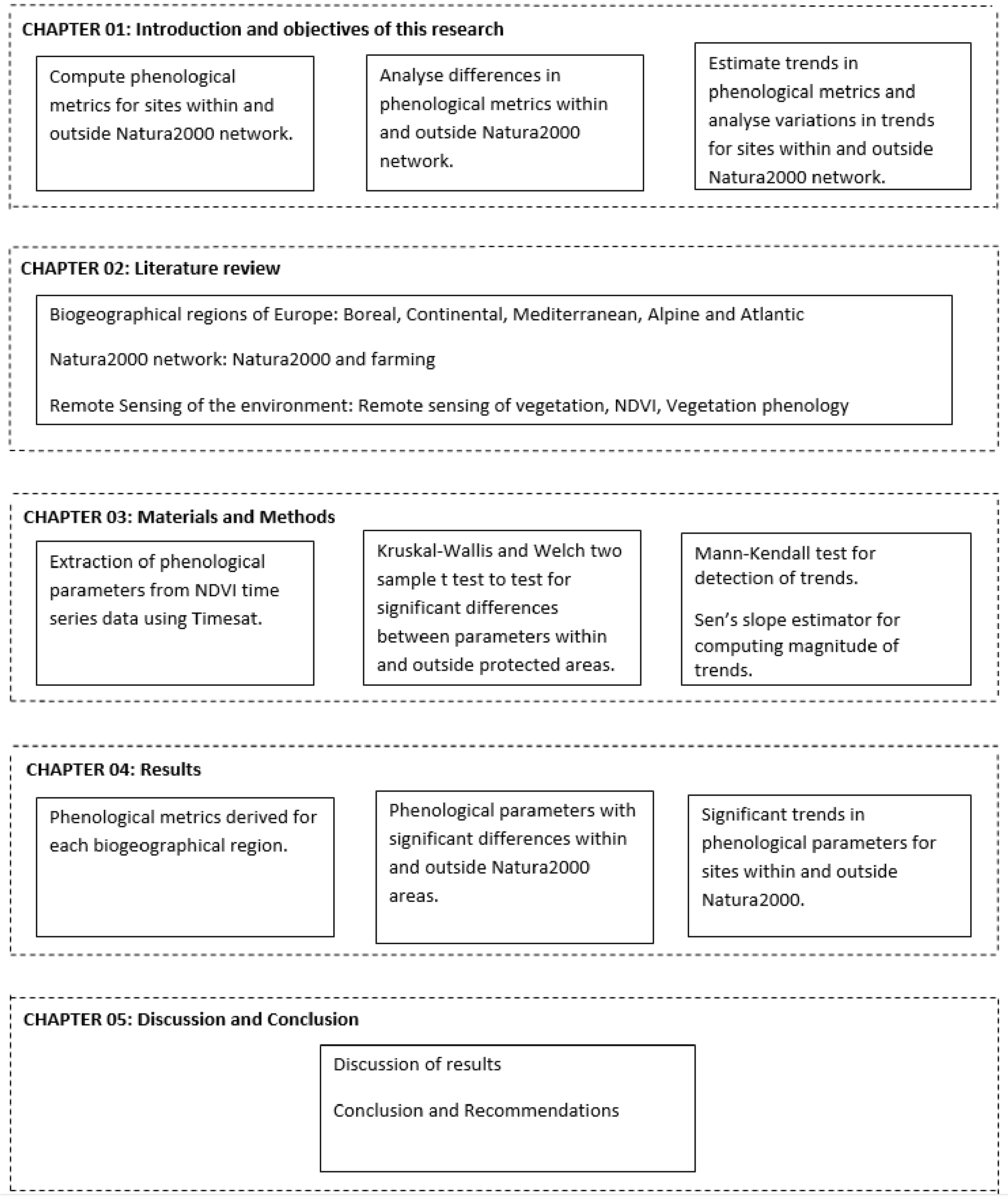

Fig. 1 Structural outline of the thesis.

2 LITERATURE REVIEW

This chapter provides an introduction and background to some important concepts that are relevant for this research.

2.1 Biogeographic Regions of Europe

EEA has classified Europe into 11 biogeographical regions namely Alpine, Anatolian, Arctic, Atlantic, Black Sea, Boreal, Continental, Macaronesia, Mediterranean, Pannonian and Steppic, each with its own set of characteristic climate, vegetation and geology (European Environment Agency 2011). They act as a useful geographical reference unit for describing the habitat types and species living under similar environmental conditions across different countries. Therefore, hereafter the term biogeographical region will be used synonymous to ecosystems. Planning at biogeographical level becomes easier as these are homogenous regions under similar natural conditions, irrespective of their political and administrative boundaries. Figure below (Fig. 2) shows a map of the 11 biogeographic regions of Europe.

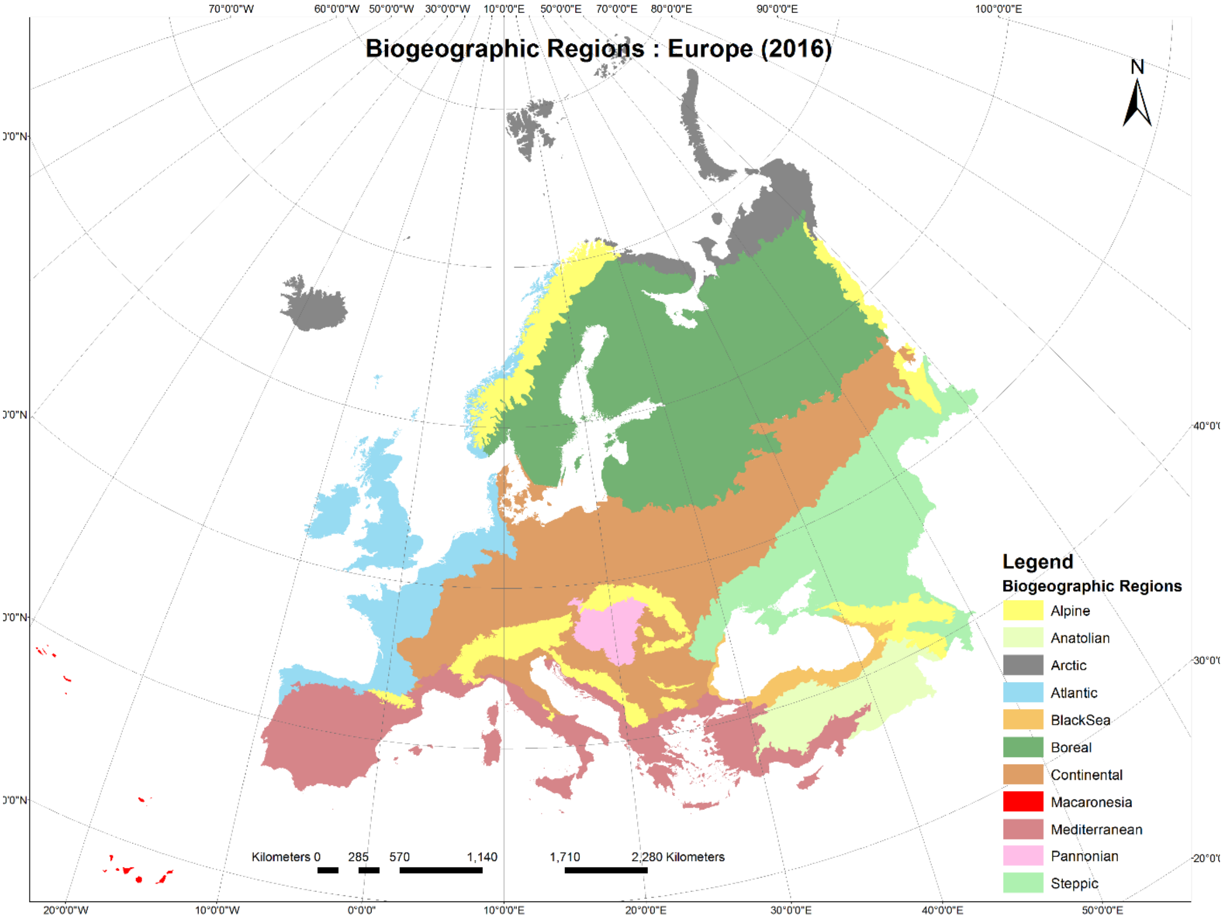

Fig. 2 Biogeographic Regions of Europe
Data Source: Biogeographical regions—European Environment Agency (2016).

Five largest biogeographical regions considered for this research and as described by the EEA are:

Boreal

Covering 1/4th of the European territory, it involves eight countries: south eastern Norway, the majority of Sweden, most of Finland, all Estonia and Latvia and the northern parts of Lithuania and Belarus and it stretches east to the Ural Mountains in the Russian Federation.
The region has a cool-temperate moist climate. Precipitation varies between 500-800 mm per year, with extremes of 300 and 1200 mm. Evaporation is low and prolonged periods of drought are rare. During winters the ground is covered by snow for several months. Average annual temperatures are mostly low, but vary much over the region: the monthly mean temperatures vary from + 20 °C to -15 °C in the warmest and coldest months and areas respectively.
The most significant climatic factors for biodiversity in this region are, firstly the length of the growing season, defining the productivity period, and secondly the amount and duration of snow cover. In the north the summer vegetation period varies between 100 days and 200 days in the south (European Environmental Agency 2002).

Continental

Covering around 2 700 000 km^2 of surface area, it is the second largest region with 23 countries. In the west a narrow strip of land separates it from the Atlantic Ocean; it extends up to the border of Asia in the east, just south of the Ural Mountains. It reaches Denmark and Sweden in the north, Italy and the Balkan Peninsula in the south. The region is not entirely continuous in countries such as Slovenia, Croatia, Serbia and Bosnia-Herzegovina. The Czech Republic is completely within the region except for a small part in southeast. Luxembourg is wholly within the region.
The climate can be defined as continental type, with mainly warm summers and cold winters. Rainfall is most abundant during summer, highest precipitation around 1700 mm per year, occurring on western slopes of mountains, while in the lowland plains precipitation can be less than 600 mm per year. The temperature in winter rise steadily from east to west but do not vary much between north and south. The average January temperature is –15 °C at the foot of the Ural Mountains, –3 °C in Warsaw and 0.6 °C in Strasbourg.
The climate of the region is favourable for vegetation growth making it responsible for the bulk of European agricultural production. However, in some areas, large variations in precipitation can cause long periods of drought, while excessive humidity sometimes leads to crop failure. Occurrence of very cold winters and long lasting periods of frost are important factors restricting vegetation growth in the central east European lowlands. A change in this climate pattern in the region may have a significant impact on agricultural production, and on forests (European Environmental Agency 2002).

Mediterranean

Spread over a surface area of 1 200 000 km^2 it incorporates 13 countries. This region covers 37% of area of Spain, 20% of Turkey, 14% of Italy, 11% of Greece and less than 10% of areas in Portugal, France, Albania, Cyprus, Croatia, Bosnia and Herzegovina, Serbia, Montenegro and Malta.

The Mediterranean climate is semi-arid in many parts and truly arid in some minor parts. Continued periods with annual temperatures over 30°C occur in all parts of the region, but, the eastern part experiences the highest temperatures. The average annual rainfall range varies between 600 and 1 200 mm per year but can be as low as 350 or even 100 mm. The most crucial periods for plant growth in this region are the short spring and autumn seasons. Wind plays a vital role in the Mediterranean region. For example, dry and cold winds from the north can cause sudden spring time and winter time anomalies and high diurnal temperature fluctuations.
The Mediterranean region has around one third agricultural land, including grasslands (European Environmental Agency 2002).

Alpine

With a surface area of 780 000 km^2, the Alpine region consists of 22 countries. Norway contributing to 17% of the area, European Russian Federation with 15%, Sweden 12% and less than 10% areas of Austria, Italy, Romania, Bosnia Herzegovina, France, Georgia, Albania, Azerbaijan, Bulgaria, Croatia, Finland, FYR (Former Yugoslav Republic) of Macedonia, Germany, Poland, Slovakia, Slovenia, Switzerland, Ukraine, and Yugoslavia.
It constitutes a number of mountain ranges with a wide climatic variability. The Alps, the Scandes, the Pyrenees, the Carpathians, the Rhodopes, the Urals, the Caucasia and the Dinaric Alps are the highlights of this region.
The high Alps of the Alpine region remarkably influence the climate of central Europe. The annual and spatial distribution of rainfall is highly variable. It mostly rains in the summer in the north while the south is dry in winter. The precipitation increases with altitude and at high altitudes the precipitation is more or less the same across the Alps (European Environmental Agency 2002).

Atlantic

This region covers 830 000 km^2 and roughly stretches from Porto in Portugal in the south to north of Trondheim in Norway. It borders the Arctic and Scandinavian Alpine regions in the north (Norway) and the Mediterranean region in the south (Portugal, Spain and France). Three countries which are completely within the northern part of the region are Ireland, United Kingdom and the Netherlands. The region also covers parts of Belgium and Denmark. The Atlantic climate is oceanic with moderate and mild temperatures and generally a high precipitation and high humidity. The eastern limit of the region roughly follows the isotherm where the annual temperature range is 16°C. Rainfall is very high in the western parts, reaching up to 3 000 mm per year on the mountains of Northwest Scotland, while it can be as little as 550 mm per year in lowlands in the eastern parts of the region (European Environmental Agency 2002).

2.2 Natura2000

In May 1992 the European Union governments adopted a legislation called the Habitats Directive in order to protect the most threatened habitats and species across Europe. This Habitats Directive along with the Birds Directive legislation adopted earlier in the year of 1979 formed the foundation for the creation of a network of sites called Natura2000. Under this, the Birds Directive entails the establishment of Special Protection Areas (SPAs) for the birds while Special Areas of Conservation (SACs) under the Habitats Directive, are created for other species and habitats. Special Protection Areas (SPAs) under the Birds Directive help in protecting and managing areas which are important for the feeding, breeding and migration of rare and vulnerable species. Similarly, Special Areas of Conservation (SACs) under the Habitats Directive offer increased protection and management to the rare and vulnerable animals and habitats. These sites are spread all across Europe and cover about 18% of Europe's land area and almost 6% of its marine territory making it the largest coordinated network in the world (Natura 2000 - Environment - European Commission 2016). The map below (Fig. 3) shows the distribution of Natura2000 sites in Europe.

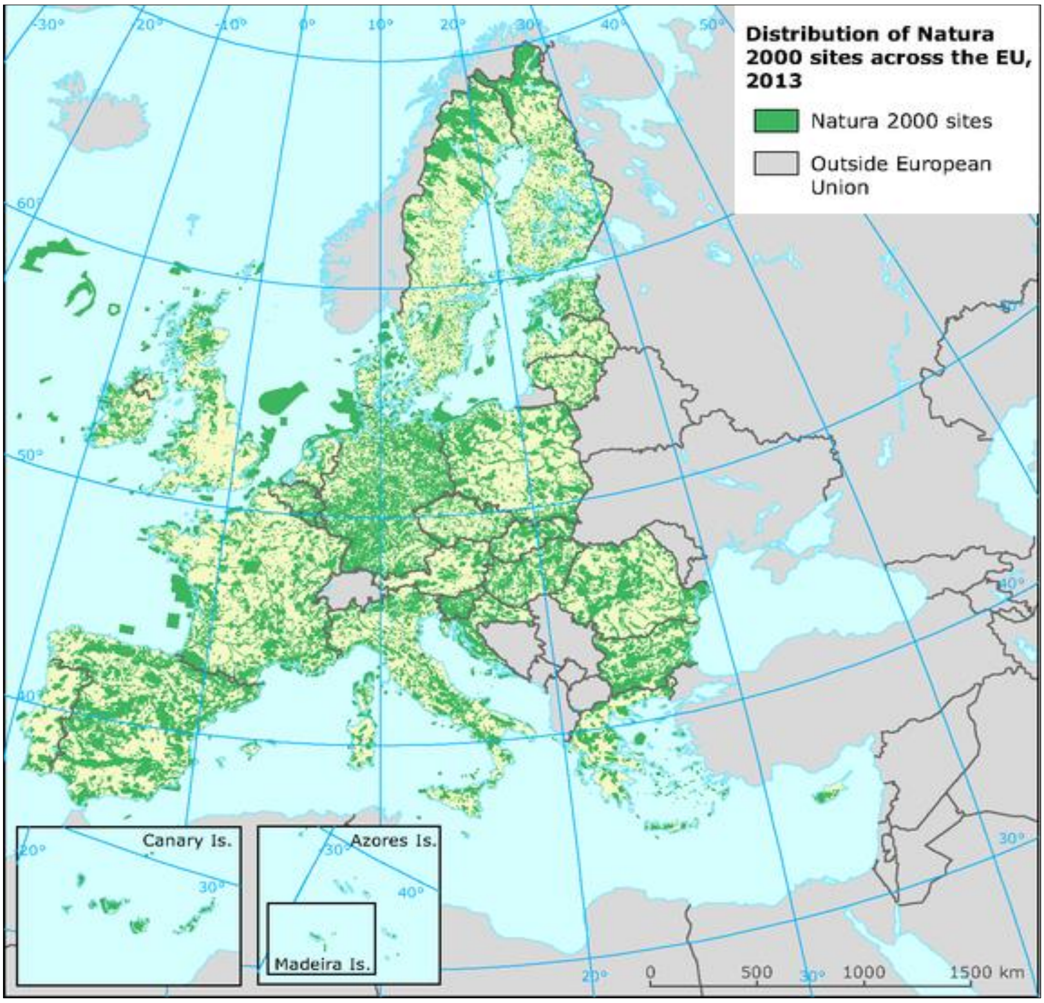

Fig. 3 Distribution of Natura2000 sites across EU
Source: EEA (2013)

Each member state, according to some scientific criteria, enlists suitable wildlife areas containing habitats and species which are listed in the Birds Directive and Habitats Directive. The procedure for designation of these sites depends on which of the two Directives is claimed for the creation or establishment of a specific site. It is the responsibility of the Member States to ensure an appropriate management of the Natura2000 sites by the conservation authorities in the respective country.

After a site has been designated as Natura2000 site, sometimes certain activities need to be limited or ceased in case they are posing a threat to the species or habitat for which the site has been designated as a Natura2000 site. However, that varies from site to site. A good ecosystem condition is not necessarily incompatible with human activities. Rather, many times different habitats and species depend on human activities for their management and survival, of which agriculture is a good example (About | Natura 2000 Networking Programme 2016).

Natura2000 and farming

As mentioned earlier, Natura2000 completely recognises humans as an essential part of nature and their role in its conservation, which is evident from the fact that farmlands makes up around 40% of the total area included in Natura2000 (European Commission 2014). The management of Natura2000 farmlands depends on whether the conservation focus is on farmland habitat or farmland species. According to European Commission (2014), for achieving a favourable conservation status of farmland habitat and species, low intensity agricultural management is necessary in the Natura2000 sites. Some agricultural practices can contribute to suitable management and conservation of Natura2000 habitats and species. These are controlled grazing, which would prevent succession to woody scrubs and trees and control invasive alien species; secondly controlled burning, to prevent establishment of woody species in absence of grazing and to maintain low nutrient conditions for structural diversity to thrive well; thirdly mowing/hay-cutting, to encourage growth of grass and herbs and eliminating woody plants; and finally restricted or no fertiliser and pesticides usage, as dry grassland types cannot tolerate any form of fertilisation and many are already adversely affected by eutrophication. Also, restricting the use of pesticides to maintain invertebrate populations can promote bird species occupying these farmlands.

2.3 Remote sensing of the Environment

Remote sensing is broadly defined as the process of acquiring information about an object without coming in physical contact with it. The fundamental basis of remote sensing is the electromagnetic spectrum. Every feature on the surface of the earth absorbs, reflects or transmits electromagnetic radiations depending on its typical chemical and physical properties. The electromagnetic (EM) radiations are detected by remote sensors and are quantified and stored in analogue or digital form. Remote sensing can either be active or passive depending on the source of these EM radiations. In passive remote sensing the sun acts as the source of radiations illuminating the object, while in active remote sensing the sensor itself emits and subsequently receives the EM radiations as in case of a Radar or a Lidar.

Since every object on the surface of the earth interacts with the EM radiations in a typical manner, we can also conclude that each feature has a specific spectral signature which distinguishes it from other objects. Spectral signatures, also known as spectral reflectance curves show the portion of incident radiation that is reflected over different wavelengths. This spectral behaviour of various features enables us to distinguish between them by analysing their reflectance properties in different spectral bands.

Remote sensing of vegetation

In terrestrial biomes ecologists and conservationists require information on vegetation which is beyond what land cover maps can supply. Remote sensing technology offers tools and techniques to monitor a variety of vegetation characteristics. The fundamental basis of measurement of these vegetation characteristics is, that the structure and composition of the vegetation and the way its components (leaves and branches) interact with the energy of a particular wavelength being captured by the sensor, determine the reflectance, transmittance and scattering of radiations by that vegetation (Horning et al. 2010). The amount of radiation reflected in a particular wavelength is determined by leaf pigment, leaf thickness, cell structure and water content in the leaf. The diagram below (Fig. 4) shows an ideal curve for healthy vegetation.

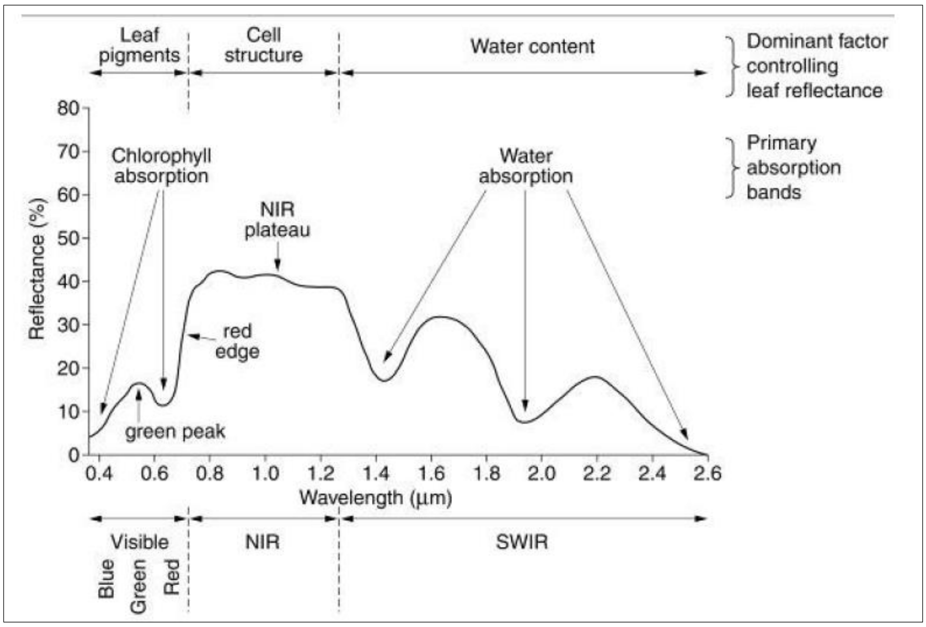

Fig. 4 A typical spectral reflectance curve for healthy vegetation.
Source: Keyworth et al. (2009).

In the visible part of the spectrum reflection of blue and red light is comparatively low because these are mainly absorbed by the leaf pigments in plants for photosynthesis. The vegetation reflects mainly green light in the visible spectrum. In the Near Infrared (NIR) region the reflectance is highest but depends on the cell structure. In the Short Wave Infrared (SWIR) band the reflectance is mainly controlled by water content; more water results in less reflectance. The wavelengths around 1.4µm and 1.95µm are called water absorption bands (Tempfli et al. 2001). In different plant species and during different growth stages of plants the amount of leaf pigments and water content may change resulting in changes in reflectance in different bands. Consequently, optical remote sensing bears the potential of providing information about the type as well as the health of vegetation.

Normalised Differential Vegetation Indices (NDVI)

The main of aim of satellite based remote sensing is to characterize the type, amount and condition of vegetation present in a scene through the amount of light reflected from a surface, which in turn is determined by the amount and properties of the solar irradiance that strike the surface and also the nature of that surface (Jackson and Huete 1991). However, as solar irradiance varies with time and atmospheric conditions, a simple measure of light is not enough to characterize the surface. Therefore, by combining bands unique spectral properties of solar irradiance could be combined to provide complimentary information about the vegetation. This combination of bands done by ratioing, differencing, ratioing differences and sums is called Vegetation Indices (VI). This led to the formulation of NDVI. Thus :

NDVI = (Near Infrared - Red) / (Near Infrared + Red)

The values of NDVI range between -1 and +1. A value of zero corresponds to absence of vegetation while values approaching +1 indicate dense healthy vegetation. Negative values indicate presence of water or snow.

The main drawback of NDVI is that it is insenstive to varaiation in vegetation over some land cover conditions (Solano et al. 2010) and also to dense vegetation (Huete et al. 2002).

Vegetation Phenology

Vegetation phenology relates to the different periodic phases in the lifecycle of a plant. Phenology linked indicators like start of growing season, end of growing season, length of growing season etc. can provide important information on the health and condition of the ecosystem. Thus phenological indicators can serve as important response indicators to assess the effectiveness of any conservation policy like Natura2000.

Phenological observations are usually conducted on a small scale, and this in-situ collection of phenological data makes the task cumbersome and time consuming. Although the in-situ observations are found to be useful, lack of in-situ data which is spatially and temporally explicit, turns out to be a drawback in assessment on vegetation phenology over large spatial scales. Considering this limitation, researchers utilized satellite derieved measurements of reflected EM radiation from the land surface to study vegetation phenology over vast areas. These metrics of land surface reflectance possess a recurring behaviour anually and the timing of these recurring changes and is generally called land surface phenology (LSP) (Hanes et al. 2014). Therefore unlike conventional field observations, which mostly include phenological data for specific plants, LSP is more generalized observation of the timing of change in reflectances from a given area due to combined activity of the vegetation present there; and these changes in reflectance are depicted by changes in vegetation indices. The values of varying vegetation indices over a given year correspond to the annual growing season of vegetation.

In the early history of satellite phenology research Goward et al. (1985) demonstrated that remote sensing derived NDVI corresponded to the known seasonality of natural and cultivated vegetation in North America. Nowadays, hypertemporal NDVI time series data from coarse resolution sensors like Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), Satellite Pour l'Observation de la Terre (SPOT)-VGT etc. are being used for studying land surface seasonal dynamics and phenology with quantifiable meaures such as start date for greening and browning, peak greenness date, length of growing season which give an important insight into the functioning of an ecosystem (Reed et al. 1994; Zhang et al. 2003). A number of studies have focussed on the use of NDVI derived from different Earth resource satellites, for the estimation of LSP, both related to natural and cultivated vegetation (De Beurs and Henebry 2004; Steenkamp et al. 2008; Liang and Schwartz 2009; De Beurs and Henebery 2010; Hamunyela et al. 2013; Pan et al. 2015; Jayawardhana and Chathurange 2016).

Although there is an increasing demand for LSP in environmental modelling and management, it is important to mention that the accuracy of these estimates is still questionable at larger scales due to lack of validation data. Also coarse resolution of hypertemporal data and signal contamination due to clouds are other limitations which can affect the accuracy of the phenological estimates. However, Zhang et al. (2009) have suggested that higher precision can be achieved in estimating vegetation phenology by using time series data with a temporal resolution of 6-16 days.

Satellite derived vegetation phenology therefore holds one key to the ecosystem condition and health. The availability of data on large spatial and temporal scales makes LSP an efficient tool for ecosystem health assessment. Regardless of this potential, LSP estimates should be carefully executed as they only provide ancillary information. However, in future the development and availabilty of ground observation data for validation is certain to strengthen the credibility of studies related to land surface phenology.

3 MATERIALS AND METHODS

3.1 Materials

This section is a description of the datasets and softwares used in the research.

3.1.1 Data

- **Biogeographical regions of Europe**
  The biogeographical regions dataset (2016 version) contains the official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network set up under the Convention on the Conservation of European Wildlife and natural Habitats (Bern Convention). This dataset consists of vector polygons of 9 biogeographical regions of Europe irrespective of the political boundaries (Biogeographical regions—European Environment Agency 2016).

- **Corine land cover (CLC) 2006 dataset for Pastures**
  The Corine land cover (2006) dataset version 17 (12/2013) is the year 2006 update of the first CLC database which was finalized in the early 1990s as part of the European Commission programme to **CO**o**R**dinate **IN**formation on the **E**nvironment (Corine). The minimum mapping unit/width for the data is 25ha/100m (Corine Land Cover 2006 seamless vector data—European Environment Agency 2016). Only the vector dataset for Corine land cover class Pastures (Level 3, 2.3.1) has been used for this study. Pastures are characterized by dominance of *Graminaceae,* are not under rotation system and their location is close to inhabited and cultivated area (EEA 1994)

- **Natura2000 dataset**
  The Natura2000 dataset consists of spatial data i.e. vector polygons of protected areas under the Bird's Directive and Habitat Directive, submitted by each member state and are validated by the European Environment Agency (Natura 2000 data-the European network of protected sites—European Environment Agency 2016).

- **Terra MODIS dataset**
  MODIS instrument
  The Moderate Resolution Imaging Spectroradiometer (MODIS) is an instrument onboard the Terra and Aqua spacecrafts. Terra with a 10:30 am descending node and Aqua with 1:30 pm ascending node, are placed in sun-synchronous near- polar, circular orbit of 705 km. The MODIS instrument measures surface reflectance in 36 spectral bands ranging in wavelenght from 0.4 µm and 14.4 µm and spatial resolution of 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36) (MODIS Web 2016).

  MOD13Q1 (16-day composite, 250m) Normalised Difference Vegetation Index (NDVI)
  NDVI data of MOD13Q1 product from Terra satellite, with a spatial resolution of 250 m and a temporal resolution of 16 days, was used for this study. This data was

obtained for the time period between 2001 to 2015 from the The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) website (MODIS Global Subsets 2016). The table below (Table 1) presents the main characteristics of MODIS NDVI data used for this study.

Table 1 Product characteristics MOD13Q1

Data Set	**Units**	**Data type**	**Valid range**	**Scale factor**
250m 16 days NDVI	NDVI	16- bit signed integer	-2000 , 10000	0.0001

The MODIS NDVI product is computed from atmospherically corrected bidirectional surface reflectances that have been masked for water, clouds, heavy aerosols, and cloud shadows (Lp Daac 2014). As stated in the MODIS Vegetation Indices (VI) user guide, MODIS VI algorithm as shown in figure below (Fig. 5), applies a filter to data based on the quality, cloud and viewing geometry retaining only higher quality data for compositing. The aim of the compositing technique is to extract a single value per pixel from the retained filtered values, which best represent each pixel over a given 16 day period. The compositing techniques use an enhanced criteria and if the observations are normal to ideal Constrained View angle - Maximum Value Composite (CV-MVC) technique is used but switches to an optional backup method called Maximum Value Composite (MVC) if conditions are less than ideal (Solano et al. 2010).

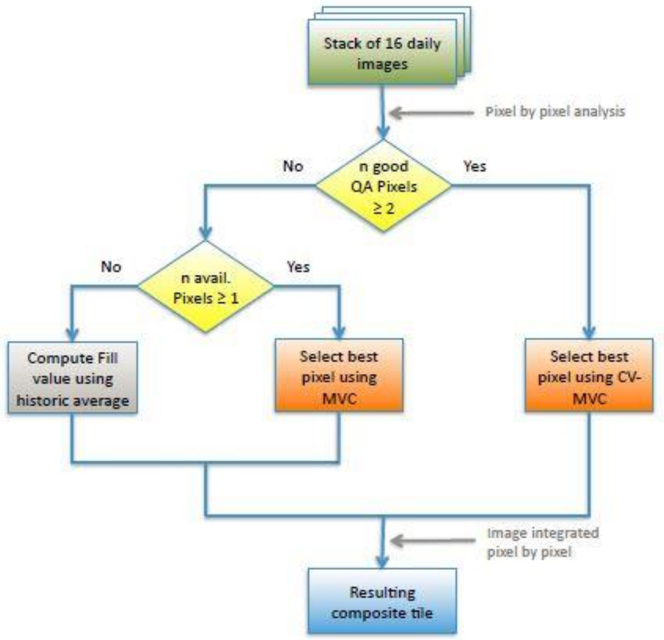

Fig. 5 MODIS VI compositing algorithm
Source: MODIS VI user guide Solano et al. (2010)

MOD13Q1 VI Quality Assurance (QA) data

The quality data or pixel reliability data from ORNL DAAC, contains qualitative values describing overall pixel quality. The description of quality data is given in the table below (Table 2).

Table 2 Ranked values describing overall pixel quality
Source: Lp Daac (2014)

Rank Key	Summary Quality Assurance	Description
-1	Fill/No Data	Not Processed
0	Good Data	Use with confidence
1	Marginal Data	Useful, but look at other QA information
2	Snow/ice	Target covered with snow/ice
3	Cloudy	Target not visible , covered with cloud

- **SPEI (Standardised Precipitation-Evapotranspiration Index) - FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) drought indicator**
  SPEI time series data for the years 1998-2013 regressed with FAPAR (Fraction of Absorbed Photosynthetically Active Radiation) was used as drought indicator (Ivits et al. 2016). The spatial resolution of SPEI drought indicator data is 1000 m. This data was supplied by the European Environmental Agency.

3.1.2 Softwares

- **ArcMap 10.2.2**
  ArcMap 10.2.2 a tool for geospatial analysis by Esri (Environmental Systems Research Institute) was used to perform all the Geographic Information System (GIS) based operations.

- **Google Earth**
  Google Earth was used as a visual aid for site selection (see methods).

- **TIMESAT**
  TIMESAT is a software primarily designed for processing time series of satellite derived vegetation indices (Jönsson and Eklundh 2004). According to the TIMESAT manual (Eklundh and Jönsson 2015), TIMESAT is capable of processing sequential data in the form of ASCII files as well as binary image data by implementing three processing methods, the Savitzky- Golay filtering method the asymmetric Gaussian and Double Logistic model functions. These functions have the ability to capture inter-annual changes making them suitable for studying vegetation dynamics. Prior to the application of different filters, ancillary data or quality data can be added by assigning weights to it which determines the certainty of NDVI values. Additionally, outliers can be removed to reduce some noise by using spike removal methods based

on median filtering or, Seasonal Trend Decomposition by LOESS (STL). Also adaptation to the upper envelope can be set to suppress the effect of low data values in order to account for the effect of negatively biased noise in the NDVI.
The main assumption on which all the methods for estimating phenological parameters through the use of satellite data is based, is that the signal is related to the vegetation vigour (Jönsson and Eklundh 2002). In addition TIMESAT assumes that all the time series are evenly sampled at an even rate (Eklundh and Jönsson 2015).
After the time series has been fitted with a smooth curve using one of the filtering methods, seasonality parameters can be extracted.

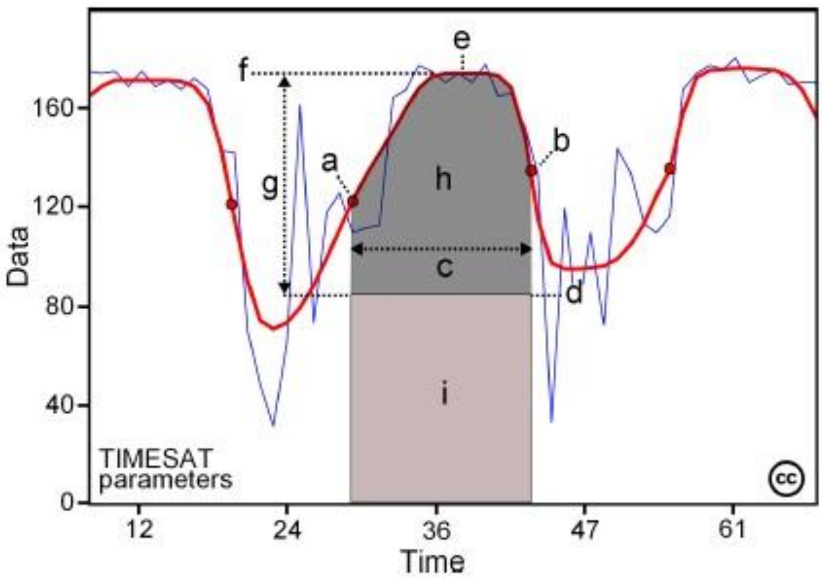

Fig. 6 Seasonality parameters generated in TIMESAT.
Source: TIMESAT software manual Eklundh and Jönsson (2015).

Various seasonality parameters can be generated in TIMESAT (Eklundh and Jönsson 2015). The parameters considered in this study and depicted in the diagram above (Fig. 6) are as follow:

1. **Time for the start of the season (a):** time for which the left edge has increased to a user defined level (often a certain fraction of the seasonal amplitude) measured from the left minimum level. Hereafter referred to as start of season.
2. **Time for the end of the season (b)**: time for which the right edge has decreased to a user defined level measured from the right minimum level. Hereafter referred to as end of season.
3. **Length of the season (c):** time from the start to the end of the season. Hereafter referred to as length of season.
4. **Time for the mid of the season (e)**: computed as the mean value of the times for which, respectively, the left edge has increased to the 80 % level and the right edge has decreased to the 80 % level. Hereafter referred to as peak of season.

5. **Largest data value for the fitted function during the season (f)**: may occur at a different time compared with peak of season. Hereafter referred to as peak value.
6. **Seasonal amplitude (g):** difference between the maximum value and the base level (average of the left and the right minimum values, represented by **d**). Hereafter referred to as amplitude.
7. **Large seasonal integral (h+i)**: integral of the function describing the season from the season start to the season end. Note that the large integral has no meaning when part of the fitted function is negative. Hereafter referred to as large integral.
8. **Small seasonal integral (h)**: integral of the difference between the function describing the season and the base level **(d)** from season start to season end. Hereafter referred to as small integral.

- **R studio**

  All the statistical computing was performed in R studio.

3.2 Methods

3.2.1 Study Area

Natura2000 network stretches over 18% of the European Union's land area (Natura 2000 - Environment - European Commission 2016) therefore an attempt was made to select sites from different parts of the European Union. Below (Fig. 7) is a flowchart of the principal steps involved in selection of the study site.

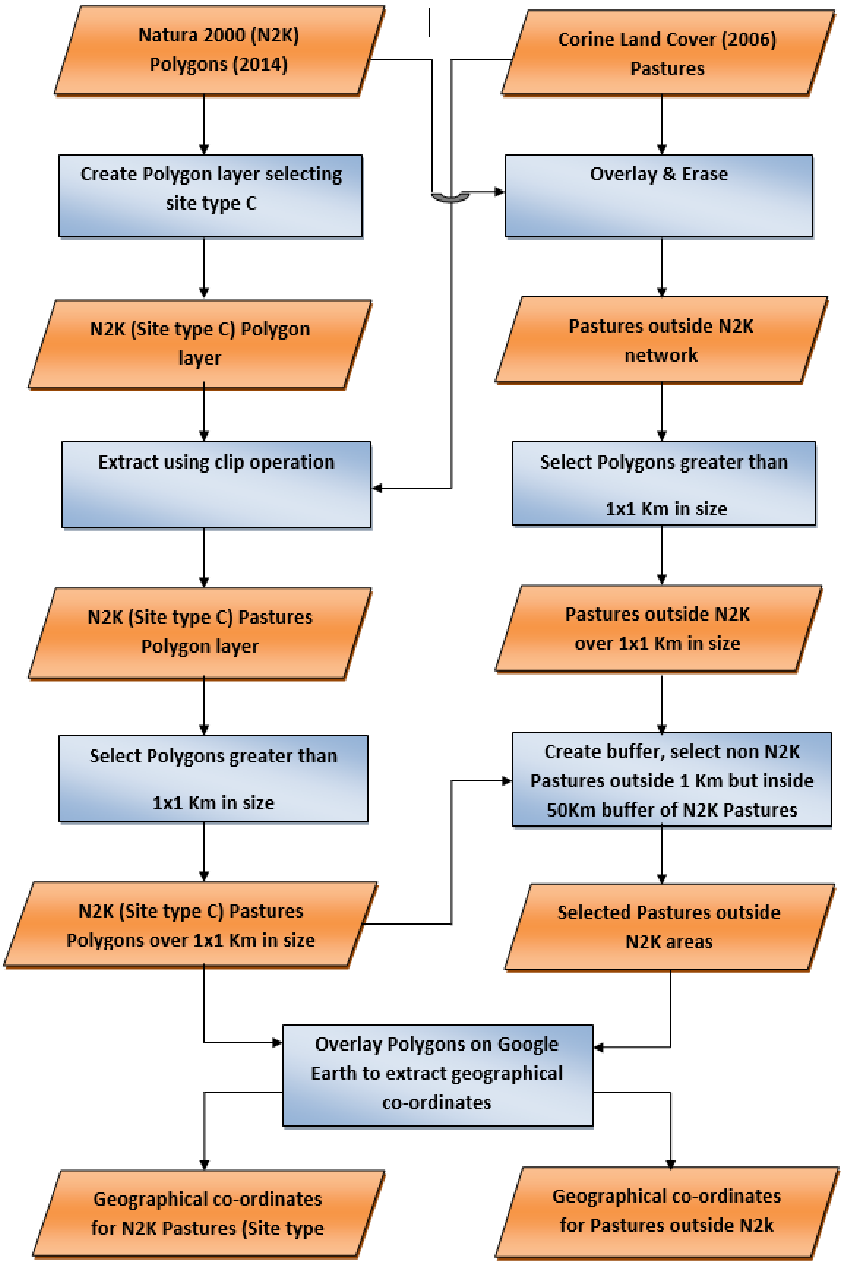

Fig. 7 Flowchart of steps involved in selection of the study site

- **Site Selection**

As mentioned earlier, main focus of this study is based on Corine land cover class ‘pastures’. It is also important to note that for determining sites inside Natura2000, site type C of Natura2000 network representing areas protected under both Birds Directive and Habitats Directive were chosen as these areas were assumed to be under strict conservation measures thereby leading to an evident impact on the health of the ecosystem.

Natura2000 pastures

Attribute selection for site type C was done on the Natura2000 polygon layer to obtain only those polygons which belonged to site type C i.e. both to the Birds Directive and the Habitats Directive. This polygon layer was overlaid on the Corine land cover class pastures to extract a layer for those pastures that belonged to Natura2000. From the resulting layer of Natura2000 pastures only polygons which were equal to or over 1x1 km^2 in area were chosen for the next step. This was done because the spatial resolution of MODIS NDVI data used is 250m, and in order to make sure that the pastures are large enough so that the central pixel is far away from the influence of signals from other land cover categories. A criteria of size greater than 1x1 km^2 considerably decreased the number of Natura2000 pastures, making it difficult to select the sites. Thus the final polygon layer depicted Natura2000 pastures in the five main biogeographic regions as shown in the map below (Fig. 8).

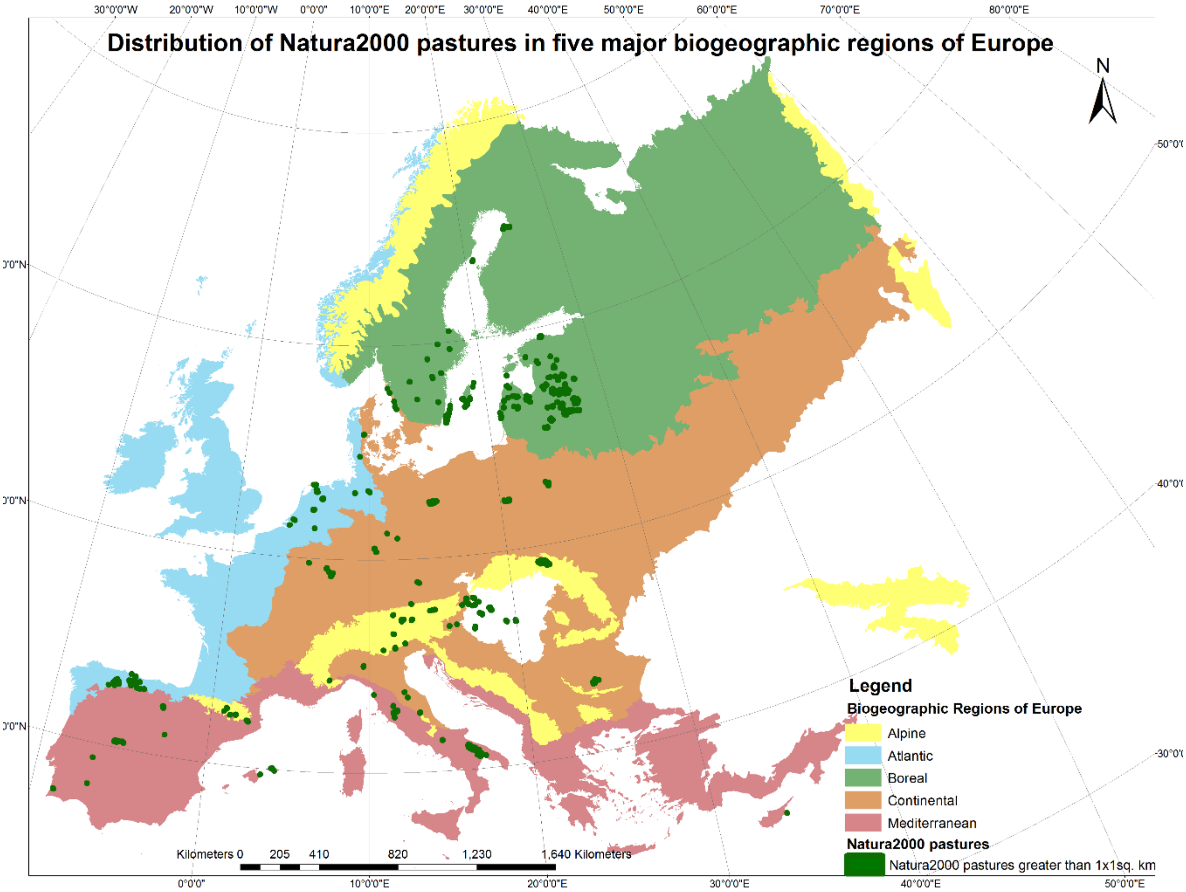

Fig. 8 Distribution of Natura2000 pastures.
Data Source: EEA (1994); Biogeographical regions—European Environment Agency (2016); Natura2000 data-the European network of protected sites—European Environment Agency (2016)

Pastures outside the Natura2000 network

A similar approach was adopted to select pastures outside Natura2000 protected areas. Using CORINE land cover class pastures and Natura2000 polygon layer GIS operations (overlay and erase) were performed to extract polygon layer for pastures outside the Natura2000 network. Only those polygons were selected which were equal to greater than 1x1 km^2 in area for the same reason mentioned above. An additional step here was to choose only those pastures outside protected areas which were outside a buffer of 1km but within a buffer of 50km. This was done in order to make sure that the pastures are at least 1 km away from the influence of any conservation practices but also not very far away from the protected area it is being compared to. Thus the final polygon layer depicted pastures outside Natura2000 network, within a buffer of 1km and 50km, in the five main biogeographic regions as shown in the map below (Fig. 9).

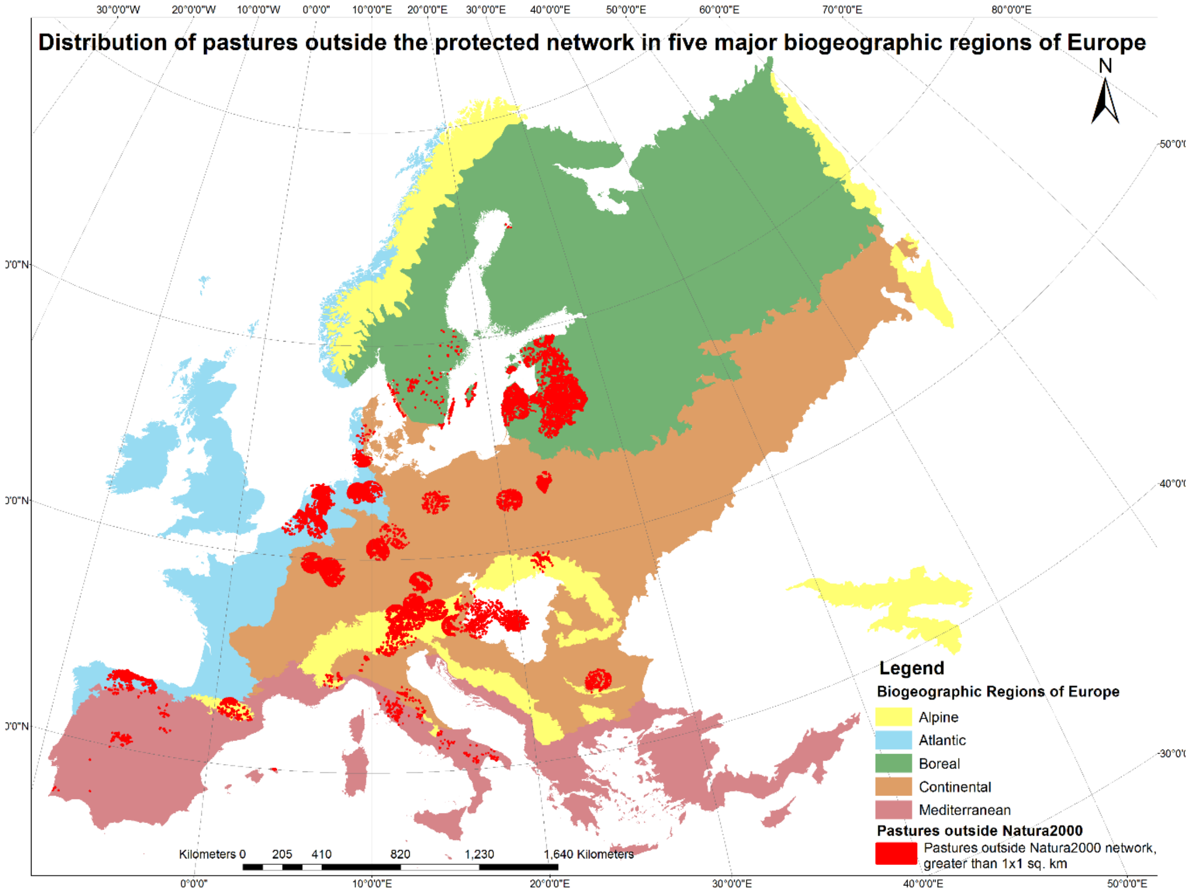

Fig. 9 Distribution of pastures outside Natura2000 network
Data Sources: EEA (1994); Biogeographical regions—European Environment Agency (2016); Natura2000 data-the European network of protected sites—European Environment Agency (2016)

Extracting Geographical Coordinates

After selecting the pastures inside and outside Natura2000 protected areas the respective polygon layer was imported to Google Earth in order to derive geographical coordinates which were later used to download MODIS NDVI data. Google Earth was used as a visual aid to make sure that the final sites being selected are homogenous in terms of land cover so that the reflectance from the central pixel is not much affected by the surrounding land cover. An example is shown in the images below (Fig. 10 and Fig. 11). Therefore, geographical coordinates were obtained from within and outside of Natura2000 network keeping the following criteria in mind:

i. The sites were distributed across the five largest biogeographical regions.
ii. Each biogeographical region was represented by two Member States.
iii. For each Member State three sites were selected from within Natura2000 network and three sites were selected from outside Natura2000 network.

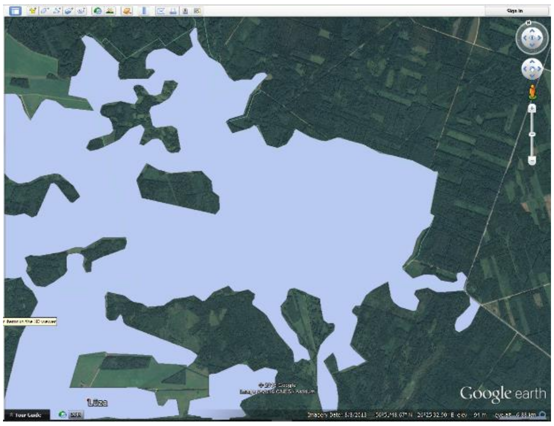

Fig. 10 Natura2000 pastures polygon layer overlay on Google Earth

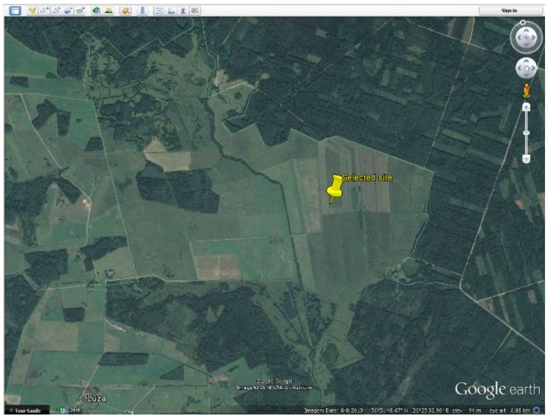

Fig. 11 Selected site within the Natura2000 pastures polygon layer

A total of 60 sites were selected. For each Biogeographical region total 6 sites were selected from within Natura2000 protected areas, 3 sites from each of the two countries representing the biogeographic region. The same methodology was followed for sites outside protected area. The extracted geographical coordinates were then arranged for every biogeographical region and country for inside Natura2000 protected areas and outside protected areas. An example of selected sites within and outside Natura2000 in Boreal region has been shown in the following tables (Table 3 and Table 4) respectively. These coordinates were used to download MODIS NDVI subsets from the MODIS Global subsetting tool and to generate the sample pixels for the study.

Table 3 Geographical coordinates of pastures inside Natura2000

Biogeographic Region	Country	Site name	Latitude	Longitude
Boreal	Latvia	Kuja	56°48'54.17"N	26°26'25.28"E
		Raznas nacionalais parks	56°18'14.60"N	27°31'11.84"E
		Kemeru nacionalais parks	56°53'51.95"N	23°36'45.59"E
	Sweden	Åkerby-Runstens sjömarke	56°41'34.92"N	16°43'37.68"E
		Hornborgasjön	58°16'30.16"N	13°32'51.38"E
		Egby sjömarker	56°52'12.00"N	16°51'4.45"E

Table 4 Geographical coordinates of pastures outside Natura2000

Biogeographic Region	Country	Site	Latitude	Longitude
Boreal	Latvia	Site 1	56°44'26.50"N	27°21'8.54"E
		Site 2	56°19'42.55"N	27°51'45.19"E
		Site 3	56°56'10.31"N	23°19'10.44"E
	Sweden	Site 1	56°49'43.01"N	16°37'31.15"E
		Site 2	57°13'28.80"N	15°54'25.22"E
		Site 3	57°59'8.07"N	13°25'30.17"E

3.2.2 Extraction of Seasonality Parameters and Statistical Analysis

The MODIS NDVI subsets downloaded for 60 sites were approximately 2.25x2.25 km^2 each. Since the spatial resolution of the MODIS NDVI product was 250m the whole subset was divided into 81 pixels. The centre most i.e. 41st pixel was selected as the sample pixel to obtain the NDVI values for each site. The following flowchart (Fig. 12) shows the main steps taken towards preparation of MODIS NDVI 16-day composite data and extraction of seasonality parameters using TIMESAT.

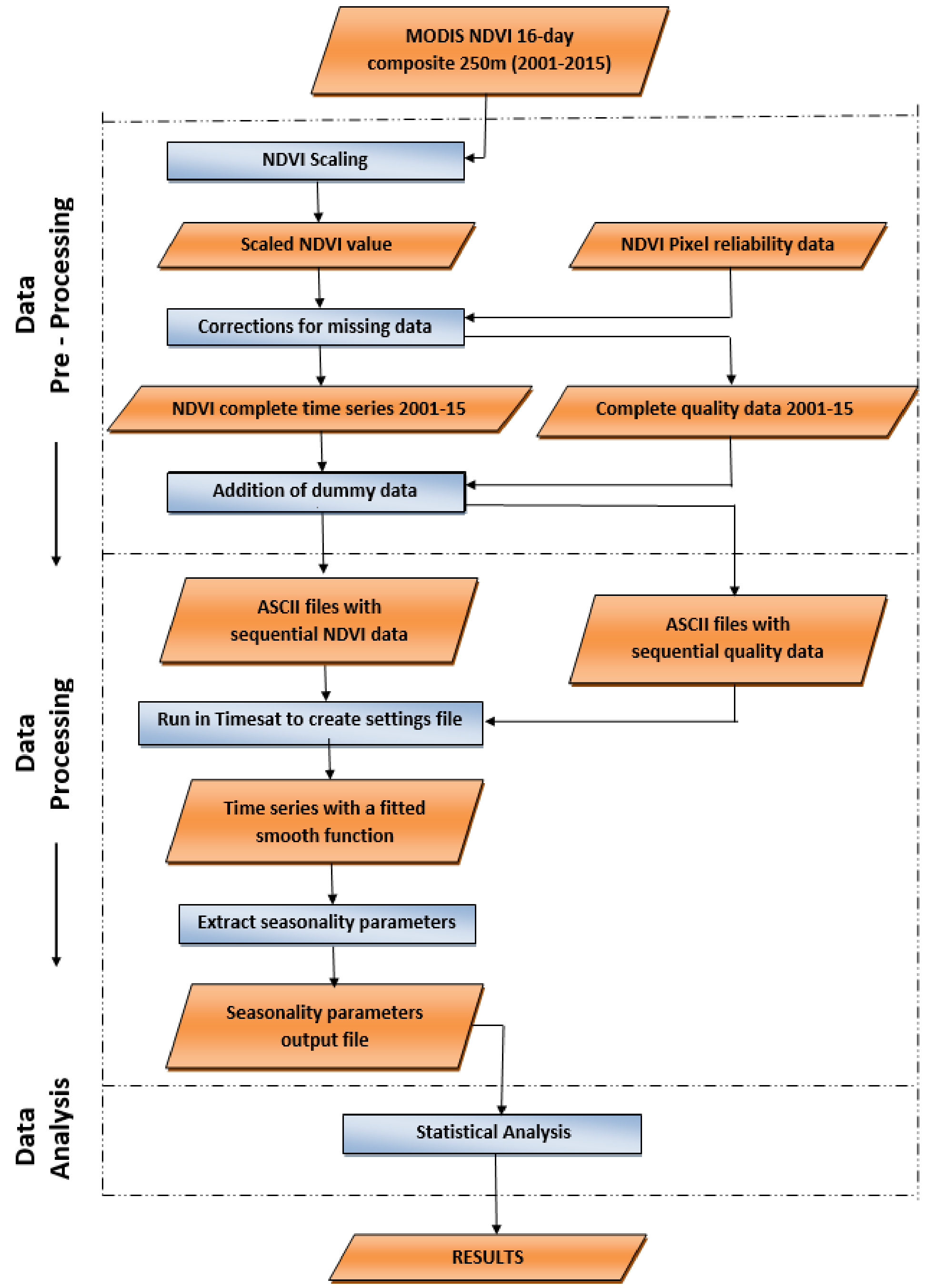

Fig. 12 Flowchart of steps involved in data preparation, seasonality data extraction and analysis.

1. **Data pre-processing**

The first step involved in the process of seasonality data extraction and analysis was preparing the data to be used as an input in TIMESAT. The three main steps undertaken for data pre-processing were:

- **NDVI scaling:** As mentioned by Lp Daac (2014), the scale factor for NDVI is 0.0001. Therefore in order to obtain actual NDVI data values that lie between -1 and +1 the original values in the data needed to be multiplied by 0.0001.
- **Correction for missing data:** It was observed that for the year 2013 NDVI data values were missing for 209th and/or 225th day of the year and for the year 2015 data values for 65th and/ or 81st day of the year. The missing data was filled in by calculating a mean of all the values of corresponding dates for all the years (2001-2015) in the time series**.** Similarly, for pixel reliability data all the missing values were filled in with a value of -1 which corresponds to Fill/No data.
- **Addition of dummy data:** According to Eklundh and Jönsson (2015), for a time series of *n* years with one growing season per year, TIMESAT is programmed to extract seasonality data for *n*-1 centre most seasons. In cases where season peaks in the middle of the year, in order to be able to extract seasonality data from each year dummy data can be added at the beginning and end of the year. Therefore, for this study dummy data was added in the beginning and end of each time series.

  Thus after the pre-processing involving the abovementioned steps ASCII files were generated to be run in TIMESAT.

2. **Data processing**

The ASCII files for NDVI time series data and the pixel reliability data were run in TIMESAT.

The weights assigned for pixel reliability data are shown in the table below (Table 5).

Table 5 Weights assigned for pixel reliability data

	Pixel reliability values	**Weight**
From	**-0.5 to 0.5**	**1**
From	**0.6 to 1.5**	**0.5**
From	**1.6 to 5**	**0.1**

The main task under data processing was to create a settings file by assigning different settings parameters and fitted functions:

i. **Spikes and outliers:** In order to remove the effect of outliers which could be present due to clouds or any other atmospheric variability, the appropriate Spike method was applied to each of the time series. Additionally, to get rid of the effect of negatively biased noise, adaptation to the upper envelope was set and given a value appropriate for the dataset.

ii. **Threshold for Start and End of Season:** Different threshold values have been used for start and end of season by different researchers. Jönsson and Eklundh (2004) used start of season threshold value of 0.10 for deriving seasonality parameters over Africa, some studies have defined it to 0.20 (Kariyeva et al. 2012; Shen et al. 2014; Suepa et al. 2016; Wang et al. 2014) while certain studies like Stöckli and Vidale (2004) have set the start of season threshold value to 0.40. White et al. (1997) tested a range of thresholds for grassland sites and found out that the increase and decrease in greenness was most rapid at a threshold value of 0.5. While analysing the Alpine grassland phenology Fontana et al. (2008) compared the phenology parameters derived from NDVI time series of different sensors to the in situ measurements. Their results show that when the threshold was set to 0.70 for MODIS NDVI, lowest mean temporal off set (in days) was observed between satellite and ground data for start of season. Since no definite single threshold value could be inferred from these studies a threshold value of 0.30, which lies somewhere between 0.10 and 0.70, was selected for both start and end of season for this study. All the settings files were set to this value because this study is based on only one land cover category i.e. pastures.

iii. **Fitting functions:** The choice of fitting functions was based on the nature of the input time series data. However, as suggested by Eklundh and Jönsson (2015), sometimes Savitzky-Golay method might generate undesirable results for noisy time series hence in such cases Gaussian or Double logistic methods can prove to be a better option.

- **Adaptive Savitzky Golay filter:** in TIMESAT this method is based on a weighted moving average method. The size of the moving window determines the degree of smoothening and can be determined by the user in TIMESAT Eklundh and Jönsson (2015). A large window causes overfitting and yields a smooth curve but will affect the ability to detect important variations in the dataset on the other hand a small window size might retain the noise in the dataset (Chen et al. 2004; Jönsson and Eklundh 2004; Hird and McDermid 2009).

  Therefore, for this study Savitzky-Golay filter was applied on time series which were less noisy. More so because the time series depicted a single and distinct seasonality as stated in the study by Hird and McDermid (2009). The figure below (Fig. 13) represents a time series with Savitzky Golay fitted function in TIMESAT.

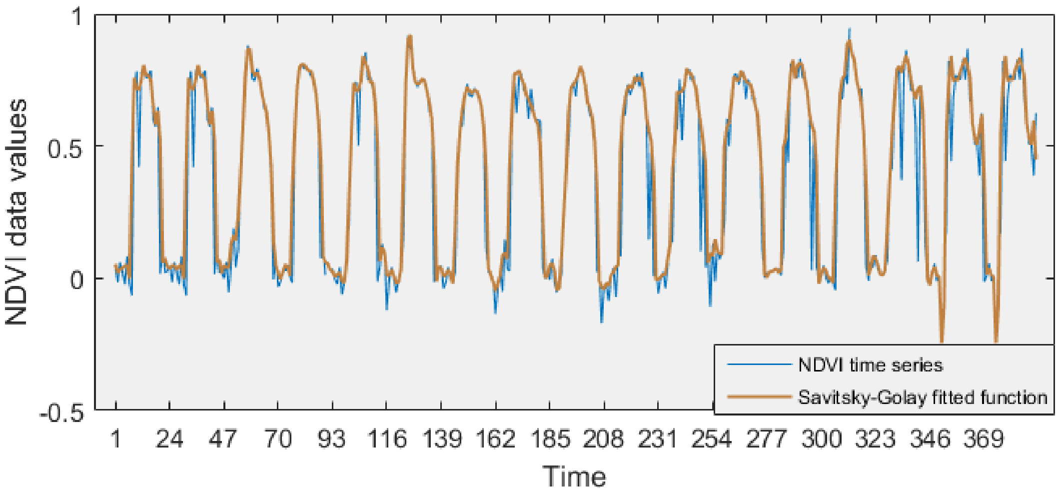

Fig. 13 Time series with Savitzky Golay fitted function

- **Asymmetric Gaussian filter :** this method is based on simple local non-linear least square fitted function used to describe NDVI variations along a season, is less sensitive to noise and can be used for Maximum Value Composites (MVCs) (Jönsson and Eklundh 2004). Gaussian filter was used in time series with noisy data to achieve best fit. The figure below (Fig.14) shows a noisy time series with Gaussian fitted function.

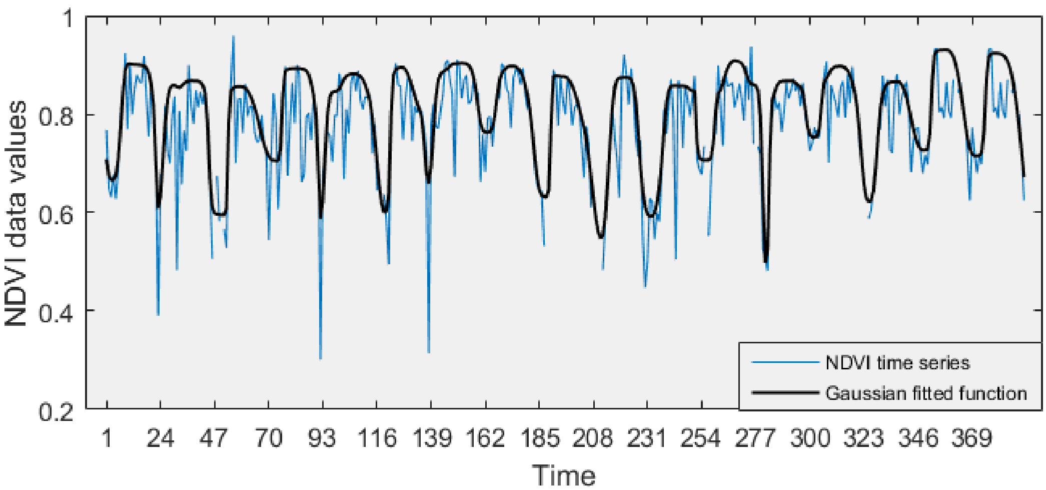

Fig. 14 Time series with Gaussian fitted function

- **Double Logistic filter:** This function is also based on least square fitting method and has been found to preserve the goodness of NDVI signal (Hird and McDermid 2009). According to (Beck et al. 2006) this method does not overestimate the length of growing season and also handles outliers effectively. However, it was found to slightly overestimate values before start of spring and underestimate values at the start of spring and these errors were caused because this function displayed equal but opposite curvature at the start and end of spring which led to abrupt NDVI values in the beginning of spring while more even values towards the end of spring. In some of the noisy time series logistic fitted method was used for smoothening. The figure below (Fig. 15) shows a time series with logistic fitted function.

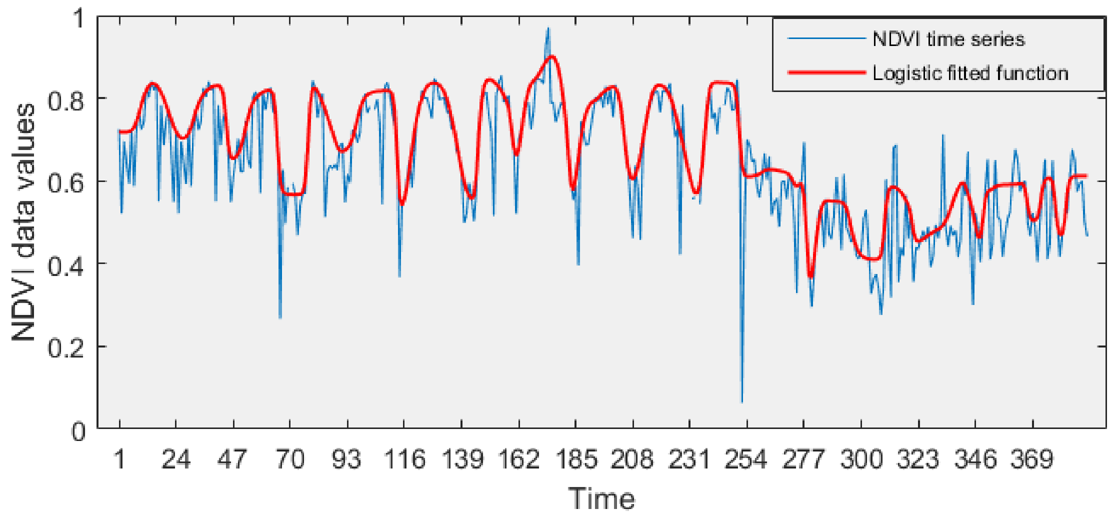

Fig. 15 Time series with Logistic fitted function

After applying the appropriate fitted function to the time series, seasonality parameters were computed for each site for further analysis. For time series spanning 15 years phenological parameters were derived for 14 seasons. The phenological parameters that were used for this study belonged to two categories. First category was the time related parameters namely Start of Season, End of Season, Length of Season, Peak of Season. The second category of parameters were productivity related parameters namely amplitude, peak value, small integral and large integral.

3. Statistical analysis

Different statistical techniques were applied for data analysis.

- **Test for normal distribution**

  The first step towards performing statistical analysis was to test the data for normality. The data was visually tested for normality by displaying it on QQ plot. Simultaneously Shapiro-Wilk test for normal distribution was performed in R Studio to decide on the choice of parametric vs non-parametric tests. The test was performed at a confidence interval of 95%.

- **Analysing variation in phenological variables inside and outside the protected network**

  In order to test for significant differences inside and outside Natura2000 protected network two different tests were implemented. For normally distributed data a parametric test called Welch Two sample t test was performed whereas a non-parametric test called Kruskal-Wallis Test was performed on the data which was not normally distributed (Gibbons and Chakraborti 2003). For both the tests confidence interval was set to 95%.

- **Trend Analysis**

  Mann-Kendall test is one of the most widely used non parametric trend test for detecting the presence of a monotonic trend. While Mann-Kendall test detects the presence of a trend (increasing or decreasing), the magnitude of a trend in a time series can be determined by using a complementary non-parametric technique proposed by Theil and Sen (Theil 1950; Sen 1968). This technique is robust against outliers as it makes use of median instead of means, however it is important to note that when found statistically significant MK test denotes the presence of a monotonic trend (linear or non-linear) while the Sen's slope is a best linear estimate of its character (Neeti and Eastman 2011).

  A number of studies have used Mann- Kendal trend test to detect the presence of a trend in time series related to NDVI, (phenological parameters in some cases) to detect the presence of significant trends and Sen's slope method to compute the magnitude of the trend (Martínez and Gilabert 2009; de Jong et al. 2011; Fensholt et al. 2012; Yin et al. 2012; Forkel et al. 2013; Ma et al. 2015).

  Mann Kendall test was computed in R studio and it yielded Mann-Kendall score (S) along with tau (τ) which is the Kendall correlation coefficient ranging between -1 and +1 (Kendall 1938). A positive S indicated an increasing trend while a negative S indicated a decreasing trend. A standardized MK Z statistics were computed in order to detect significant trends. If the computed MK Z statistics were greater than the Z critical which is equal to 1.96 at 95% confidence interval in our case, the trends were considered significant (Onyutha et al. 2014). The Kendall tau coefficient was analysed to determine and compare the strength of the trends between different ecosystems while the Theil-Sen's slope was analysed to determine the magnitude of the trends.

  This was supplemented by the use of SPEI drought indicator data (Ivits et al. 2016), in order to see if the trends in vegetation vigour could have possibly resulted due to the effect of drought on different ecosystems.

4 RESULTS

This chapter presents the key findings of this research. It is divided into three main sections. Each section elucidates results obtained for each of the objectives formulated towards achieving the aim of the research.

4.1 Seasonality Parameters

Eight seasonality or phenological parameters derived from MODIS NDVI data were tested to determine those parameters which could act as robust indicators of ecosystem condition and health. The eight parameters have been listed under two categories productivity related parameters i.e. amplitude, peak value, large and small integral and time related parameters i.e. start, end, length and peak of growing season. Descriptive statistics in the table below (Table 6) summarize the eight phenological parameters and present the mean, median, maximum and minimum values for each parameter for study sites inside and outside Natura2000 network, for five biogeographic regions.

Boxplots were created for the visualization of the data distribution, for each of the phenology metrics as shown below (Fig. 16-20).

Table 6 Summary statistics for eight phenological parameters

Region	Summary Statistics	Productivity Related								Time Related							
		Amplitude (NDVI values)		Peak value (NDVI values)		Small integral (integral values)		Large integral (integral values)		Start of season (days)		End of season (days)		Length of season (days)		Peak of season (days)	
		in	out	in	out	in	out	in	out	in	out	in	out	in	out	in	out
Boreal	Mean	0.65	0.74	0.83	0.83	7.41	9.30	10.11	10.77	143	119	367**	367**	224	248	246	245
	Median	0.78	0.83	0.83	0.84	8.55	10.28	10.16	10.75	145	119	368**	368**	222	248	246	244
	Maximum	0.94	0.97	0.93	0.92	11.97	12.96	11.54	13.55	211	262	427**	413**	286	338	322	344
	Minimum	0.29	0.23	0.74	0.68	3.12	1.66	7.62	6.14	85	35	305	307	149	120	209	195
Continental	Mean	0.60	0.68	0.86	0.84	7.80	9.49	12.45	12.40	106	90	368**	368**	261	278	220	221
	Median	0.54	0.69	0.86	0.84	6.79	9.96	12.38	12.13	109	87	368**	366**	258	281	224	223
	Maximum	0.97	0.93	0.94	0.92	16.19	17.92	16.83	18.83	242	354	478**	541**	359	369**	353	378**
	Minimum	0.36	0.17	0.76	0.74	2.44	0.38	6.07	2.83	35	18	247	178	116	33	90	126
Mediterranean	Mean	0.42	0.40	0.72	0.72	4.74	4.82	9.75	10.47	127	120	369**	370**	242	253	265	250
	Median	0.42	0.45	0.73	0.72	4.76	4.96	9.75	10.95	122	110	370**	368**	245	263	257	240
	Maximum	0.65	0.64	0.86	0.91	8.58	7.94	14.62	13.50	246	280	446**	434**	322	353	342	342
	Minimum	0.26	0.17	0.50	0.54	2.36	1.21	4.87	3.92	51	50	296	334	118	92	171	139
Alpine	Mean	0.84	0.76	0.86	0.85	11.36	11.21	11.79	13.15	104	90	369**	370**	265	280	225	226
	Median	0.86	0.85	0.87	0.86	10.92	11.55	11.88	13.70	104	82	368**	370**	263	283	231	230
	Maximum	1.01*	1.12*	0.96	0.93	15.94	20.90	16.25	18.69	178	188	429**	429**	371**	373**	285	291
	Minimum	0.64	0.20	0.72	0.69	8.26	3.25	8.14	7.63	27	30	309	312	187	183	130	155
Atlantic	Mean	0.39	0.23	0.81	0.87	5.75	3.57	13.59	15.42	95	112	370**	379**	275	267	229	248
	Median	0.29	0.21	0.82	0.87	4.11	3.16	13.63	15.39	88	98	373**	372**	285	270	232	242
	Maximum	0.91	0.53	0.92	0.92	15.19	14.98	20.40	26.14	269	256	499**	600**	389**	486**	373**	386**
	Minimum	0.08	0.06	0.55	0.80	0.87	0.43	5.53	6.48	24	32	272	272	98	101	88	146

(*) amplitude value exceeds 1 due to data discrepancy. (**) the season continues to the next year.

BOREAL

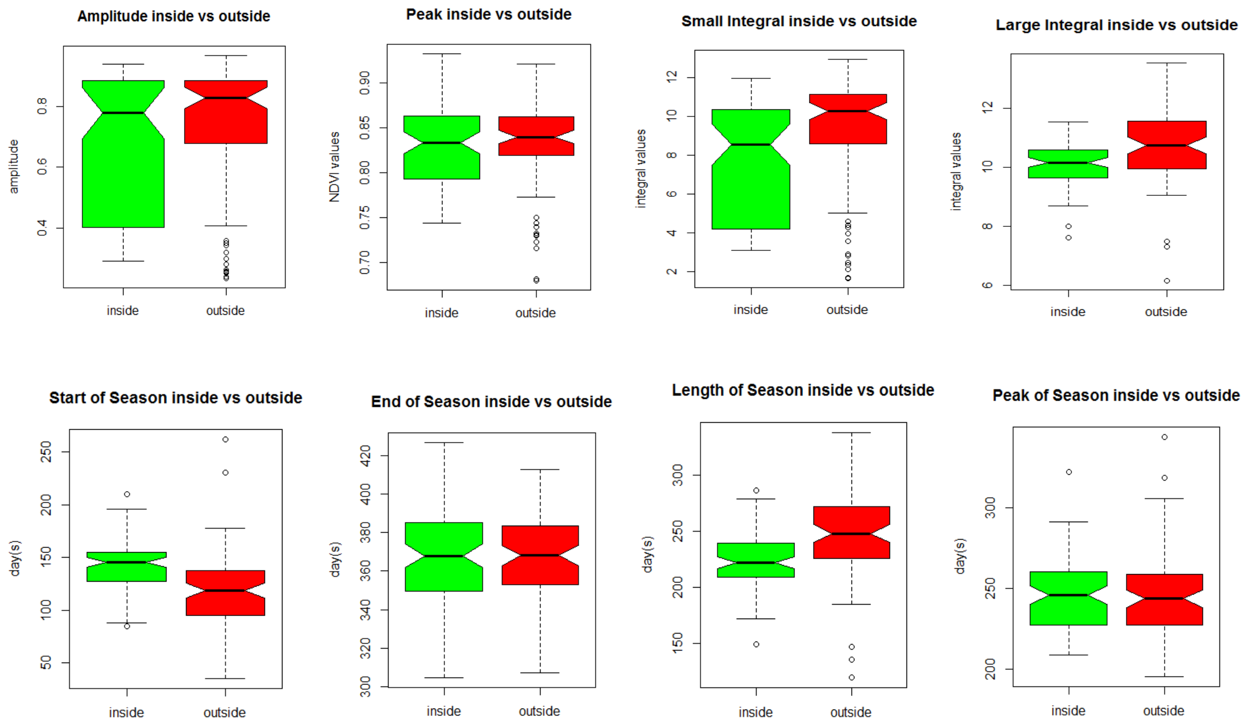

Fig. 16 Boxplots: data distribution in Boreal region **inside** and **outside** Natura2000 network

CONTINENTAL

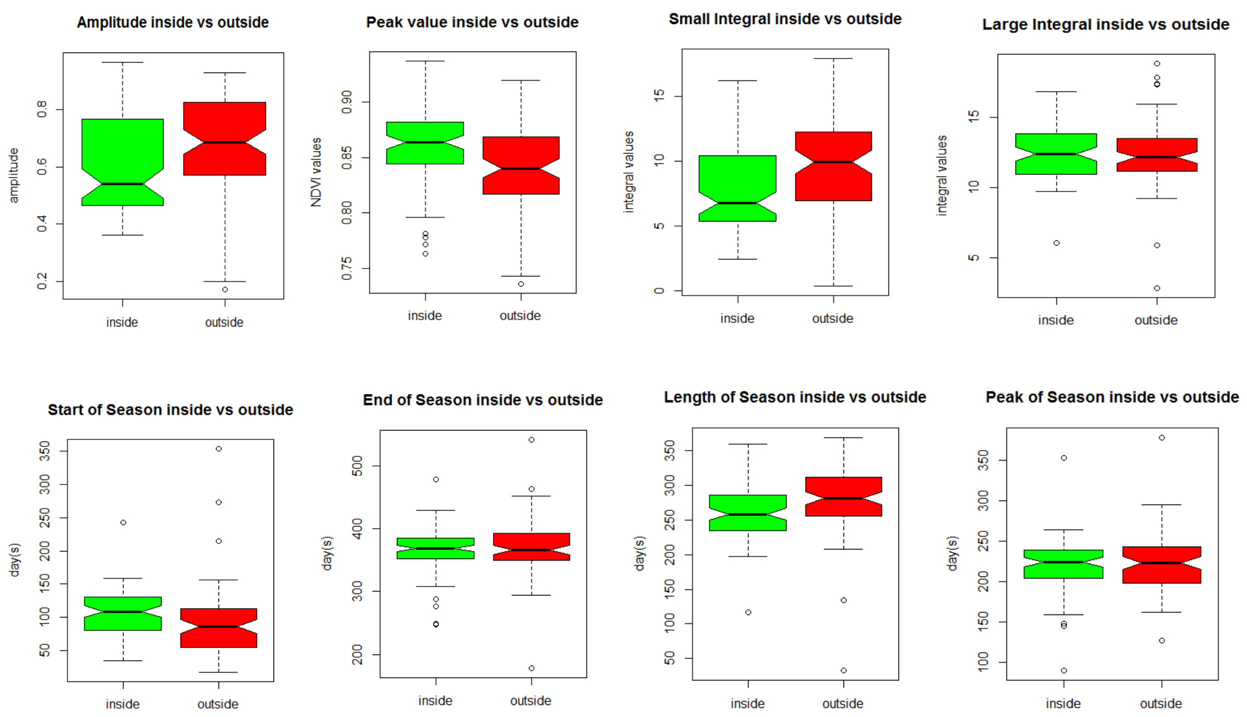

Fig. 17 Boxplots: data distribution in Continental region **inside** and **outside** Natura2000 network

MEDITERRANEAN

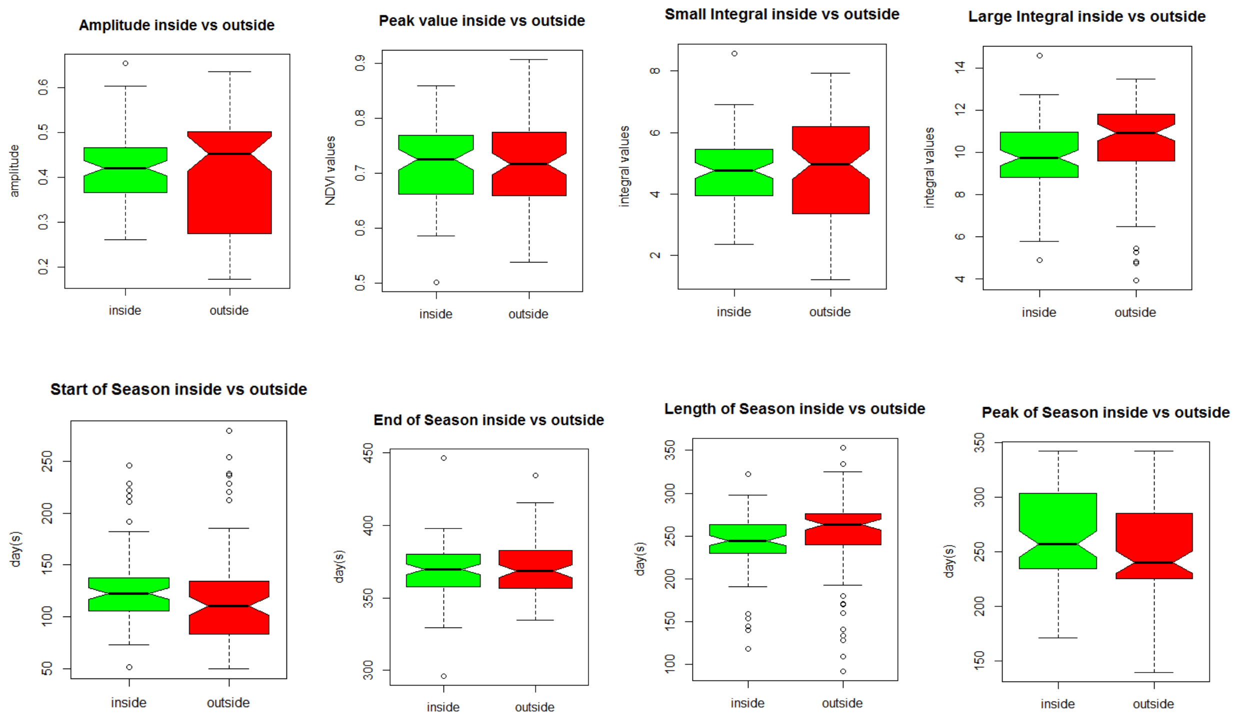

Fig. 18 Boxplots: data distribution in Mediterranean region **inside** and **outside** Natura2000 network

ALPINE

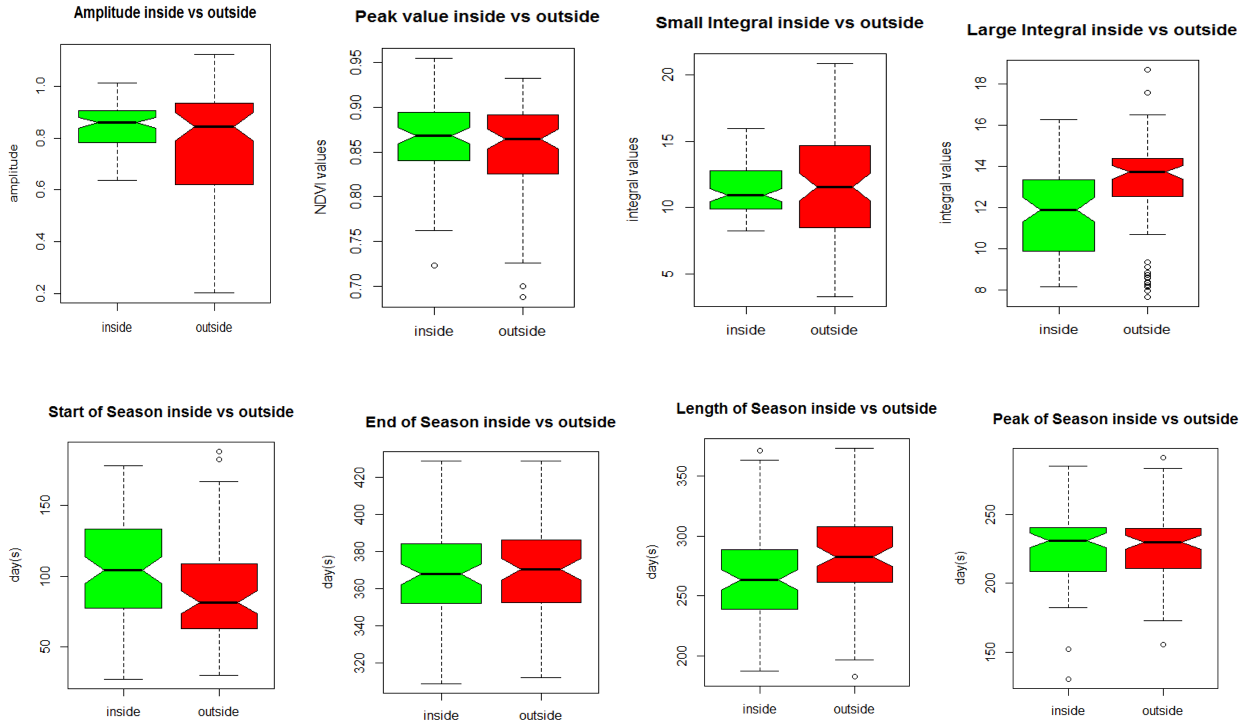

Fig. 19 Boxplots: data distribution in Alpine region **inside** and **outside** Natura2000 network

ATLANTIC

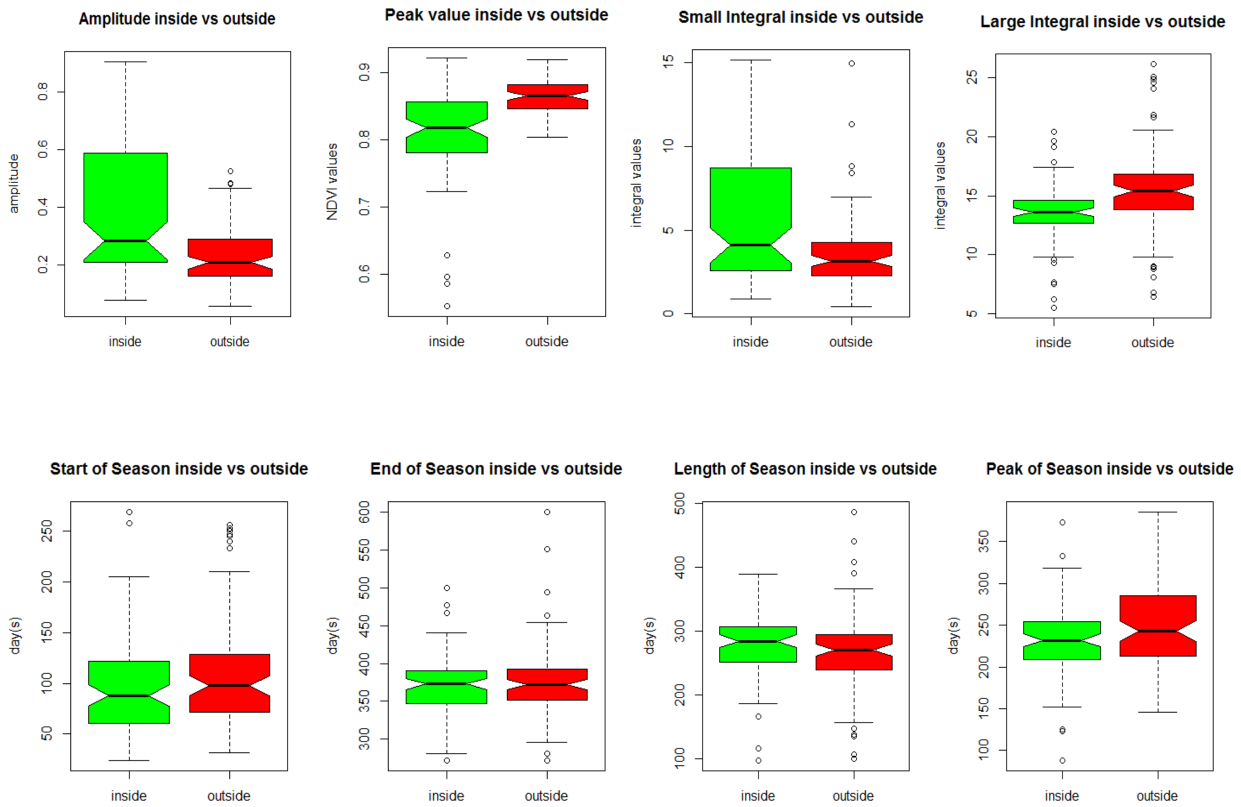

Fig. 20 Boxplots: data distribution in Atlantic region **inside** and **outside** Natura2000 network

The above boxplots display region wise data distribution for eight phenological metrics within and outside the Natura2000 protected network. Each box shows the interquartile range (25 to 75 percentile). The thick line in the middle represents the median of the data and the whiskers depict the minimum and maximum values. The outliers are represented as separate entities.

The tabular (Table 6) and graphical representations (Fig.16-20) provides us with certain approximation of the values for each phenological metric and also the estimated differences that exist between the protected and unprotected areas in terms of these seasonality parameters within each region.

4.2 Analysis of variation in phenological parameters inside and outside Natura2000 protected network

Results from hypothesis testing for significant differences inside and outside protected areas are compiled in the table (Table 7) below. It displays all the p values computed for the tested hypothesis. The tested hypothesis stated there is no significant difference for the phenological parameters between protected and unprotected areas. For a given phenological parameter, the difference for sites located within and outside Natura2000 network was considered statistically significant at 5% threshold (p value less than 0.05). The results which were observed to be statistically significant have been highlighted in the table. Median values for each phenological parameter were used to calculate the differences (whether significant or non-significant) between areas located within and outside Natura2000 network, as it is insensitive to outliers. These differences render a general overview of whether the protected areas are characterized by higher or lower values for a given parameter, compared to unprotected areas.

Table 7 Variation in phenology metrics inside and outside Natura2000 sites

Region	Productivity Related				Time Related			
	Amplitude	Peak value	Small integral	Large integral	Start of season	End of season	Length of season	Peak of season
Boreal	Out > In p= 0.1539	Out > In p= 0.3997	Out > In p= 0.00004733	Out > In p= 0.00004301	Out (early) In (late) p= 3.009 e^{-8}	Out (late) In (early) p= 0.9291	Out (long) In (short) p= 5.704 e^{-8}	Out (early) In (late) p= 0.5842
Continental	Out > In p= 0.0007041	In> Out p= 0.8677	Out > In p= 0.0002349	In> out p= 0.828	Out (early) In (late) p= 0.001192	Out (early) In (late) p= 0.785	Out (long) In (short) p= 0.001067	Out (early) In (late) p= 0.8677
Mediterranean	Out > in p= 0.8727	In > Out p= 0.8558	Out> In p= 0.6992	Out > In p= 0.0007632	Out (early) In (late) p= 0.04327	Out (early) In (late) p= 0.9557	Out (long) In (short) p= 0.003291	Out (early) In (late) p= 0.02022
Alpine	In > Out p = 0.2184	In > Out p = 0.2628	Out > In p= 0.9633	Out > In p= 0.0000159	Out (early) In (late) p= 0.00428	Out (late) In (early) p= 0.885	Out (long) In (short) p= 0.0119	Out (early) In (late) p= 0.7825
Atlantic	Out > In p= 0.00003776	Out > In p= 5.99 e^{-10}	In > Out p= 0.0006454	Out > In p= 0.00002901	Out (late) In (early) p= 0.04948	Out (early) In (late) p= 0.4361	Out (short) In (long) p= 0.09363	Out (late) In (early) p= 0.009646

An overview of differences in the productivity related (■) and time related (■) parameters for inside (in) and outside (out) Natura2000 sites. The highlighted (■) are statistically significant as is evident from the p values.

The overall results displayed in the table above (Table 7) reveal a general tendency of some of the phenological parameters. For the seasonality parameters related to time, in 100% of the ecosystems the start of the growing season was significantly different inside and outside protected areas, out of which, in 80% of the ecosystems Natura2000 sites are marked by a late onset of season. Similarly, in 80% of the ecosystems the seasonal length was significantly different between the protected and non-protected areas, where the sites outside the protected network were characterized by a longer seasonal length. Therefore, start of season and length of season were the two parameters showing a consistent unidirectional tendency. Peak of season although not significant in all cases, does exhibit a general pattern of early season peak outside protected areas in comparison to Natura2000 sites and corresponds in the direction of start of season. On the contrary end of season does not display any consistent such pattern.

In case of productivity related parameters, for large integral the difference between protected and non-protected areas was statistically significant for 80% of the ecosystems and in all those ecosystems sites outside Natura2000 protection network were characterized by a higher value of large integral. Similarly, for small integral, differences between sites inside and outside Natura2000 network were statistically significant for 60% of the ecosystems, out of which 66% were marked by higher small integral values outside protected areas. Although not statistically significant, the general tendency depicted by seasonal amplitude is of exhibiting higher values outside the protected sites compared to protected sites. Peak value on the other hand does not display any such general tendencies.

- **Boreal region**

  Productivity related parameters: All the NDVI related parameters were observed to be higher outside the conservation areas than inside. The amplitude was higher outside Natura2000 protected areas by 6.2% while the peak value was higher by 1.2%. Small integral and large integral values were found to be higher outside the protected areas by 18.4% and 5.6% respectively.

  Time related parameters: The season start was 26 days earlier outside the conservation areas, however season ended almost at the same time within and outside protected areas with a difference of 1 day. Early onset of season in non-protected areas led to an increase in the length of season by 26 days. The seasonal peak was observed to be 2 days later within protected areas.

- **Continental region**

  Productivity related parameters: Seasonal amplitude was higher outside conservation areas by 24.4% and small integral values were higher by 37.9%. On the contrary peak value and large integral values were found to be higher on Natura2000 sites by 2.4% and 2% respectively.

  Time related parameters: The onset of season inside Natura2000 sites was noted to be 22 days before the onset of season outside Natura2000 sites, whereas the difference in end of season was only 2 days earlier in unprotected areas causing the seasonal length to increase by 23 days in sites which were not under conservation. The seasonal peak was observed only 1 day earlier in sites outside conservation areas.

- **Mediterranean region**
  Productivity related parameters: The seasonal amplitude, small and large integral were higher outside Natura2000 sites by 6.9%, 4.1% and 11.6% respectively. Peak value on the contrary was higher within Natura2000 sites by 1.4%.

  Time related parameters: Start of season for this region was approximately 7 days earlier in the non-protected sites. The season ended 2 days earlier, the season length was 18 days longer outside of the protected areas. The peak of the season was also detected to be 17 days earlier.

- **Alpine region**
  Productivity related parameters: The seasonal amplitude and peak value were detected to be higher inside natura2000 sites by 1.2% each. Whereas the small and large integrals were greater outside the protected areas by 5.6% and 14.2% respectively.

  Time related parameters: An early onset of season by 22 days was noticed outside protected areas. The season culminated 2 days later increasing the length of season by 20 days outside protected areas. The time of the seasonal peak occurred only 1 day earlier in unprotected areas.

- **Atlantic region**
  Productivity related parameters: In the Alpine region seasonal amplitude along with peak value and large integral were observed to be higher outside Natura2000 sites by 32%, 6% and 12.1% respectively. On the other hand, small integral was detected to be higher inside Natura2000 sites by 26.1%.

  Time related parameters: Unlike other regions the season in Atlantic region started 10 days earlier in the Naura2000 sites and ended 1day late compared to sites outside the protected network resulting in a longer seasonal length of 15 days. The seasonal peak was also observed 10 days earlier inside Natura2000 sites.

  For Atlantic ecosystem the difference between 75% of the phenological parameters for inside and outside of Natura2000 sites were found to be statistically significant.

4.3 Inter-annual trend analysis

- **Presence of monotonic (linear/ non-linear) trends**

Out of 420 trend tests performed on 60 sites for seven seasonality parameters namely, amplitude, peak value, small integral and large integral, start of season, end of season and length of season; 4 cases exhibited no trends while 416 exhibited a presence of a monotonic trend i.e. either positive or negative. Only 10% of the trends were detected to be statistically significant at 95% confidence interval. All the positive (upward) and negative (downward) trends were compiled together to obtain a general overview of the trends in different ecosystems. The table below (Table 8) presents a thorough analysis of the results obtained from the Mann-Kendall trend test. It displays the percentage of sites exhibiting positive and negative trends, computed for different parameters inside and outside Natura2000 areas.

Table 8 Overall trend analysis

Region		Productivity related								Time related					
		Amplitude		Peak value		Small integral		Large integral		Start of season		End of season		Length of Season	
	Trend	in	out	in	out	in	out	in	out	in	out	in	out	in	out
Boreal	+ve	17%	50%	17%	50%	33%	50%	33%*	67%	67%	33%	33%	17%*	33%	50%
	-ve	83%	50%	83%	50%	67%	50%	50%*	33%	33%	67%	67%	67%*	67%	50%
Continental	+ve	17%	17%	67%	17%	50%	33%	67%	67%	33%	50%	67%*	33%	67%	67%
	-ve	83%	83%	33%	83%	50%	67%	33%	33%	67%	50%	17%*	67%	33%	33%
Mediterranean	+ve	17%	17%	17%	67%	33%	17%	33%	33%	50%	67%*	67%	50%	33%	17%
	-ve	83%	83%	83%	33%	67%	83%	67%	67%	50%	17%*	33%	50%	67%	83%
Alpine	+ve	17%	0%	33%	17%	50%	0%	50%	67%	33%	50%	67%	83%	67%	50%
	-ve	83%	100%	67%	83%	50%	100%	50%	33%	67%	50%	33%	17%	33%	50%
Atlantic	+ve	33%	50%	33%	67%	17%	50%	17%	50%	67%	67%	83%	33%	33%	50%
	-ve	67%	50%	67%	33%	83%	50%	83%	50%	33%	33%	17%	67%	67%	50%

An overview of all the positive (+ve) and negative (-ve) trends (significant and non-significant).
* one site exhibited no trend.

- **Significant monotonic trends**

As mentioned earlier only 10% of the calculated trends were found to be statistically significant i.e. only 40 trends out of a total of 420. The significant trends have been complied in Table 9. It is evident from the table that significant trends are predominantly observed in the productivity related metrics as compared to time related parameters. Furthermore, negative trends are more predominant in sites within as well as outside Natura2000 network. However, there is no clear evidence of difference in trends between sites which are a part of Natura2000 and sites which are not.

In order to quantify the trends, the Theil-Sen's slope method was used. The slope values have only been generated for the significant trends at a particular site and are presented in the table below (Table 9) The slope values represent the rate of change in median values for a given parameter over a period of 15 years.

Table 9 Significant trends

Region	Productivity related								Time related					
	Amplitude		Peak value		Small integral		Large integral		Start of season		End of season		Length of Season	
	in	out	in	out	in	out	in	out	in	out	in	out	in	out
Boreal	↓ -0.006	↑ 0.011	↓ -0.004		↓ -0.056									
Continental	↓ -0.033 ↓ -0.003	↓ -0.044 ↑ 0.022			↓ -0.69 ↓ -0.095	↓ -0.88 ↑ 0.57								↑ 5.8
Mediterranean		↓ -0.007			↑ 0.097	↓ -0.1	↑ 0.16							
Alpine		↓ -0.0226	↓ -0.003 ↓ -0.004	↓ -0.004 ↓ -0.0007	↑ 0.12	↓ -0.12	↑ 0.11 ↑ 0.09						↑ 3.7	
Atlantic	↑ 0.004 ↓ -0.013	↑ 0.008	↓ -0.004	↓ -0.004	↓ -0.26	↓ 0.21	↓ -0.12		↑ 1.9 ↑ 8.8			↑ 9.8	↓ -2.1	↓ -3.2

Total 40 in number, trends detected in all the regions for various seasonality parameters. Each arrow represents a site (out of a total of 6 sites per region for within and 6 sites per region for outside Natura2000 areas) showing either a positive (↑) or a negative (↓) trend for within (in) or outside (out) Natura2000 areas. The values next to the arrow denote the magnitude of the trend.

- **Association of significant trends with the SPEI drought indicator**

  The significant trends obtained above were compared to the SPEI drought indicator data. Although this time series does not exactly match the NDVI time series that has been used for this study, it covers approximately the same period and is certain to provide some insight into the effect of drought on these ecosystems. The significant trends were compared to significant positive R values computed by regression of SPEI and FAPAR anomalies for all 60 sites. Only two sites in the Mediterranean region, were found to coincide. Both the sites were in Spain, one of which was a Natura2000 protected site, Sierra de Gredos. Positive trends were exhibited by this site for small integral (τ= 0.54) and large integral (τ= 0.41) and the corresponding SPEI/FAPAR anomaly R value for this site was 0.288. The second site was from outside conservation area in Spain, which depicted a negative trend in amplitude (τ= -0.64) corresponding to SPEI/FAPAR anomaly R value of 0.41. Therefore, on the whole no strong influence of the drought was observed on the trends.

- **Kendall tau coefficient (τ)**

  Different ecosystems respond in different ways to external factors like climate change, change in management practices or sudden disturbances, and statistical significance alone cannot determine the strength of this impact on an ecosystem.

Therefore, Kendall tau coefficient values were compared between ecosystems in order to get an overview of how the overall trends for each of the phenological parameters have been across different ecosystems. The Kendall tau coefficient which is equivalent to the coefficient of correlation r, in regression analysis measures the direction and strength of relationship of the trend. The results have been summarised below:

Amplitude: the seasonal amplitude values were seen to have declined over the years for the Continental, Mediterranean and predominantly for the Alpine ecosystems for most of the sites irrespective of their conservation status (Fig. 21)

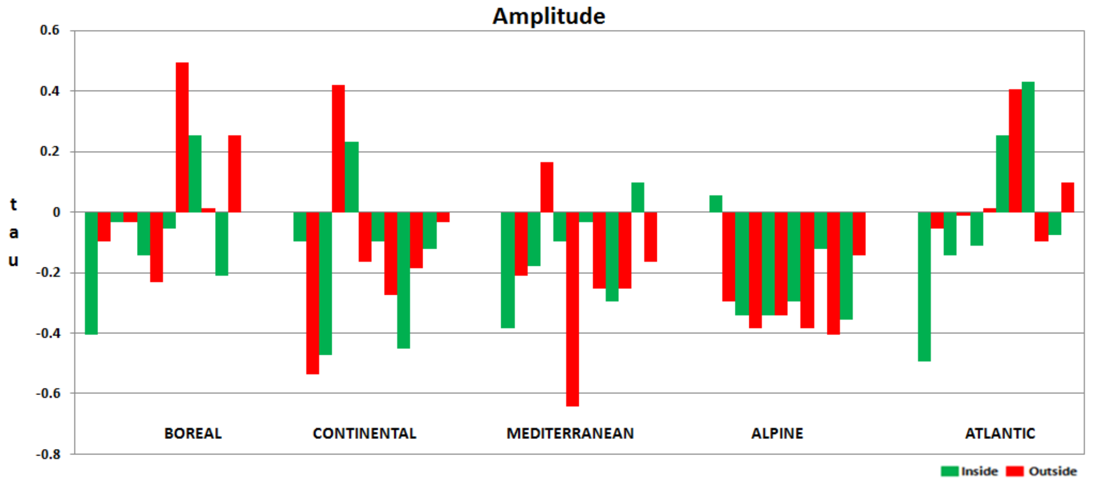

Fig. 21 Tau values for seasonal amplitude

Peak value: the trends in seasonal peak values primarily exhibit a negative nature for all ecosystems. However, in the Continental ecosystem positive trends were observed inside Natura2000 sites while on the contrary in the Mediterranean ecosystems Natura2000 pastures displayed negative trends in peak values. The Alpine ecosystem witnessed the highest frequency and strength of negative trends compared to all other ecosystems (Fig. 22).

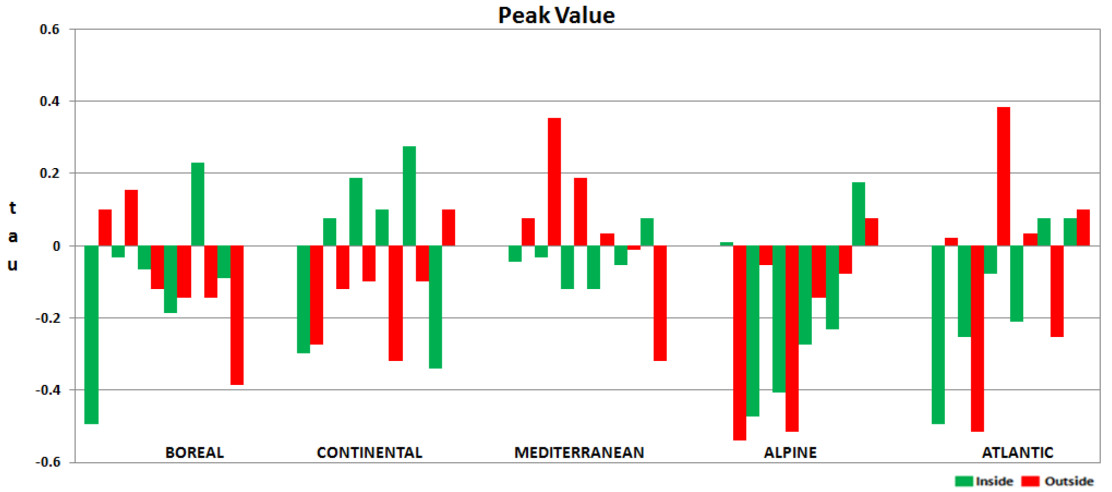

Fig. 22 Tau values for seasonal peak

Large integral: Mixed trends were observed across the Boreal, Mediterranean and Alpine ecosystems for Large integral values. By contrast, Continental ecosystems observed mostly upward trends while Atlantic ecosystems observed mostly downward trends for Large integral values both inside and outside natura2000 areas (Fig. 23)

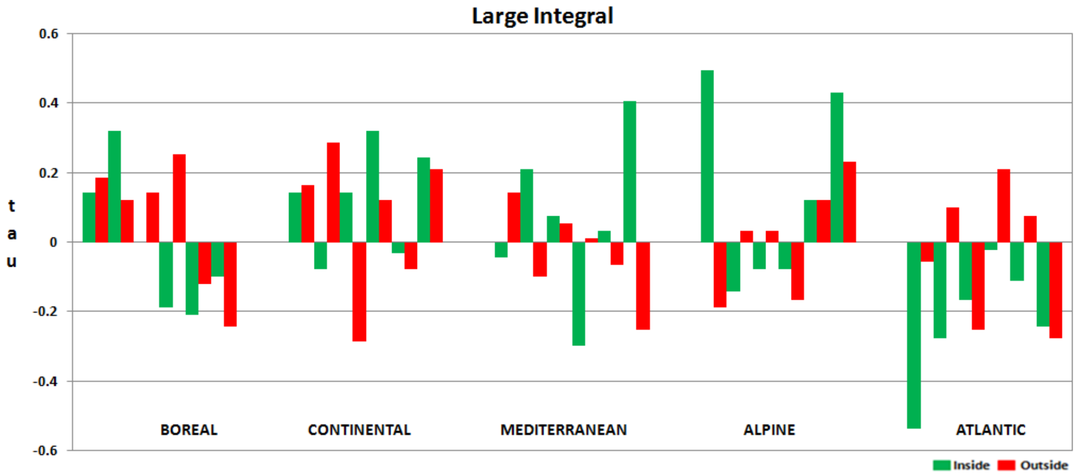

Fig. 23 Tau values for large integral

Small integral: In Boreal and Continental ecosystems, negative and positive trends were seen to be equally prevalent for Small integral. However, for Mediterranean, Alpine and Atlantic ecosystems majority of the trends were observed to be negative indicating decline in grassland productivity. The frequency and strength of trends were noticeably higher for Alpine ecosystems (Fig. 24)

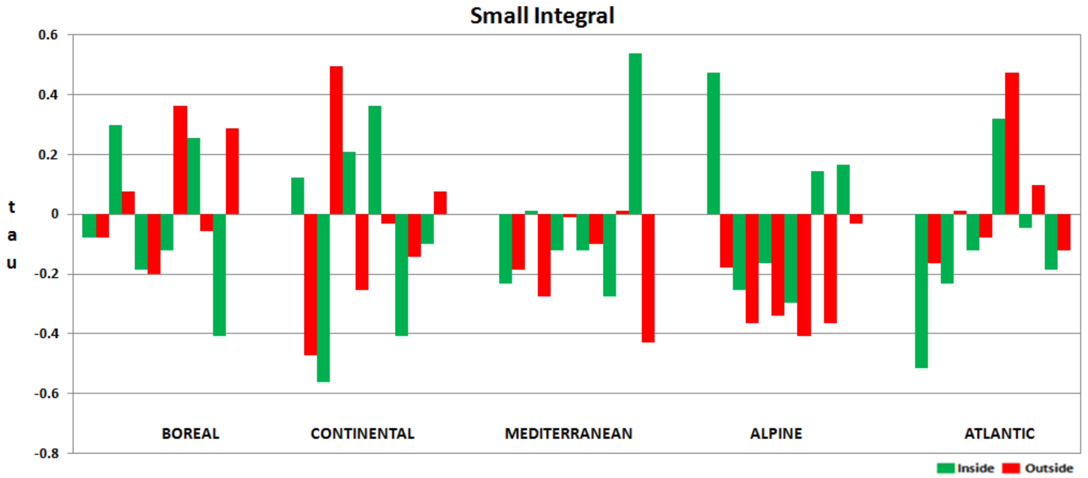

Fig. 24 Tau values for small integral

Start of season: The season start witnessed mixed negative and positive trends in Boreal, Continental, Alpine and Atlantic ecosystems, with higher strengths of both trends in the Continental and Atlantic ecosystems. The Mediterranean ecosystem however, exhibited a positive shift in onset of season for majority of the sites (Fig. 25)

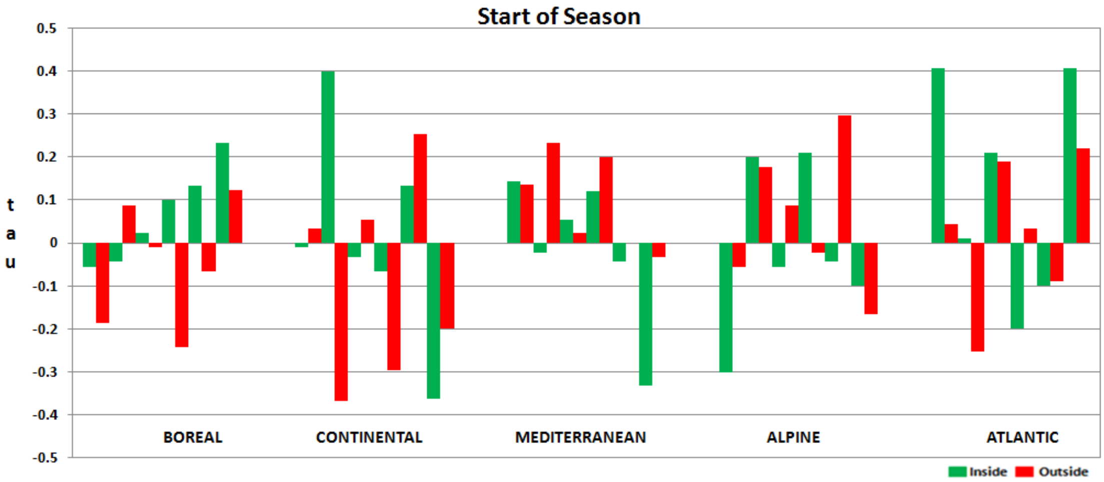

Fig. 25 Tau values for start of season

End of season: End of season was marked by primarily very weak trends in the Boreal, Continental, Mediterranean and Atlantic ecosystems both in upward and downward directions barring a couple of strong trends. Alpine ecosystem on the other hand mainly displayed positive trends indicating a shift towards a late season end (Fig. 26).

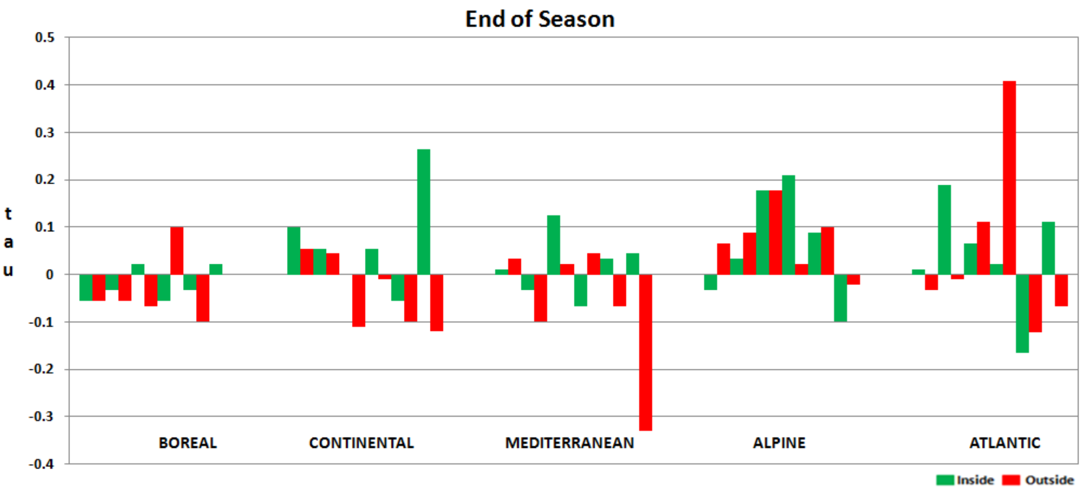

Fig. 26 Tau values for end of season

Length of season: The length of season was observed to exhibit weak mixed i.e. both upward and downward trends in the Boreal ecosystem and strong mixed trends in the Continental ecosystem. Mediterranean and Atlantic ecosystems were dominated by negative trends, indicating a shift towards shorter seasonal length. In the Alpine ecosystem positive trends were predominant, especially within natura2000 sites (Fig. 27)

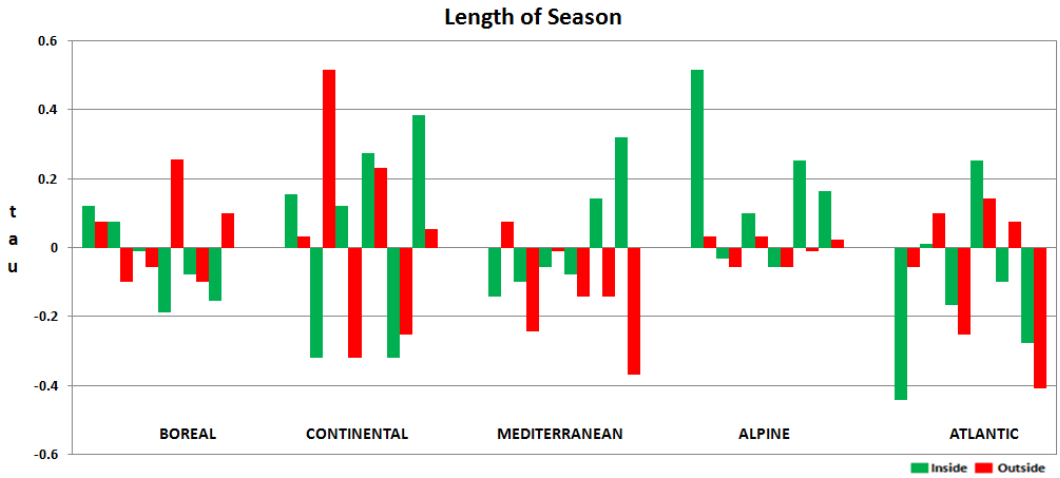

Fig. 27 Tau values for length of season

5 DISCUSSION AND CONCLUSION

This chapter reflects on the key findings which were deduced as a step towards the accomplishment of the aim of this study. The aim of this study was to test if the phenological metrics derived through remote sensing could act as indicators of ecosystem condition and health thereby giving an insight into the performance of Natura2000 conservation policy. This chapter has been divided into four sections. The first two sections reflect on the main findings of the research, related to each objective, by revisiting the original research hypothesis. The third section presents the sources of uncertainty and their implications. The final section concludes the study and suggests some recommendations for future research.

5.1 Analysis of variation in phenological parameters inside and outside the Natura2000 protected network

Discussion of results

The research hypothesis for the second objective stated that the establishment of Natura2000 will have an impact on the vegetation vigour of the pastures which belong to the protected network. Statistical tests conducted to test the hypothesis confirmed that the differences in some of the phenological parameters which determine the vegetation vigour were statistically significant for protected and unprotected sites. Furthermore, these differences followed a consistent pattern over various ecosystems indicating that these parameters could be used as indicators to characterize the vegetation vigour inside the protected areas, as result of the impact of their conservation status, thus highlighting the efficacy of Natura2000.

As directed by the European Commission (2014) low intensity farming management or traditional farming is a fundamental requirement of Natura2000 farmlands. Therefore, management practices mainly concerning restricted usage of fertilizers and pesticides is bound to have an impact on the primary productivity of these Natura2000 pastures. In regard to this, Beaufoy et al. (1994) stated that pastures under low intensity farming are characterized by low yields. Similarly, Willems and Nieuwstadt (1996), who analysed the effect of cessation of fertilization on productivity and species number on calcareous grasslands, found out that the yearly above ground production of grasslands decreased while the number of species increased in all the cases. These evidences clearly support the findings of this research, because productivity related parameter, large integral, was found to vary significantly inside and outside protected areas.

The large integral represents integrated NDVI values of the signal captured during the growing season from recurrent and persistent vegetation (Olsen et al. 2015) and it is well documented that integrated values of NDVI represent the annual aboveground primary productivity (Goward et al. 1985; Tucker and Sellers 1986; Paruelo and Lauenroth 1995; Yang et al. 1998; Enkhzaya and Tateishi 2010; Budde et al. 2004). In addition to this, the small integral represents the integrated NDVI signals from recurrent vegetation during a growing season (Olsen et al. 2015), although not significant in all cases but it lies in agreement with the large integral for 60% of the ecosystems. Therefore, it is clear that the differences between these two productivity metrics for inside and outside conservation areas are due to the difference in the aboveground primary productivity which is a result of difference in their protection status.

A similar significant pattern was observed in the onset of season. Earlier onset of growing season outside conservation areas could be a possible outcome of management practices, where intensive farming practices tend to accelerate the vegetation growth causing the vegetation to appear earlier outside protected areas as compared to pastures within the Natura2000 network. The length of the growing season was harmonized with the start of the growing season. This can be attributed to the fact that if the onset of growing season of grassland vegetation is earlier outside conservation areas while the end of season occurs at the same time, the length of season will consequently be longer outside conservation areas.

5.2 Inter-annual trend analysis

Discussion of results

The research hypothesis for trend analysis stated that there will be a difference in inter-annual trends for various parameters, within and outside Natura2000 areas, demonstrating the influence of Natura2000 conservation policy. Statistical testing of this hypothesis did detect the presence of trends, however the trends were too weak to be statistically significant. Since no consistent patterns were observed in trends, there was not enough evidence to support the research hypothesis. While the study shows a general tendency towards negative trends, a lack of clear visible trends could be a consequence of short span of time series. It is sometimes quite unlikely to follow consistent trends in such a short time series, spanning for 15 years in this case. Likewise, the trend analysis was performed on a single pixel with spatial resolution 250m representing each site, hence, there is a possibility that the strength of overall NDVI signal from this small area was too weak or affected by noise, thereby lowering the stability of NDVI signal which in turn affected the presence of significant trends (Olsson et al. 2005; Bolin et al. 2009).

Although it is relevant to consider the importance of statistical significance in research, the practical importance of a research question cannot be entirely answered using statistical tests. This can only be done by complementing the research with non-statistical information (Daniel 1977). Keeping this in mind, along with other factors like the short length of time series which could have an effect on the trends, Kendall tau coefficients were compared to see the trends of various phenological parameters across different ecosystems for all the sites in general. Consequently, the pastures in Alpine ecosystem exhibited the maximum frequency and strength of negative overall trends in productivity metrics. Ivits et al. (2016) found, that mostly agricultural areas in the Alpine ecosystems were significantly impacted by drought. However, when the sites were compared to SPEI drought indicator data (Ivits et al. 2016), it showed a negative correlation between SPEI and FAPAR indicating that these negative trends could not have been influenced by drought. One reason that could explain these downward trends in productivity metrics is the abandonment of pastures in the Alpine region as suggested by a number of studies (Tappeiner and Cernusca 1993; Pornaro et al. 2013; Strebel and Bühler 2015) which is occurring because of easy availability of cheaper fertilizers resulting in enhanced productivity of lowland grasslands and alternatives for fodder for animals (Condé et al. 2002; Spiegelberger 2006). However, this hypothesis requires further investigation.

General Discussion

The Natura2000 pastures investigated for this study have been assigned a conservation status under the Birds Directive and the Habitat Directive. A number of policies have been working to protect and maintain the grassland ecosystem both at national and EU level. In such cases, assessing the effectiveness of a specific conservation measure becomes difficult. On the other hand, if evidences from studies reveal, it is important to realise that a conservation policy is being well implemented, irrespective of its type. Grassland conservation policies aim at improving the biodiversity of pastures by preventing agricultural intensification (Collins and Beaufoy 2012) and it is suggested by a number of studies that intensive agricultural practices lead to increased herbage production but decreased grassland biodiversity (Cupina et al. 2005; Koukoura et al. 2005; Plantureux et al. 2005; Vuckovic et al. 2005). The above mentioned assertions underpin the results of this research obtained for the differences in productivity related and time related phenological metrics for protected and un-protected pastures. This information is valuable in the context that the site established under Natura2000 has continued to remained under traditional agricultural practices and thus under protection, as is evident from the significant differences in phenological parameters.

The presence of mixed and weak trends in all the phenological parameters makes it difficult to agree on any one or more parameters as clear indicators of the differences in trends for the protected and un-protected pastures. On the other hand, the concentration of more negative trends in the productivity related metrics indicate that over the past few years in majority of the European grassland ecosystems, the primary production has decreased. Declining primary productivity is an indicator of improving structural biodiversity suggesting that the pressure of intense agricultural activities on these pastures has decreased over the years consequently improving the quality of these grasslands. However, at the same time, declining productivity could also be drought-induced. For example, the droughts of the years 2003, 2005 and 2011 in Europe were observed to have a considerable impact on the declining vegetation productivity (Ciais et al. 2005; García-Herrera et al. 2007; Sepulcre-Canto et al. 2012). Another reason for decline in the primary productivity of pastures could be abandonment of agricultural grasslands or pastures. As mentioned earlier conservation policies aim at preserving the pastures by restricting intensive agricultural activities on them, affecting their productivity. This makes these pastures economically unprofitable leading to their abandonment (European Forum on Nature Conservation and Pastoralism – Policy 2016). However, these hypotheses require further research.

5.3 Sources of uncertainty and their implications

- **Limitations of NDVI composites:** In order to reduce the noise in NDVI data due to presence of clouds or any other atmospheric variability Maximum Value Composite (MVC) data values have been used. Despite the use of MVC some atmospheric noise residuals tend to persist in the data (Jönsson and Eklundh 2002). The principle that MVC is based on allows the highest NDVI value to be picked up for a given pixel from cloud contaminated data over a given period of time. This could lead to imprecise estimation of plant phenology because while greening period those high values will be chosen from later days in the given time periods while in the browning phase the higher values will tend to be chosen from earlier days of the given time period (Pettorelli 2013). These factors are therefore likely to cause uncertainties in the phenology metrics.

- **50 km Buffer for selecting pastures outside Natura2000 network:** While selecting sites outside Natura2000 protected network for comparison, an outside buffer limit of 50km was chosen. However, the spatial variability of temperature and rainfall over this distance is likely to influence the phenological development stages of vegetation, consequently, leading to differences in parameters within and outside protected areas.

- **Autocorrelation:** While performing trend analysis with NDVI time series, it is important to take care of outliers, seasonality and auto-correlation since they can affect the p values making less significant trends to appear significant (de Jong et al. 2011) and one way to counteract it, is to remove the seasonality (Hussian 2005). These effects have been taken care of, firstly by integrating the NDVI values to derive the seasonality or phenological parameters which are annual values thus free from seasonality. The second approach is the use of a non-parametric Mann-Kendall trend test and Sen's slope estimator for trend analysis which takes care of the outliers.

- **Threshold values for seasonality:** the threshold value for start and end of season should have been calibrated to ground observations. Different researchers have suggested different threshold values therefore the choice of threshold value was arbitrary. In addition to this, a single threshold value was applied to all the biogeographic regions for start and end of season, however, according to De Beurs and Henebry (2010), since the phenological events vary with different latitudes, having a fixed value for a large study area is likely to yield unreliable results. They also suggested that it is not reasonable to have same values for the start and end of season since the timing and rate of onset of growing season is completely independent of the end of the growing season.

- **Savitzky Golay window size:** Chen et al. (2004) suggested that a small window size for Savitzky-Golay filter sometimes tends to over fit the data points making it hard to capture long-term change trend and that a value between 4-7 is considered feasible. However, a window size of less than 4 has been used in a number of cases to achieve a best for time series while generating the settings file. This could have an effect on the reliability of the seasonality parameters derived using Savitzky-Golay filter.

- **Upper Envelope Settings:** The seasonality metrics derived from the NDVI data are controlled by a number of settings in TIMESAT. According to the TIMESAT manual, the results can vary depending on different settings such as upper envelope settings i.e. number of envelope iterations and adaptation strength (Eklundh and Jönsson 2015). This is likely to introduce uncertainties in the computation of seasonality parameters.

- **Validation:** to determine the accuracy of land surface phenology has been an important but a very challenging task for the remote sensing community. This is due to the lack of ground validation data and without the availability of ground observation data it is difficult to substantiate that the phenological changes identified from satellite based data are genuine in existence (Hamunyela et al. 2013). However, validation is considered out of the scope of this study. This research does not aim at finding out when a particular event is occurring, or determining the absolute values for productivity of the ecosystem, assuming that we have, for each year, robust approximated measures. The aim here is to look for those parameters or measures which can be used to observe changes within an ecosystem.

5.4 Conclusions

Summary

Recalling, the overall aim of this research was to test the potential of land surface phenology as an indicator for assessing the effectiveness of conservation policies like Natura2000. The first objective towards the aim was to generate phenological metrics which could be tested as robust measures of comparison between the protected areas and areas outside protection network. Eight phenological parameters, differentiated into two categories, productivity related i.e. amplitude, peak value, small integral and large integral; and time related i.e. start of season, end of season, length of season and peak of season were computed for further analysis. The second objective was to look for significant differences between the protected and un-protected areas emerging as an outcome of the conservation status of Natura2000. Finally, the third objective was to perform trend analysis in order to analyse the differences in trends within and outside protected areas.

Conclusions from this research

The following conclusions are drawn from this research:

- The productivity related parameter large integral which represents the seasonal recurrent and persistent growth and time related seasonality parameters, start and length of season are capable of acting as robust indicators of ecosystem condition, indicating the performance of Natura2000. These parameters displayed a consistent pattern across the majority of the ecosystems, in characterizing the vegetation vigour for pastures within and outside the Natura2000 network highlighting the health of ecosystem and thus the effectiveness of Natura2000.

- The trend analysis did not yield any substantial results, which could be considered adequate to conclude that the estimated trends in vegetation vigour for protected and unprotected areas were influenced by the conservation policies.

Recommendations

The following recommendations are suggested for related future studies in order to reach robust conclusions on the development of indicators of ecosystem health by the use of land surface phenology:

- Future researchers may consider using NDVI time series data for a longer period of time to verify the results of this research. Also, time series data used for this study was from the year 2001 onwards, while most of the sites were established as Natura2000 sites in late 90's or early 2000's so it was difficult to detect any clear trends. A longer time series would give a better picture of the trends of vegetation vigour for not only the sites which were newly included in Natura2000 network, but also for the sites which were already under conservation before being included in the Natura2000 network. In this regard, historical data from Landsat can be used. According to Wulder et al. (2012), the open access to Landsat data has led to its usage in several domains related to Earth system processes, including vegetation phenological studies. Generation of synthetic Landsat imagery by combining the spatial resolution of Landsat and temporal resolution of MODIS (Gao et al. 2006; Gao et al. 2010), hold a great potential for phenological studies.

- This study was based on sample sites represented by a single pixel. Future studies may consider selecting a cluster of pixels as a representative of the study site in order to ensure a better strength and quality of the NDVI signal, particularly for trend analysis. Bolin et al. (2009) suggested that, the trends computed using linear least square regression, estimate significant trends (if any) for any given pixel without conveying any information on the overall significance of trends for all the pixels of a region. Accordingly, they developed a spatio-temporal regression model using Gaussian Markov Random Fields and proposed that the use of spatial dependencies in remotely sensed NDVI data yielded a better precision in obtaining smoother trends, significant over larger contiguous areas. This approach can be followed in future studies to obtain better trend estimates.

- Similar future studies may consider using vegetation indices other than NDVI for trend analysis. For example, the Plant Phenology Index (PPI), a physically-based vegetation index developed by Jin and Eklundh (2014), which can be applied across a wide range of vegetation types. PPI has been demonstrated to lie in good linear correlation with ground estimated Leaf Area Index (LAI) and has been proposed to be relatively less sensitive to snow as compared to the NDVI and Enhanced Vegetation Index (EVI), especially in higher northern latitudes like the Boreal ecosystems.

Vegetation phenological and productivity metrics have a strong potential in mapping the condition of ecosystems as they repeatedly acquire the spatial patterns of vegetation dynamics and provide an integrated measure of ecosystem responses to changes in climate, management practices and anthropogenic disturbances. However, it is also important to keep in mind that remote sensing is just a tool which can provide considerable amount of ancillary information, it cannot replace the first-hand knowledge about the area therefore this information needs to be handled carefully.

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