Determining the Impact of Fire Severity on Vegetation Regrowth As a Result of the Greek Forest Fires 2007

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by

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Abstract

Forest fire plays a key role in the global carbon cycle and is a primary disturbance factor of forest ecosystems. Fire is an important ecological factor of the European Mediterranean Region. In 2007, about 292657 hectares of the area were affected by forest fire in Greece, 189128 hectares (65% of the total burned area of Greece) were in the Peloponnese Peninsula. Fire severity is the direct result of the combustion process and is related to the rate at which fuel is being consumed. Many studies have already been conducted to map fire severity using different burn severity indices and most of the researches were based on field based validation. A few studies have used the coarse resolution time series data to assess fire severity and its impacts on vegetation recovery. Therefore, this study was a remote sensing approach to map fire severity and to assess its effects on the vegetation of Peloponnese Peninsula, Greece, using Moderate-resolution Imaging Spectroradiometer (MODIS) time-series [2003-2013] and its available data products.

Two established fire severity indices, differenced Normalized Burn Ratio (dNBR) and Relative differenced Normalized Burn Ratio (RdNBR) were used to detect fire severity. According to the dNBR-initial assessment, 71%, 25% and 4% of the total fire perimeter was under high, moderate and low severity category respectively. The dNBR-extended assessment showed that after the fire, the ecosystem restored at some extent in one year, as, 12%, 40% and 41% of the area in fire perimeter was respectively under the high, moderate and low severity category. In initial and extended assessments, both of the indices revealed that the four major fire affected land cover classes were woody savannah, mixed forest and croplands.

MODIS derived Fire Radiative Power (a measure of the rate of heat radiant output from a fire) and Fire Radiative Energy (temporal integration of FRP) were used to estimate the amount of total fuel consumption due to the fires. Areas under the high severity in initial and extended assessment showed higher fuel consumption and in total 3.12 Teragram (Tg) of fuel burned during the fires. Time series analysis of two MODIS products, LAI (Leaf Area Index) and NDVI (Normalized Difference Vegetation Index), were conducted in this study to understand the vegetation dynamics and change in vegetation phenology cycle after the fires. Time-series and Area under Curve analysis showed that the vegetation recovery rate of woody savannah under all of the severity categories was higher than the recovery rates of mixed forests.

Key words: dNBR, Fire Radiate Power, Fire Severity, MODIS, Vegetation Regrowth

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ADAR	Airborne Data and Acquisition and Registration
AF	Active Fire
AGB	Above Ground Biomass
AMSR-E	Advanced Microwave Scanning Radiometer
AOD	Aerosol Optical Depth
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BA	Burned Area
BRDF	Bidirectional Reflectance Distribution Function
CBI	Composite Burn Index
CNES	National Centre for Space Studies, France
CORONA	
dNBR	Difference Normalized Burn Ratio
EA	Extended Assessment
ECMWF	European Centre For Medium-Range Weather Forecast
EEA	European Environment Agency
ENVISAT	Environmental Satellite
EO1	Earth Observing-1
ESA	European Space Agency
ETC/BD	European Topic Centre for Biological Diversity
ETM+	Enhanced Thematic Mapper plus
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EVI	Enhanced Vegetation Index
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization
FC	Fuel Consumption
FRE	Fire Radiative Energy
FRP	Fire Radiative Power
GADM	Global Administrative
GDEM	Global Digital Elevation Model
GFAS v1.0	Global Fire Assimilation System version 1.0
GFED 3.1	Global Fire Emission Database version 3.1
GLAS	Geoscience Laser Altimeter System
GOES	Geostationary Operational Environmental Satellites
HRVIR	Haute Résolution dans le Visible et l'Infra-Rouge
IA	Initial Assessment
ICESAT	Ice, Cloud, and Land Elevation Satellite
KH-4B	Key Hole 4B

LAI	Leaf Area Index
LiDAR	Light detector and Raging
LP DAAC	Land Processes Distributed Active Archive Center
MCD	Meaning Combined Product
MERIS	Medium Resolution Imaging Spectrometer
MIR	Middle Infra-red
MODIS	Moderate Resolution Imaging Spectroradiometer
MTCI	MERIS Terrestrial Chlorophyll Index
NASA	National Aeronautics and Space Administration
NATURA 2000	Ecological network of protected areas in the territory of the European Union
NBR	Normalized Burn Ratio
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-red
NOAA	National Oceanic and Atmospheric Administration
OG	Onset of Greenness
ORNL DAAC	Oak Ridge National Laboratory Distributed Active Archive Centre
pRI	Photochemical Reflectance Index
RdNBR	Relative Difference Normalized Burn Ratio
SACs	Special Areas of Conservation
SAR	Synthetic Aperture Radar
SCIs	Sites of Community Importance
SDF	Standard Data Form
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SPAs	Special Protection Areas
SPOT	Satellite Pour l'Observation de la Terra
SWIR	Short-wave Infra-red
TM	Thematic Mapper
TOC	Top of Canopy
VIIRS	Visible Infrared Imager/Radiometer Suite

Chapter 1
Introduction

1.1 Background

Forest fire is a disturbance factor for almost all the terrestrial ecosystems (Chuvieco et al., 2007). The impact of forest fire on vegetation is multifarious through removing the existing vegetation coverage, affecting the post-fire vegetation regrowth and its composition (Epting et al., 2005; Röder et al., 2008). Large scale biomass burning modifies global carbon cycle, changes landscape patterns and diversity, thus, influencing the energy balance of forest ecosystems. Forests require a long retrieval time to restore the biomass level and vegetation structure after the fire events (Tanase et al., 2011).

In recent decades, forest fires annually destroyed about four million square kilometres of global forest lands with an estimated carbon emission to the atmosphere of two Giga Tonnes (GT) (van der Werf et al., 2010). Forest fire is common in the Mediterranean climatic region where an extended hot dry summer leads the fallen branches, leaves and other dry materials. These combustible materials can then initiate large scale forest fire, which can severely damage vegetation, shape landscape pattern and diversity, influence energy flows in global carbon cycle (ScienceDaily, 2012).

Forest fire is an important ecological factor of European Mediterranean forests; on average, 60,000 fires occur every year which burn about one million hectares of forest areas across Europe (San-Miguel-Ayanz et al., 2009; Ridder, 2007). In the year of 2007, five southern Mediterranean European countries (Spain, Portugal, Italy, France and Greece) had a total of 575,531 hectares of burned area. This number was higher than the average of last twenty eight years of fire statistics in these countries, whereas, the number of fire occurrence (45,623) was lower than the average number of fire occurrence in last twenty eight years. A large part of the European forests under the NATURA 2000 nature protected sites was also affected by the forest fires (Bassi et al., 2008).

In 2007, Greece has experienced massive ecological and socio-economic losses due to large scale forest fires. Prolonged drought and heat waves, low humidity together with strong wind initiated the infernos into large scale devastating fires. The total burnt areas were estimated 225,734 hectares (JRC, 2008) and about 30,132 hectares were within the boundaries of the NATURA 2000 protected area network (WWF, 2007). During August 2007, wildfires inflamed 200,000 hectares of land across the Greek mainland including 173,000 hectares of rural land in the Peloponnese peninsula (Blake et al., 2008).

Forest fire varies in space and time and several approaches have been implemented by researchers to assess the post-fire effects within the landscape. Field measurements and visual image interpretation were implemented for burned area estimation (Escuin et al., 2008). However, field measurements are time consuming and labour intensive and associated with difficulties, such as, uncertainties in quantifying fire severity, steep and high elevated terrain with inaccessibility in some area (Brewer et al., 2005, Hall et al., 2008). The drawbacks from the field measurements lead scientists to adopt remote sensing approach for assessing post-fire impacts on forest ecosystems. The variation in spectral signature of objects on electromagnetic spectrum after the fire event facilitates the detection of burned area over landscape (Barrett & Kasischke, 2013).

Several approaches have been implemented for fire severity mapping utilizing visible, near-infrared and mid-infrared region of the electromagnetic spectrum (Key & Benson, 1999; Miller & Thode, 2007; French et al., 2008). Fire severity mapping through spectral mixture analysis of Landsat TM was conducted by Rogan and Franklin (2001). The same satellite sensor has later been used in a semi-automated object-oriented model by Mitri and Gitas (2004) to map the burned area in the Mediterranean region. Díaz-Delgado et al. (2003) mapped the fire severity and categorised them in seven classes. This study was an initiative to develop an interaction with fire severity and vegetation recovery using NDVI. A comparison of fire methods by Brewer et al. (2005) listed six approaches and opined NBR (Normalized Burn Ratio) as an effective burn index. Moreover, Zhu et al. (2006) evaluated the sensitivity of burn severity index, differenced Normalized Burn Ratio (dNBR), with other algorithms using Landsat data and field plot-based measurement called the Composite Burn Index (CBI) for different ecosystems in the United States. Hoy (2007) evaluated the potential of the NBR with other spectral indices for fire severity in Alaskan Black Spruce Forest. Furthermore, NBR and dNBR were implemented with different datasets [e.g., MODIS reflectance and active fire products (Merino-de-Miguel et al., 2010; Veraverbeke et al., 2010a)] and even the combination of datasets MODIS and ASTER [MASTER] (Harris et al., 2011). In an attempt to estimate burn severity in a heterogeneous landscape with dNBR and relative differenced Normalized Burn Ratio (RdNBR), Miller and Thode (2007) came up with the idea of setting threshold values for different severities under dNBR and RdNBR to map burn severity. Some of the researchers investigated under two different assessment scenarios, initial and extended assessment, to observe how the fire severity varies over time (French et al., 2008; Holden, 2008; Veraverbeke et al., 2011).

Satellite observation of the radiative energy released during the fire is an indirect way of estimating the total fuel consumption (Kaufman et al., 1998). The rate of energy released (Fire Radiative Power or FRP) is proportional to the fire size and fuel load (Wooster et al., 2005; Ellicott & Vermote, 2012). The integration of FRP provides the estimate of fire radiative energy which is directly proportional to the total emission during the fire (Wooster et al., 2005). Several satellite sensors are able to retrieve the fire radiative power (FRP) and fire radiative energy (FRE) and are potential to quantify the fuel consumption (Wooster et al., 2003; Roberts et al., 2011; Ellicott et al., 2009; Kaiser et al., 2012). Among those sensors, the MODIS (Moderate Resolution Image Spectrometer) sensor offers a better temporal resolutions which can detect active fires and also can immediately measure fire severity (Justice et al., 2002). MODIS has the same spectral bands like Landsat and the visible, near-infrared (NIR) and shortwave-infrared (SWIR) wavebands have been used to map fire severity (Vermote et al., 2009). Many researches have used different spatial resolution of MODIS data products to map fire severity and to monitor the post-fire impacts on ecosystems (Chuvieco et al., 2005; Roy et al., 2005; Loboda et al., 2012). Walz et al. (2007) compared MODIS and Landsat images to assess the burn severity in Western Australia and found that a strong similarity in spectral characteristics. Therefore, in this research, MODIS data products were used to map fire severity, to estimate FRP and FRE and also MODIS LAI and NDVI products were used to assess the impacts of fire severity on vegetation of Peloponnese Peninsula.

Forest fire alters carbon reservoirs to carbon emission sources (Running, 2008; van der Werf et al., 2010). Therefore, quantification of fuel consumption during fire events is important to understand the carbon cycle and vegetation dynamics (Ellicott et al., 2009). In order to assess the effect of fire disturbance on vegetation regrowth, researchers used several spectral indices in their assessment, such as, NDVI (Lunetta et al., 2006; Veraverbeke et al., 2010b; Petropoulos et al., 2014), pixel based regeneration index (pRI) derived from SPOT-VEGETATION (VGT) NDVI, in relation to burned area and fuel consumption (Lhermitte et al., 2011). Reduction of spectral signature in near-infrared (NIR) region after the fire is the key to measure the fire impacts on different types of vegetation coverage (Jakubauskas et al., 1990; Pereira et al., 1999).

Many researches related to fire severity have been conducted so far to develop the derivation methods of fire severity and validation of the datasets used for fire mapping, which resulted in improvement of accuracy in fire severity mapping and to monitor its impacts on the vegetation. Hence, only a few studies have used the coarse resolution time series data to assess the fire severity and its impacts on the vegetation (Gitas et al., 2012). However, an integrated research of fire severity together with vegetation regrowth is still required to understand how the vegetation regeneration pattern approaches under different severity conditions. Therefore, this research was a remote sensing approach using MODIS time series [2003-2013] data products to assess the magnitude of large scale forest and its impacts on vegetation of Peloponnese peninsula, Greece after the Greek forest fires of 2007.

1.2 Research Problem and Objectives

Devastating fires across the Peloponnese peninsula, in 2007, resulted in a significant impact on forest ecosystems (JRC, 2008). Variations in fire severity across the landscapes after the forest fires are mainly on vegetation and the after impact of fires are on the post-vegetation recovery (White et al., 1996). It is necessary for forest managers and decision makers to understand the spatial variability of fire severity in relation to meteorological, topographical and ecological factors to assess the impact of wildfire on vegetation. Although research into fire severity and its effects on the landscape not a new, few studies have been conducted to evaluate the ability of remotely sensed data to characterise fire severity and its impact on vegetation phenology. The main objectives of this research were:

- To conduct an initial and extended assessment of burn severity in relation to topographic factors,
- To establish a relationship between fire severity and fuel consumption with the heat emitted during the forest fires and
- To assess the regrowth pattern of vegetation in relation to the fire severity

1.3 Research Questions

- What is the extent of change in fire severity over time?
- Which factors are influencing the fire severity?
- How much fuel consumed during the forest fires?
- Is there any relationship exist between the MODIS derived Fire Radiative Power (FRP)/Fire Radiative Energy (FRE) and different severity categories?
- What is the pattern of vegetation regrowth under different severity categories and landcover classes after the forest fire?

1.4 Justification of the Study

Assessment of fire severity and its impacts on vegetation using remote sensing is not a new research arena. Several publications and researches have already been done to evaluate the spatial variation of fire severity and its impacts on vegetation recovery using remote sensing techniques and also integrating field based methods with remote sensing. Although there are many studies on burn severity and spatial extension of burned area assessment using remote sensing data, there are very few studies have been conducted to evaluate immediate and extended effect of burn severity on the forest ecosystems and on the trend of vegetation regeneration using moderate resolution time series data.

Chapter 2
Literature Review

This chapter describes the review of relevant literature, different terminologies of forest fire mapping, fire severity indices, satellite sensors in estimating fuel consumption, effects of forest fire on vegetation phenology and previous researches on the Greek Forest Fire 2007.

2.1 Terminology

The impacts of fires are on vegetation and before discussing the impacts following basic terminologies are important: fire intensity, fire line intensity, fire severity, spectral index, fire regime, and fire radiative power.

Fire severity or **Burn Severity** can be described as:

- physical, chemical and biological changes experienced by the ecosystem after the fire occurrence (Landmann, 2003; Stow et al., 2007; Chafer, 2008; Pérez-Cabello et al., 2009)
- the degree of alteration that fire causes to an ecosystem (Brewer et al., 2005, Eidenshink et al., 2007)
- the magnitude of change in ecosystem caused by fire (Key & Benson, 2006)

Fire severity implies to the short-term fire effects in the immediate post-fire environment while **burn severity** quantifies both the short- and long-term impact as it includes response processes (Veraverbeke et al., 2010). Therefore, to quantify the degree of changes of any fire these two terms, fire severity and burn severity, are often used interchangeably (Keeley, 2009). Lentile et al. (2006) brought an apparent distinction among these terms by another term **fire disturbance continuum** which addresses three different temporal fire effects phases: pre-fire, during fire and post fire (Jain et al., 2004; Veraverbeke et al., 2010).

Fire ecologists are in confusion whether they include or exclude, **ecosystem response** (e.g., re-growth, regeneration and resilience) in quantifying fire severity, as, the inclusion of this term has been proved to result significant negative correlation between direct fire impact and regeneration ability (Díaz-Delgado et al., 2003). Hence, most of the fire ecologist in remote sensing community excluded ecosystem response from the term burn severity Keeley, 2009.This research was conducted under both immediate and extended assessment to observe the impacts of fire severity on vegetation. Therefore, considering the time period [2003-2013] of assessment and for terminological consistency, the term "fire severity" was used in this study.

Initial Assessment (IA)
IA is executed immediately after the fire event (Key, 2005)

Extended Assessment (EA)
EA is a certain amount of time elapses between the fire event and the assessment (Key & Benson, 2006)

Fire Intensity
Fire intensity describes the physical combustion process of energy release from organic matter (Keeley, 2009)

Fireline Intensity (in KWm^{-1})
Fireline intensity is a measure of the rate of energy released from a fire per unit length of the burning front (Byram, 1959)

Spectral Index
Spectral index is derived from the ratio of spectral reflectance and is a combination of different sensor bands (Lentile et al., 2006; Wulder et al., 2009)

Fire Regime:
The frequency, seasonality, intensity, severity, fuel consumption and spread patterns of fires that prevail at a certain location are referred to as the fire regime (Gill, 1975; Bond and Keeley, 2005)

Fire Radiative Power (FRP):
The rate of energy release of the fires which is measured in megawatts per pixel and gives an indication of both biomass consumption rate and fireline intensity (Roberts et al., 2005; Smith & Wooster, 2005; Roberts et al., 2009)

2.2 Remote Sensing of Forest Fire

Traditional methods of forest fire mapping and monitoring are labour-intensive, and limited to space and accessibility (Bertolette & Spotskey, 2001;Mitri & Gitas, 2008;Gitas et al., 2012). Remote sensing is a technique with spatial and temporal capabilities which can gather information for large burned and for inaccessible area (Chuvieco & Congalton, 1988; Jakubauskas et al., 1990; White et al., 1996; Patterson & Yool, 1998). Spectral differences in specific region of the electromagnetic spectrum helps to distinguish between burned and unburned area (Kasischke et al., 2000). Remote sensing offers a time and cost-effective alternative for mapping of post-fire impacts on environment with the use of various airborne and space-borne sensors (Gitas et al., 2012). A number of researches has conducted using satellite sensors to assess fire severity and post fire impacts on environment. Among those, AVHRR, Landsat TM/ETM+, SPOT, IKONOS sensors were used widely for fire severity mapping (Zhu et al., 2006; Veraverbeke et al., 2011; Roy et al., 2005; Chafer et al., 2004; Mitri & Gitas, 2013).

2.2.1 Remote Sensing of Burned Area Mapping

Satellite sensors used in burned area mapping provides the details of spatial extent of burning and used to identify individual fires to provide elusive fire regime information, such as, ignition frequency and fire size distributions (Archibald et al., 2010). Satellite sensor facilitates to detect burned and unburned area before and after fire though the change in spectral signature on the electromagnetic spectrum (White et al., 1996). Visible and shortwave infrared region of the electromagnetic spectrum are used to detect the change in spectral signature of vegetation after the fire (Epting et al., 2005).

Several spectral indices have been used so far for mapping burned area (Escuin et al., 2008, Merino-de-Miguel et al., 2011). The difference in spectral response using the ratio of NIR and SWIR is a common way to detect burned area (**Table 1**).

Table 1: Spectral indices used in burned area mapping

Spectral Indices	Formula Description
Normalised Burn Ratio (NBR)	NBR= [(NIR – SWIR) / (NIR + SWIR)]
Differenced Normalised Burn Ratio (dNBR)	DNBR = $[NBR_{pre\text{-}fire} – NBR]_{post\text{-}fire}$
Relative Difference Normalised Burn Ratio (RdNBR)	NBR_{pre}-NBR_{post}/sqrt(NBR_{pre})

Several methods were developed and implemented in previous researches, an overview of the methods used in burn area mapping is as follows,

Normalized Burn Ratio (NBR) has become accepted as the standard spectral index to estimate fire/burn severity (Garcia & Caselles, 1991; Epting & Verbyla, 2005; Key & Benson, 2006). The index relates to vegetation vigour and moisture by combining near infrared (NIR) and shortwave-infrared (SWIR) reflectance (Table 1).

Landsat sensor were used in several researches as it has the unique properties of operating in SWIR region and a desirable 30m resolution for local scale studies (Key & Benson, 1999; Van Wagtendonk et al., 2004, Veraverbeke et al., 2010). Since, fire effects on vegetation produce a reflectance increase in the SWIR spectral region and a NIR reflectance drop (Pereira et al., 1999).

Bi-temporal image differencing can be applied frequently on pre and post-fire NBR images resulting in the differenced Normalized Burn Ratio (dNBR) (Key & Benson, 2006). Miller and Thode (2007) proposed a relative version of the dNBR, named RdNBR, which takes into account the pre-fire condition, therefore, rather than being a measure of absolute change, it reflects the change caused by fire relative to the pre-fire condition. Key (2005) explained two temporal constraints in defining the fire severity assessment timing on the estimation of post-fire effects. The first constraint was the lag timing in recovering ecosystems where inappropriate as lag timing can hide the fire effects and the second one is the seasonal timing, i.e., the biophysical conditions that vary throughout the year, regardless of the fire.

Verbyla et al. (2008) found a clear discrepancy in dNBR values between two different Landsat assessments, which was partly attributed to the seasonal timing of the bi-temporal acquisition scheme, while another part of the difference was due to the changing solar elevation angles at the moment of the image acquisition. Apart from these studies, relatively little attention has been devoted to the temporal changes in the NBR and its consequence to estimate fire/burn severity. This is probably due to the 16-day repeat cycle of Landsat and the problem of cloudiness which restricts image availability to infrequent images over small areas Ju & Roy, 2008. Therefore, Multi-temporal Moderate Resolution Imaging Spectroradiometer (MODIS) data bridged up the gap of image availability and it is the only high temporal frequent coarse resolution (250m/500m/1km) sensor which has the spectral capability, i.e., acquisition of reflectance data in the SWIR region besides to the NIR region Justice et al., 2002, to calculate the NBR. In this study, two spectral indices (dNBR and RdNBR) have used to detect burned area.

2.2.2 Fire Radiative Power and Energy

Fire radiative power (FRP) is the radiative components estimated from Earth observing satellite sensors which offers alternative methods in quantifying the biomass consumed (Wooster et al., 2005). Several methods have been employed to detect FRP,

Bi-spectral method, using two distinct channels (usually 4 and 11 μm), provides details about the fractional size and sub-pixel temperature of fire components (Giglio & Kendall, 2001; Wooster et al., 2005). Due to potential errors associated with channel miss-registration and point spread function (PSF) differences between channels (Giglio & Kendall, 2001). Wooster et al. (2005) suggested that this method is primarily effective for high resolution sensors.

Single channel approach with fire and background components retrieves FRP from the mid-infrared (4 μm) region (Justice et al., 2002). Kaufman et al. (1998) established an empirical relation between instantaneous FRE and pixel brightness temperature measured in mid-infrared channel. The thermal bands have the potentiality to estimate of the power released by fire. This value can be used to provide estimation of the fire radiative energy (FRE) which linearly related to the biomass burned amount needed by the atmospheric emissions modeling community (Kumar et al., 2011). Govaerts et al. (2008) presented that FRP product is potential as a new method to estimate emission from fires. Wooster (2002) investigated the relationship between FRP/FRE and fuel consumption using small-scale experimental fires in which spectroradiometers recorded the radiative emission for the entire burning process at 5 to 10 second intervals. Later, Wooster et al. (2005) updated this research providing additional evidence of the effectiveness of using instantaneous and total FRE measurements to estimate biomass consumed from fire.

Wooster et al. (2005) investigated the calibration relationship between biomass consumption and fire radiative energy, which calculate from FRP retrieved from sub-pixel fires of satellite imagery product through one or two spectral channels. This experimental work demonstrated that FRP assessment via independent hyperspectral and MIR radiance approaches show good agreement. It is also explained the relationship between FRE and fuel mass combusted is linear and highly significant, and FRP is well related to combustion rate, however the radiation from still-hot fuel bed also contribute significant FRP from areas where combustion has stopped sometimes. They suggested that FRE assessment can be a powerful tool to supplement existing burned-area from fuel consumption measures. In order to understand the impact of spatiotemporal resolution of polar-orbiting and geostationary sensors to satellite-based estimates of FRP and FRE characteristics emitted from open biomass burning, Freeborn et al. (2011) superimposed the timing and extents of the Terra and Aqua granules onto the SEVIRI active product.

Ellicott et al. (2009) presented a methodology to estimate FRE globally for 2001 –2007 at monthly time steps using MODIS sensor. The basic of FRE employment to measure fire radiative energy (FRE) is the fact that the rate of biomass consumed is proportional to the rate of FRE. They integrated FRP estimates from MODIS FRP to calculate FRE, subsequently apply the FRE-based biomass consumption coefficients to calculate the total biomass burned from fire in Africa and compare it with published estimates by Roberts and Wooster (2008). The results shows that FRE estimates from MODIS FRP derivation produces realistic estimates, even though it was underestimated than the SEVIRI products.

Specifically, Kumar et al. (2011) compared the biomass estimated from conventional FRP temporal integration of MODIS active-fire detections and power law FRE estimation methods with in-situ measurement of the prescribed fires and available fuel load information in the literature (Australian and Brazilian fires). The results suggest that FRE power law derivation methods gives more reliable burned biomass estimates under sparse satellite FRP sampling conditions, it is also able to correct the satellite active-fire detection omission errors when the FRP power law distribution parameters and the fire duration information are available.

Roberts et al. (2011) employed burned area (BA) and active fire (AF) measures of FRE to quantifying biomass burning related fuel consumption and carbon emissions. They developed a methodology to integrate burned area and active fire measures of FRE in order to deliver a high temporal resolution emissions inventory, maximizing the benefit of each data type without requiring additional information in Africa. From each individual fires detected by both types of data, they estimate fuel consumption per unit area (FC_A: $g.m^{-2}$) using the ratio of FRE-derived total fuel consumption to BA. They discovered this synergistic approach is useful to narrow the gap between GFEDv3 and FRE-derived emissions inventories. Besides, they suggested that the geostationary FRP observation can be used to estimate daily emission distribution more accurate over the diurnal fire cycle in order to atmospheric transport models. Over a sequential researches review, Ellicott and Vermote (2012) suggested that fire radiative energy (FRE) is potential to provide efficient and accurate tool for monitoring and measuring biomass consumed and emissions from fire events. However, the validation of FRE estimates needs larger spatial and temporal resolution data.

A software which calculates biomass burning emissions by merging the Fire Radiative Power (FRP) derivation from MODIS is employed by Kaiser et al. (2012) to perform simulations of the atmospheric aerosol distribution with and without the assimilation of MODIS aerosol optical depth (AOD). This software, The Global Fire Assimilation System (GFAS v1.0), correcting gaps in the observations due to cloud cover and filtering spurious FRP observations of volcanoes, gas flares and other industrial activity. Therefore, Randerson et al. (2012) specifically developed a preliminary method to combine 1km thermal anomalies (active fires) and 500m burned area observation from MODIS to estimate fire influence globally.

2.2.3 Active Fire Detection

FRP data can be derived from a number of sources including observations provided by the MODIS, SEVIRI and GOES instruments and the rate of thermal radiation released by fires is believed to correlate with the rate of associated smoke generation and fuel consumption (Wooster et al., 2005; Kaiser et al., 2012; Freeborn et al., 2008).

The active fire detection methods are advantageous as it offers accurate detection, quantification and assessment of fire's rate of radiative heat release which is related to the rate of fuel consumption and smoke emission (Wooster et al., 2005; Ichoku & Kaufman, 2005; Freeborn et al., 2008). In combination with post-fire burned area estimation, active fire detections and FRP datasets are potential to estimate EO-derived fuel consumption per unit area (Roy & Boschetti, 2009; Roberts et al., 2011). MODIS and some geostationary systems provide active fire products which are widely used in studies of regional or global atmospheric chemistry-transport models, for developing periodic assessments of land cover changes (e.g., tropical deforestation), and for fire and ecosystem management planning and policy development (Justice et al., 2002; Roberts & Wooster, 2008; Wooster et al., 2012). The radiometer sensors used to provide an indication of the rate of energy release of the fires [Fire Radiative Power (FRP)] are available over nearly a decade sampled four times daily at 1-km resolution (from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the Terra and Aqua polar-orbiting platforms), and every 15 min at 5-km resolution and thus it is possible to characterize the daily and seasonal patterns of burning (Archibald et al., 2010; Wooster et al., 2003; Giglio et al., 2006).

Various measures have been applied to describe active fire characteristics through both remote sensing and fire ecology literature.

Lentile et al. (2006) grouped the remote assessment of fire products in two main application groups.

- The detection of actively burning areas using a combination of optical and thermal imagery; and
- The use of thermal imagery (airborne and satellite) to estimate the energy radiated from the fire as it burns.

There are three characteristic which can be derived from satellite sensors products and/or its derivation out of eight characteristics above. The first is fire temperature which measured through thermal infrared cameras and imagery by Riggan et al., 2004, then fuel combusted that estimated based in fire radiative power/energy by Kaufman et al., 1998 and Wooster, 2002. The last characteristic mentioned is fire energy output which can be measured using fire line intensity or fire radiative power/energy Kaufman et al., 1998, Wooster et al., 2003 and Roberts et al., 2005.

Table 2 summarizes a number of available sensors which have been using to map and monitor active fire characteristics and post-fire effects (Lentile et al., 2006; Ellicott & Vermote, 2012):

Table 2: Remote sensing systems relevant to active and post fire detection

Sensors	Temporal resolution	Spatial resolution (km)	VIS-MIR bands (μm)	TIR bands (μm)
Advanced Along Track Scanning Radiometer[1]	2 days	1	0.56,0.66, 0.86, 1.6	3.7,11,12
Advanced Land Imager[2]	16 days	0.01–0.09	0.44,0.48, 0.56,0.64,0.79,0.87, 1.25,1.65, 2.23	
Advanced Spaceborne Thermal Emission and Reflection Radiometer[3]	16 days	0.015–0.09	0.56,0.66, 0.82,1.65, 2.17,2.21, 2.26,2.33, 2.34	8.3,8.65, 9.1,10.6, 11.3

[1] http://www.le.ac.uk/ph/research/eos/aatsr/
[2] http://eo1.gsfc.nasa.gov/Technology/ALIhome1.htm
[3] http://asterweb.jpl.nasa.gov/

Sensors	Temporal resolution	Spatial resolution (km)	VIS-MIR bands (μm)	TIR bands (μm)
Along Track Scanning Radiometer[4]	3 days	1	0.55,0.67, 0.87,1.6	3.7,10.8, 12
Advanced Very High Resolution Radiometer[5]	daily 4 images	1.10	0.63,0.91, 1.61	3.74,11, 12
Hot Spot Recognition Sensor System[6]		0.37		3.8,8.9
Hyperion[7]	16 days	0.03	[220 bands: 0.38–2.5μm]	
IKONOS[8]	3 days	0.001–0.004	0.48,0.55, 0.67,0.81	
Indian Remote Sensing-1A,B[9]	22 days	0.036–0.072	0.55,0.65, 0.83	
Indian Remote Sensing-1B,C[10]	24 days	0.023–0.188		
Landsat 5, 7[11]	16 days	0.015–0.09	0.48,0.56, 0.66,0.85, 1.65,2.17	11.5
Moderate Resolution Imaging Spectroradiometer[12]	daily 4 images	0.25–1.0	19 bands	16 bands

[4] http://www.atsr.rl.ac.uk/
[5] http://www.nesdis.noaa.gov/
[6] http://www.itc.nl/research/products/sensordb/getsen.aspx?name=HSRS
[7] http://eo1.gsfc.nasa.gov/technology/hyperion.html
[8] http://www.spaceimaging.com/
[9] http://www.isro.org/
[10] http://www.isro.org/
[11] http://landsat.gsfc.nasa.gov/
[12] http://modis.gsfc.nasa.gov/

Sensors	Temporal resolution	Spatial resolution (km)	VIS-MIR bands (μm)	TIR bands (μm)
Quickbird[13]	1-5 days	0.001–0.004	0.48, 0.56, 0.66, 0.83	
VEGETATION [14]	daily 1	1.15	0.55, 0.65, 0.84, 1.62	

2.3 Forest Fire and Vegetation Phenology

Fire is an integral part of forest ecosystems and itself it is an important factor in global scale that affect the ecological functioning of many ecosystems cause devastating consequences on vegetation dynamics (partially or entirely remove the vegetation layer) and ultimately through disturbing global biogeochemical cycling and more particularly through bringing overwhelming impacts on global carbon cycle; thus put ultimate impacts on post-fire vegetation composition particularly in case of many European ecosystems (Epting & Verbyla, 2005; Lentile et al., 2006; Pausas, 2004; Riaño et al., 2007).

The impacts of forest fire on vegetation are mostly apparent as a result of some critical issues of the subjected vegetation patterns such as burning susceptibility leading to eternal adjustment in the composition of the vegetation community, limited vegetation cover, biomass loss and overall changes in land-use pattern (Pérez-Cabello et al., 2009). Brown and Smith (2000) pointed up the relationships of fire interactions with the natural climatic issues. They listed some weather parameter, relative humidity, wind speed, drought (frequency, persistence), length of fire season, lightning (dry vs. wet), dry cold fronts, blocking high pressure (persistence) which are potential contributors following a fire event to occur and also summarized the fire-resultant atmospheric components [e.g., Carbon dioxide (CO_2), Carbon monoxide (CO), Methane (CH_4), Water vapour (H_2O)] that are contributors to global climate change.

[13] http://directory.eoportal.org/pres_QUICKBIRD2.html
[14] http://www.spot-vegetation.com/

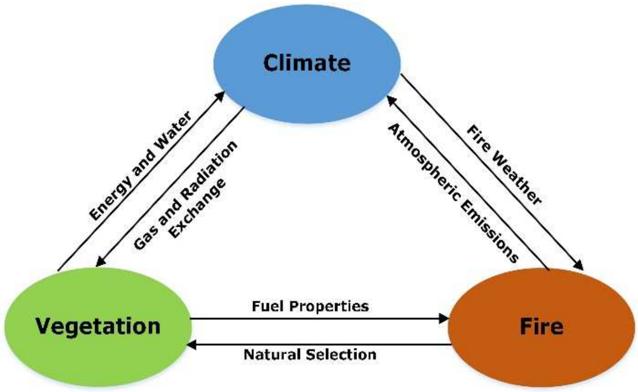

Figure 1: Climate change, forest fire and vegetation structure, all are under a continuous, close and dynamic relationship. If there is any adjustment in one factor, will lead to an immediate change in the other two (from Brown & Smith, 2000).

2.3.1 Satellite Sensors and Indices for Assessing Vegetation Regrowth

Vegetation regrowth or regeneration process is a complex issue and is influenced by numerous factors, topographic-climatic influences, plant composition, topographic parameters, soil characteristics etc. (Gitas et al., 2012). Given the limitations of ground based phenological observation (Ralhan et al., 1985; Newton, 1988; Bhat, 1992; Kikim & Yadava, 2001; Sundarapandian et al., 2005; Mishra et al., 2006) through different vegetation phenological variables (time of onset of 'greenness', time of end of 'greenness', duration of the growing season, rate of 'green up', flowering and rate of senescence etc.), remote sensing technique has been using to understand the phenological characteristics. Considerable amount of remote sensing studies have focused on the use of the Normalized Difference Vegetation Index (NDVI) for assessing the burn severity impacts on natural vegetation (Isaev et al., 2002; Díaz-Delgado et al., 2003; Chafer et al., 2004; Ruiz-Gallardo et al., 2004; Hammill & Bradstock, 2006).

Capturing the vegetation phenology was done through several methods, Justice et al. (1985) have analyzed the phenology of global vegetation using meteorological satellite data. White et al. (1996) used the specific date range of Landsat TM images to depict the post-fire condition which also reduced the difference in vegetation phonology, sun-angle, and weather conditions between pre and post-fire condition. Roy and Ravan (1996) quantified the biomass distribution in dry deciduous forest using Landsat Imagery. According to them, forest characterized by heterogeneity, temporal variation due to change in phenology and background reflectance, thus, biomass is potentially related with the phenology. Post-fire vegetation changes are abrupt immediately after fire (Pereira et al., 1999), whereas, a more gradual and progressive vegetation regeneration process is initiated in several weeks after the fire (Viedma et al., 1997; Van Leeuwen, 2008).

Specific study related to spectral indices to assess after fire vegetation regrowth mostly done by using Landsat TM data (White et al., 1996; Lunetta et al., 2006; Veraverbeke et al., 2012; Petropoulos et al., 2014). MODIS data products were employed multi-temporally to analyze the vegetation dynamics (Veraverbeke et al., 2010; Veraverbeke et al., 2010; Veraverbeke et al., 2011). However, the indices used as the basic to analyze are varying, NDVI (White et al., 1996; Lunetta et al., 2006; Petropoulos et al., 2014), fraction of vegetation cover model based on Spectral Mixture Analysis (SMA) (Veraverbeke et al., 2012), difference normalized burn ratio (dNBR) Veraverbeke et al., 2010; Veraverbeke et al., 2010; Veraverbeke et al., 2011), and pixel based regeneration index (pRI) from SPOT-VEGETATION normalized difference vegetation index (NDVI) along with NBR from Landsat data by Lhermitte et al. (2011).

Multi-temporal remote sensing data provide a unique opportunity for repetitive and relatively low-cost global monitoring of vegetation and associated dynamics and to estimate phenological variables from local to global scale (Wang et al., 2005, Myneni et al., 1997; Dash et al., 2010). Advanced Very High Resolution Radiometer (AVHRR) sensor, MODerate resolution Imaging Spectroradiometer (MODIS) sensor, Medium Resolution Imaging Spectrometer (MERIS) sensor (not currently operated) and several other sensors provide vast spatial coverage and fine temporal re-visit period which have contributed towards the wide usage of remote sensing data for studies of phenology (Jeganathan et al., 2010). MODIS sensors were used to estimate the phenological transition dates for natural vegetation in the northern mid-to-high latitudes (Zhang et al., 2004), while the AVHRR were used to study the seasonal pattern of natural vegetation and crops at regional to global scales (Goward et al., 1985; Malingreau, 1986; Townshend et al., 1987; Lloyd, 1990; White et al., 2005).

Van Wagtendonk et al. (2004) opined about the importance of phenology in mapping and monitoring of forest fire. They paired up the dNBR from AVIRIS and Landsat ETM+ by phenology and moisture between the two dates, pre and post-fire, and then validate it with the sixty three (63) field plots CBI. Later an evaluation of indices from Landsat TM and ETM+ satellite imagery for assessing burn severity were done by Epting et al. (2005) in interior Alaska considering the fact of errors that can be caused by difference in phenology and other products related properties. Key (2005) listed factors affecting remote sensing of fire severity and vegetation recovery, site phenology is included as a fire independent temporal factor. It is related with the fire seasonal timing, to capture the best time for phenology and snow in low and high elevation areas, he proceed two post-fire datasets respectively.

Phenology was analyzed site specifically using MODIS datasets based on vegetation structure, seasonal variation (Wang et al., 2005). A spatial and temporal validation of MODIS-LAI by Privette et al. (2002) showed that MODIS product can be used to derive phenological information in a Kalahari Woodland, from peak-biomass, senescence, peak dry season and minimum foliar biomass, and rapid green-up into the next wet season. Zhang et al. (2003) tried to improve models and understanding of inter-annual variability in terrestrial ecosystem carbon exchange and climate-biosphere interactions through an attempt of more accurate measurements of regional to global scale vegetation phenology (dynamic) using the MODIS datasets.

Many researchers have extracted landscape phenology information successfully from time-series satellite sensor data at regional-to-global scales (Justice et al., 1985; Zhang et al., 2006; Dash et al., 2010). Jeganathan et al. (2010) analyzed the distinctions between two phonological variables: onset of greenness (OG), estimated using the Enhanced Vegetation Index (EVI) from MODIS data where MODIS provides the only global product (MOD12Q2) freely available at present; and MERIS Terrestrial Chlorophyll Index (MTCI) from MERIS data where MTCI have the greater correlation with canopy chlorophyll content and the only operationally available product providing information on canopy chlorophyll content at global scale (Dash & Curran, 2007).

Working with the phenological variables extracted from satellite sensors, most previous studies were depended on the large correlation between NDVI and the amount of green vegetation biomass (Dash et al., 2010), and used the normalized difference vegetation index (NDVI) to, first, extract phenological variables and then quantify ecosystem response to climate change over continents and decades (Reed et al., 1994; Myneni et al., 1997; White et al., 1997; Zhou et al., 2001). However, NDVI varies with both the amount of green vegetation biomass and the concentration of chlorophyll (Gitelson & Merzlyak, 1998; Huete et al., 2002; Mutanga & Skidmore, 2004), and saturates at high levels of both (Dash et al., 2010). Moreover, image misalignment, sensor mis-calibration (Vermote & Kaufman, 1995) and changing atmospheric conditions (Tanre et al., 1992) as a result of temporal variation in the presence of cloud, water, snow or shadow (Goward et al., 1985; Huete et al., 2002), all may have directed to an unexplained variation in a smooth growth curve (Dash et al., 2010); and as a consequence from previous studies experiences' it has been difficult to extract phenological variables characteristically and consistently from raw NDVI time-series data (Reed et al., 1994). In this current study, time series of MODIS vegetation indices (LAI and NDVI) were used to identify the impacts of fire severity on the vegetation recovery.

2.4 Previous Researches on the Greek Forest Fires 2007

Xanthopoulos (2013) stated that Greece, under the Mediterranean climate, is facing serious forest problem every summer. Moreover, according to Karali et al. (2014), due to climate change the current trends in Mediterranean climate specifically in Greece, has indicated longer and more intense summer droughts which even extend out of season. Related to this fact, the frequency of forest fire occurrence and intensity are also rising. They also find that critical fire risks are expected to increase by as many as 50 days per year by the end of the century.

Iliadis et al. (2002) proved that after 1974, Greece has been facing severe forest fire problem, thus in order to reduce the destruction they did a research employing a heuristic expert system for forest fire guidance in Greece. Knorr et al. (2011) showed that meteorological conditions have contributed to the fire outbreak in Peloponnese as well as Euboia (modern Greek: EVIA) at the end of August, 2007. Koutsias et al. (2012) tried to map the burned area that occurred in Peloponnese in 2007 and found that rising proportions of burned areas in humid and sub-humid climatic region are clearly related to the weather patterns. Climate implication during the 2007 wildfires was investigated by Kaskaoutis et al. (2011) through atmospheric concentrations derived from MODIS sensors. An object-based classification was employed using SPOT-4 HRVIR images in Peloponnese, East Attica, Pelion and Paranitha by Polychronaki and Gitas (2012) for burned area mapping. Besides, a high accuracy of the methods used according to kappa test, they found out that spectral information and contextual information could overcome much of the existing confusion between burned areas and other land cover types (i.e., water bodies and shadows).

Three spectral indices were evaluated on fire severity estimation of Peloponnese, Greece after 2007 wildfires (Veraverbeke et al., 2010). Illumination effects to the dNBR optimality is discussed by Veraverbeke et al., 2010, this study considered the image acquisition time combined with modification of pixel c-correction methods in estimating the dNBR value which resulted in a more reliable change detection. Later, Veraverbeke et al. (2010) studied the temporal dimension of dNBR fire/burn severity. Veraverbeke et al. (2012) assessed the post-fire vegetation regeneration using spectral mixture analysis on Landsat TM imagery. It is useful to understand the recovery of mixed-vegetation as this analysis quite effective to derive fractional vegetation cover maps. This spectral mixture analysis also considers the constituting terrain feature, soil brightness, taken from lithological map. Later Veraverbeke et al. (2012) mentioned alternative spectral index for rapid fire severity assessment based in single date short-wave infrared (SWIR) and mid infrared (MIR) reflectance. As the opposite of dNBR, the SWIR-MIR index (SMI) is strong against scattering caused by smoke plumes over active fires which allow assessing the fire severity rapidly.

Petropoulos et al. (2014) quantified spatial and temporal vegetation recovery dynamics based on Earth Observation data (Landsat TM and ASTER GDEM) and Geographic Information System, in Mount Parnitha approximately 30km north of the Greek capital Athens after 2007 fire event. They used NDVI as the spectral indices for vegetation re-growth mapping. Using the same spectral indices, Lanorte et al. (2014) tried to assess and monitor the vegetation recovery in Galizia (North Spain) and Peloponnese (South Greece) based on the same fire event from SPOT-VEGETATION Normalized Difference Vegetation Index (NDVI) according to the statistical approach of the Fisher Shannon (FS) information plane.

Chapter 3
Study Area

This section gives an overview about the geographic location, climate, landuse, vegetation of the study area.

3.1 Geographic Location

This research has conducted on Peloponnese one of the Greek Islands located between 36°23'34.72"N–38°19'48.10"N and 21°7'13.58"E–23°7'42.41"E (**Figure 2**). The study area covers an area of 21,439 square kilometres.

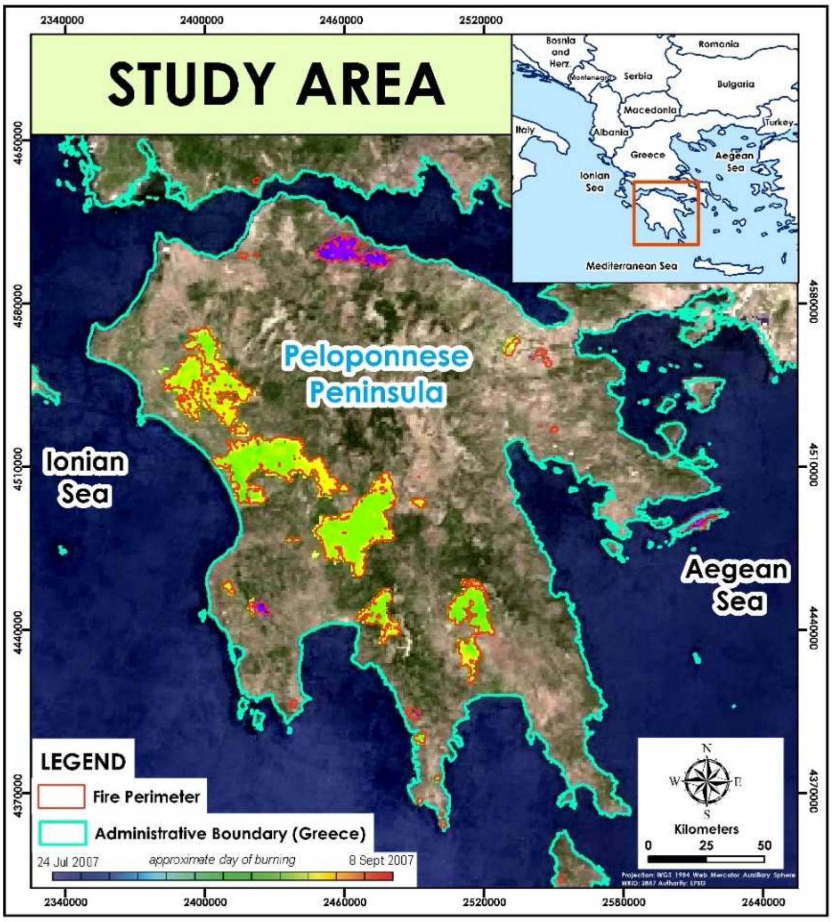

Figure 2: Study Area (Peloponnese Peninsula, Greece)

The peninsula is divided into seven regions called 'prefectures' or 'nomes'. In the centre of peninsula there is Arcadia and the other six are places are Corinthia, Argolis, Laconia, Messinia, Elis and Achaia[15].

3.2 Climate

Peloponnese is under Mediterranean climate (hot, dry summer and winter). The average temperature is 14.1°C (57.4°F) with total annual precipitation averages 810.8 mm (**Figure 3**).

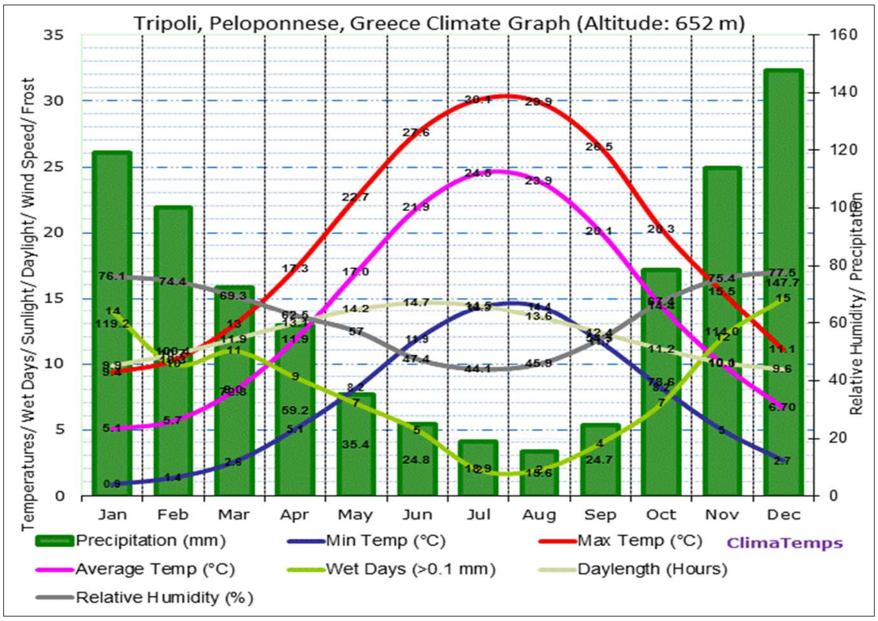

Figure 3: Climate graph of Tripoli, Peloponnese (Greece)
[Source: wordtravels.com[16]]

Highest rainfall occurs mostly between October and March, summer is from June to August with very minimal rainfall and temperature varies from around 30°C to 40°C. In the northern part of the peninsula, temperatures are much lower. The western Peloponnese has less severe winters but also got the most rainfall; the eastern areas are drier and arid. November to March has more rainy day than other month[17].

[15] http://www.britannica.com/EBchecked/topic/449351/Peloponnese
[16] http://www.wordtravels.com/Cities/Greece/Peloponnese+Peninsula/Climate
[17] http://www.wordtravels.com/Cities/Greece/Peloponnese+Peninsula/Climate

3.3 Land Cover/Landuse

According to Daniil et al. (2012), northwest area majority covered by grassland/shrub, with mixed forest and agricultural area. While the urban area and industry is located almost in the central part. Gatsis et al. (2001) observed the land cover/use changes over 2 decades from 1986–1998 and classified the land cover/use into ten classes. They found that bare rocks is increasing 0.3%, Bare soils 0.1% difference, Burned area 3.5%, crops are increasing 1.2%, dense bushes and Pine trees decreasing by 0.2%, open bushes decreasing by 0.3%, open bushes has increased by 0.1% while Quarry decrease by the same percentage, at last urban areas has developed by 3.5%. The mountainous area of Peloponnese is covered with a mixture of evergreen and deciduous forest[18].

3.4 Vegetation and Protected Area

Peloponnese has a diversity of vegetation type, from tree to shrubs. According to Tan et al. (2001), by August 2000 the Flora Hellenica Database already held 54.060 records from the Peloponnese and the level of endemism of vegetation in Peloponnese is 12%. In Peloponnese, mountainous are mainly covered with *Abies cephalonica* and *Pinus nigra and Juniperus foetidissim* and *Juniperus drupacea*, besides, there are conifer and castanea forests are common in Peloponnese peninsula[19,20,21].

Natura 2000 is an ecological network of protected area in Europe. The main purpose of this ecological network is to assure the long-term survival of most valuable and threatened species and habitats[22]. Hadjigeorgiou and Zervas (2009) have evaluated the production systems in protected areas of Greek "Natura 2000" sites and it covers about 18.2% of the total land area of Greece. One of their study area was in the center of Peloponnese, where three "Natura 2000" sites cover 200,000 hectares (ha).

[18] http://www.srcosmos.gr/srcosmos/showpub.aspx?aa=8422
[19] http://www.investingreece.gov.gr/default.asp?pid=127&nwslID=17&sec=9
[20] http://www.greekmountainflora.info/Pages/Peloponnese.htm
[21] http://www.hylawerkgroep.be/jeroen/index.php?id=28
[22] http://ec.europa.eu/environment/nature/natura2000/index_en.htm

Chapter 4
Materials and Methods

This section elucidates all the data products used, steps of data processing and analysis conducted in this research.

4.1 Data Products

Different temporal and coarse spatial resolution datasets freely distributed from Land Processes Distributed Active Archive Center (LP DAAC) were used in this research. From the literature review, it was found that the spectral and temporal characteristics of MODIS sensor, operating on both Terra and Aqua spacecraft, is able to detect active fire and fire severity using its available wavebands (Bands 1-2 are 250m; Bands 3-7 are 500m; and Bands 8-36 are 1000m). All the relevant data products available from MODIS sensor were used to meet the research objectives. Below is the list of MODIS data product used in this research:

Table 3: MODIS Data Products used in this research

Short Name	Platform	Data Product	Raster Type or Format	Spatial Resolution (m)	Time Interval
BRDF-Adjusted Reflectance					
MCD43A4	Combined (Terra and Aqua)	Nadir BRDF-Adjusted Reflectance	Tile	500m	16 day
MODIS Active Fire Products					
MCD14ML	Combined	Global Monthly Fire Location Product	ASCII	Individual fire pixel	Monthly
Normalized Difference Vegetation Index					
MOD13Q1	Terra	Vegetation Indices	Tile	250m	16 day
MYD13Q1	Aqua	Vegetation Indices	Tile	250m	16 day
Leaf Area Index					
MCD15A2	Combined	Leaf Area Index – FPAR	Tile	1000m	8 day
Thermal Anomalies and Fire					
MCD45A1	Combined	Monthly Burned Area Product	Tile	500m	Monthly

Short Name	Platform	Data Product	Raster Type or Format	Spatial Resolution (m)	Time Interval
MOD14*	Aqua	Thermal Anomalies & Fire	Tile	1km	Daily
MYD14*	Terra				
Land Cover					
MCD12Q1	Combined	Land Cover Type	Tile	200m	Yearly
VCC/VCF					
MOD44B	Terra	Vegetation Continuous Field	Tile	250m	Yearly
Calibrated Radiances					
MOD021KM	Terra	Calibrated Radiance	Tile	1km	Daily
MYD021KM	Aqua				

*Only Cloud Mask used

4.1.1 Nadir BRDF-Adjusted Reflectance (MCD43A4)

This MODIS rreflectance product provides 500 metre reflectance data which is an adjusted reflectance product using bidirectional reflectance distribution function (BRDF). Validation of this BRDF-adjusted surface reflectance product was done at Sahel by Samain et al. (2008) and at the Southern Great Plains site by Knobelspiesse et al. (2008, also based on land cover (i.e. in Boreal forest by Lyons et al. (2008) or in Paddy field by Susaki et al. (2007). The accuracy of the high quality MODIS operational albedos at 500m is well less than 5% albedo at the majority of the validation site, even those albedo values with low quality flags have been found to be preliminary within 10% of the field data.

4.1.2 MODIS Active Fire Products (MCD14ML)

This is the near real time data, available for last 24/48 hours and 7 days in KML, WMS, shapefile and text file (ASCII) format. MCD14ML is a global monthly fire location product. This research considered the data from 1st June, 2007 to 30th September, 2007.

4.1.3 Calibrated Radiances (MOD021KM/ MYD021KM)

MODIS calibrated radiances products are calibrated and geo-located radiances at aperture for all MODIS spectral bands at 1km resolution.

It is generated from the MODIS Level 1A scans of raw radiance and in the process converted to geophysical units of W/(m^2 um sr). There are two channels available in the original resolution, 250 m channels (MOD02QKM) and 500 m channels (MOD02HKM). The data used in this study is from 10th July to 30th September, 2007.

4.1.4 Thermal Anomalies and Fire (MOD14/MYD14)

MOD14 and MYD14 are level-2 swath data provided daily at 1km resolution. These products include fire-mask, algorithm quality, radiative power and numerous layers describing the fire pixel attributes. These products attained validation using active fire reference data derived from ASTER and Landsat-5 TM (30m resolution) data sources. Similar number of ASTER scenes was used for each temporal subset providing unbiased multi-year sampling of fire pixels.

4.1.5 Land Cover Type (MCD12Q1)

MCD12Q1 is a short name of MODIS Land Cover Type product, Land Cover Type Yearly L3 Global 500 m SIN Grid, provides data characterizing five land cover classification systems. This product derived from both (Terra and Aqua) sensors using a supervised decision-tree classification method Friedl et al., 2010. Validation research by Wu et al. (2008 by comparing MODIS product with other global land cover products (The University of Maryland global land cover product, the International Geosphere-Biosphere Programme Data and Information System Cover and Global Land Cover 2000) with the National Land Cover Dataset 2000 (NLCD-2000) to evaluate the accuracy of estimates of aggregated cropland areas in China. They found that MODIS dataset has the best fit in describing China's croplands. Globally the accuracy of the IGBP layer of the MODIS Collection 5 Land Cover is estimated to be 74.8% with a 95% confidence interval on this estimate of 72.3-77.4%. Besides, separate analysis of urban land cover class in this product based on Landsat data indicates an overall accuracy of 93%.Comparison of MODIS Collection 5 retrievals of vegetation phenology with in-situ measurement collected in New England field sites resulted well. The data used in this study is from the year 2006 to 2008.

4.1.6 Vegetation Indices (MOD13Q1/MYD13Q1)

Global MODIS vegetation indices are produced to provide consistent spatial and temporal comparison of vegetation conditions. These data are available with the interval of 16 days at 250 meter spatial resolution in the Sinusoidal projection. Validation is based on many supporting studies, the accuracy is within ±0.025 which represents the ability to retrieve a top of canopy (TOC) and nadir VI value when observation area is in high quality (clear, no sub pixel cloud, low aerosol, and sensor view angle < 30 degrees), normalized difference vegetation index (NDVI) accuracy is within ±0.020. In this study, time series of thirteen years [2003 to 2013] was used to under the vegetation phenology.

4.1.7 Leaf Area Index (MCD15A2)

MODIS global Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) product is acquired in every eight days at 1km resolution. MODIS LAI product was validated by Fang et al. (2012 using a global LAI field measurement database, the accuracy is 0.66 LAI unit RMSE is reached when all biomes are taken in account. If broadleaf forest is excluded, then it is lower to 0.5 LAI unit RMSE. Thirteen year [2003-2013] time series data was considered in this research to under the vegetation condition before and after fire.

4.1.8 Thermal Anomalies (MCD45A1)

This is a Thermal Anomalies and Fire MODIS monthly data product, taken from both platforms Aqua and Terra. A global assessment of temporal reporting accuracy and precision of this product was employed by Boschetti et al. (2010) using a systematic evaluation to six years of MODIS burned area and active fire product data.Data from July to September, 2007 was used in this study to define the fire perimeter.

4.1.9 Vegetation Continuous Fields (MOD44B)

This is a product from Terra platform, Vegetation Continuous Fields (VCF) MODIS data product. It is a sub-pixel level representation of surface vegetation cover estimates globally, produced annually with 250m spatial resolution. Hansen et al. (2003) validated this data product using supervised classification approach of high resolution IKONOS imagery and high resolution ETM+ data from two areas, one in Western Province, Zambia and another in the state of Colorado in the US and found standard errors for each area are 11.5 and 11.6 respectively. Moreover, the accuracy of this product was estimated through an assessment of the training data’s accuracy, and from limited in-situ field validation datasets. Date for the year of 2006 to 2008 were used in this research study.

4.2 Ancillary Datasets

4.2.1 Elevation Data: ASTER GDEM 30 meters

Global Digital Elevation Model (GDEM) is developed based on Digital Elevation Model generated from a stereo-pair of images acquires with nadir and backwards angles over the same area by ASTER. The accuracy for this global product were 20m at 95% confidence for vertical data and 30m at 95% confidence for horizontal data.

4.2.2 Climate Data

Meteorological dataset were collected from the meteorological web data-portal, Weather Underground[23]. Dataset of three weather stations (Kalamata, Araxos and Andravida) from 1st April to 30th September, 2007 were analyzed to find out the effects of meteorological condition on fire ignition and fire sprawl.

4.2.3 Forest Type (2006)

Pan-European Forest Type Map 2006, beta version 1.0, were used to assess the loss of vegetation coverage after the fires in 2007. This dataset is derived from the Satellite imageries of 2006, Spot-4 (HRVIR), Spot-5 (HRG) and IRS-P6 (LISS-III) and is resampled to 25m. The data has been validated by Kempeneers et al. (2011).

4.2.4 Forest Loss Dataset

Hansen et al. (2013) quantified global forest change from time-series analysis of 654,178 Landsat 7 ETM+ images. They developed a dataset considering the changes in global forest extent from 2000 to 2012 at 30m spatial resolution at the equator. Forest loss for 2007, derived from Global forest cover loss 2000-2012, was used in this study to validate the findings of this research.

4.2.5 TIMESAT

TIMESAT is a program package to extract seasonal parameters. This software is developed to optimize the usage of remotely sensed time-series data to gain information on seasonal vegetation development (Eklundha & Jönssonb, 2012). In this research, three different smoothing filters (Gaussian, Logistic and Savitsky-Golay) of TIMESAT software were applied to the raw MODIS-LAI and MODIS-NDVI time-series datasets [2003-2013] to derive phenological calendar.

[23] http://www.wunderground.com/

4.2.6 Forest Canopy Height Dataset

Simmard et al. (2011) attempted to map forest vertical structure globally using spaceborne light detector and raging (LiDAR) data [January to December, 2005]. This global canopy height data was used in this research with the active fire product to estimate fuel consumption.

4.2.7 Natura 2000 Sites Dataset

Natura 2000 is an ecological network composed of sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs and Special Areas of Conservation, SACs). As for validation, The European Topic Centre for Biological Diversity (ETC/BD) is responsible as well as creating an EU wide descriptive database. For the spatial data (borders of sites) which is submitted by each Member State is validated by the European Environment Agency (EEA) and linked to the descriptive data[24].

4.2.8 Greece Administrative Boundary

GADM is a geographic database of global administrative areas (boundaries). It describes the spatial features which is administrative area globally with attributes such as the name and variant names. These files were extracted from GADM version 1.0, in March 2009.

[24] http://www.eea.europa.eu/data-and-maps/data/natura-2000-eunis-database#tab-metadata

4.3 Data Analysis

For burn severity assessment, MODIS Nadir BRDF-Adjusted Reflectance (MCD43A4) and Burned Area product (MCD45A1) were used. Calibrated radiances, thermal anomalies and fire and burned area product were used to meet the second research objective of this study. Vegetation indices (LAI & NDVI) and other vegetation and land surface change products used to meet the third research objective (**Figure 4**).

The use of different data products under different sections are given below,

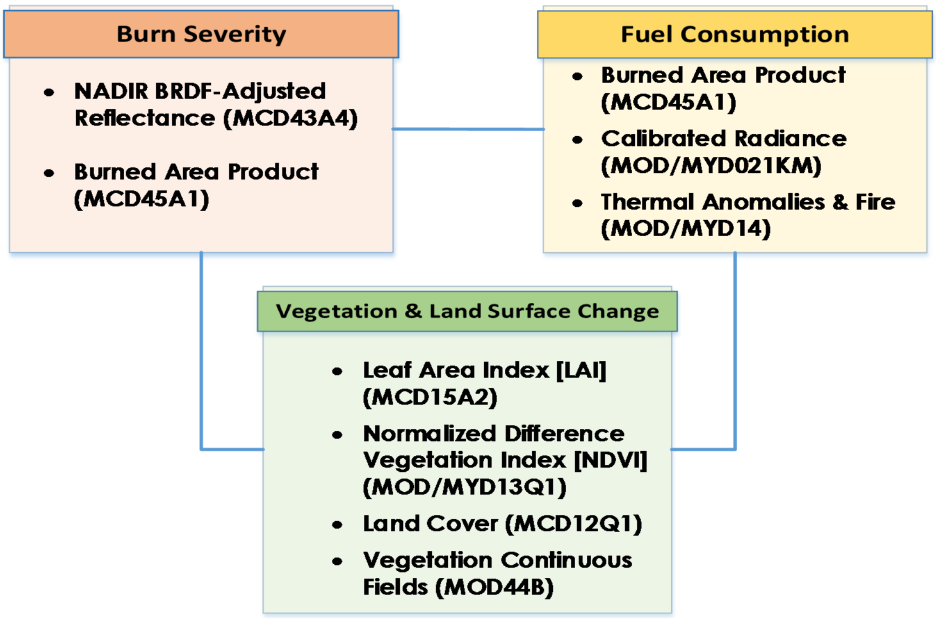

Figure 4: MODIS datasets used in this research

The research was conducted under three research objectives and to accomplish each objective different steps had been taken. The methodologies thus divided into three different sections (burn severity, fuel consumption and vegetation dynamics) and were discussed in detail in the following sections.

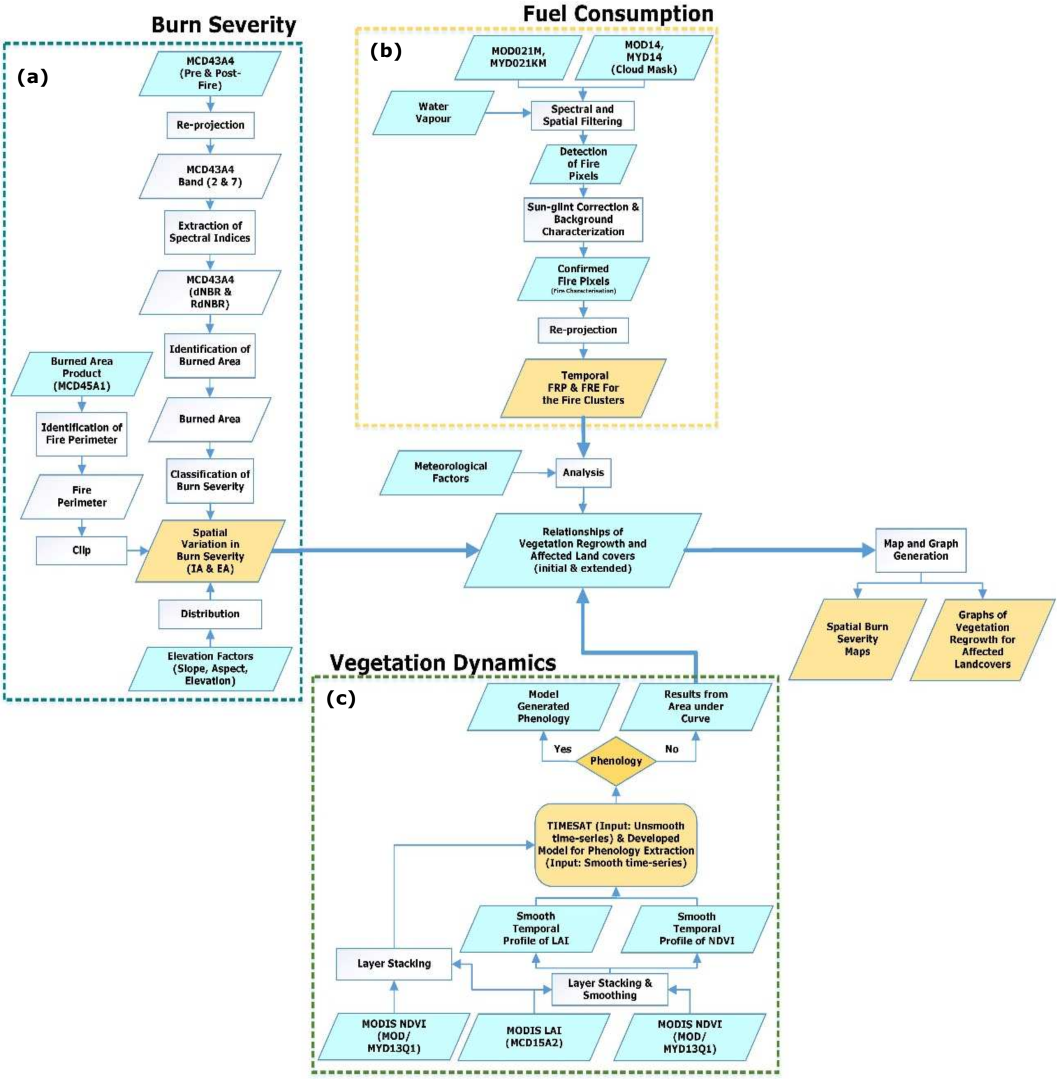

Figure 5: Flow chart describing the specific steps to reach the research objectives [(a) burn severity; (b) fuel consumption; (c) vegetation regrowth]

4.3.1 Methodology (Burn Severity)

MODIS NADIR BRDF-Adjusted Reflectance (MCD43A4) were re-projected from sinusoidal into geographic projection. Band 2 (NIR) and Band 7 (SWIR) were used to calculate NBR, dNBR and RdNBR under Initial Assessment and Extended Assessment. The burned area was

identified with the spectral indices and the monthly burned area product was employed to identify the fire perimeter in the study area (**Figure 5a**).
Data used for IA was from 30 September, 2006 (pre-fire) to 30 September, 2007 (post-fire) and for EA was from 10 June, 2007 (pre-fire) and 9 June, 2008 (post-fire). The dates were selected as much close as possible to do the assessment under same environmental conditions (**Figure 6**).

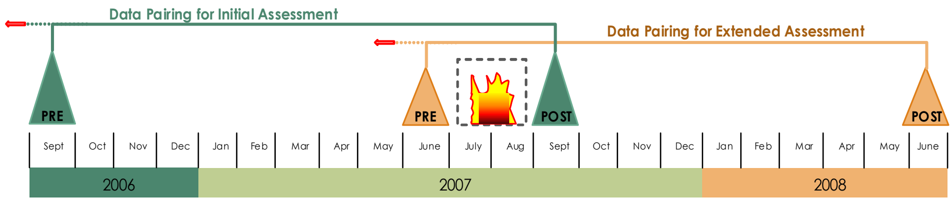

Figure 6: Data pairing for initial and extended assessment of burn severity

Burn area products (MCD45A1) used to define the fire perimeter and all the analysis were conducted considering the fire perimeter. Landcover data product (MCD12Q1) for the year 2006 to find out the effects of fire severity over time. The analysis started from extraction of spectral indices, NBR, band 2-(Near Infrared) & band -7 (Shortwave Infrared) of MCD43A4 data (pre and post-fire) for two assessments (IA & EA) were used to calculate the burn severity indices.

In this study, to identify burn regions from unburned regions another algorithm developed by Key and Benson (1999), differenced Normalized Burn Ratio (dNBR) which is a bi-temporal approaches by subtracting post-fire NBR values from pre-fire NBR values (Table 1). The result value ranging from -2 to +2, positive value refer to the regions that were severely burned while the negative refer to the area of which less affected by the fire. The uncertainty that caused errors to a bi-temporal method are come from geometric, illumination, atmospheric and phonological differences (Escuin et al., 2008), however, it produced better accuracy than NBR (Key & Benson, 2006; Roy et al., 2006). Another burn severity index used in this study, a modification of dNBR, Relative Differenced Normalized Burn Ratio (RdNBR). The threshold values of the dNBR and RdNBR for heterogeneous landscape by Miller and Thode (2007) were used to define the severity categories (high, moderate, low and unburned) under different landcover classes. Topographical factors (elevation, aspect and slope) were then used to check the fire severity distribution.

4.3.2 Methodology (Fire Radiative Power (FRP) and Fuel Consumption)

For FRP retrieval and fuel consumption, the active fire detection algorithm developed by Wooster et al. (2012) was followed in this research. Bow-tie effect is an artefact of MODIS sensor, this effects were removed before processing the active fire data products. MODIS calibrated radiances and thermal/active fire products were used to retrieve fire radiative power. Atmospheric correction of the radiance product was done using MOD14 cloud and water mask before to use in the active fire detection algorithm. Spatial (Non-Gaussian Kernels) and spectral (Planck's radiance) filters were used to detect potential fire pixels. After background correction, the active fire pixels were confirmed. Sun glint identification and desert boundary masking were done to retrieve the fire radiative power and to characterize the fires. Finally, confidence assessment and error estimation of detected fire pixels done before re-projecting the radiance dataset. Total Fire Radiative Power and Energy is then assessed for the detected fire pixels (**Figure 5b**).

4.3.3 Methodology (Vegetation Regrowth)

The severity data was resampled (using majority function: kernel 2 x 2 pixels) to 1km resolution before to identify the most affected landcover classes. All the vegetation regrowth analysis were done considering top three most affected landcover classes. Temporal dataset of MODIS LAI (MCD15A2) and MODIS NDVI (MOD/MYD13Q1) for thirteen years [2003-2013] were used to analyze the vegetation dynamics over time. For MODIS-LAI, data layers were stacked without smoothing for the input of TIMESAT to define the phenology. The MODIS-LAI and MODIS-NDVI time series data was smoothed using the Discrete Fourier Transformation (DFT) model developed by Dash et al., 2010 to define the vegetation phenology. The research assumption was that if the models will not give the exact or closest date of start (onset of greenness) and end (end of senescence) of phenological cycle then the alternative option will be to check the phenological cycle considering as a whole year using Area under Curve analysis. The phenological smoothing functions used in this study did not give the exact date of phenological period, so, the research was relied on the results from Area under Curve (AUC) analysis (**Figure 5c**).

Chapter 5
Results

This section presents results from the key analyses conducted in this research.

5.1 Initial and Extended Assessment of Fire

According to dNBR-initial assessment, 71.11% of the fire perimeter area was under the high severity, 24.57% under moderate severity and 3.88% under low severity and only 0.22% was under unburned area and 0.23% were under unclassified area. In RdNBR-initial assessment, the high severity was about 74.96%, moderate 22.55% and low 2.18% (**Table 4**).

Table 4: Initial assessment of fire severity (dNBR and RdNBR)

Severity Class	dNBR (IA)		RdNBR (IA)		dNBR & RdNBR (IA)
	%	Area (ha)	%	Area (ha)	Change in Area (%)
High	71.11	134490.29	74.96	141773.04	5.14
Moderate	24.56	46461.84	22.55	42648.71	8.94
Low	3.87	7334.27	2.18	4122.30	77.91
Unburned	0.21	412.23	0.12	223.29	84.61
Unclassified	0.22	429.40	0.19	360.70	19.04
Total	**100**	**189128.05**	**100**	**189128.05**	

dNBR-extended assessment comprised high severity area 12.04%, moderate and low severity were 40.11% and 40.64% respectively, unburned 6.55% and 0.2% unclassified area. RdNBR- extended assessment showed 1.02% area was under high, 16.47% moderate and 70.42%, unburned area was 11.92% and 0.17% was under unclassified area (**Table 5**).

Table 5: Extended assessment of fire severity (dNBR and RdNBR)

Severity Class	dNBR (EA)		RdNBR (EA)		dNBR vs RdNBR (EA)
	%	Area (ha)	%	Area (ha)	Change in Area (%)
High	12.04	22775.75	1.01	1923.74	**7269.64**
Moderate	40.12	75867.64	16.46	31140.60	36.95
Low	40.64	76863.86	70.42	133184.90	96.90

Unburned	6.77	12813.50	11.92	22552.46	99.00
Unclassified	0.42	807.2853	0.172	326.34	10.52
Total	100	**189128.05**	100	**189128.05**	0

5.2 Natura 2000 sites in Fire Perimeter

The study area occupied 17.37% of its area under Natura 2000 sites. In table 4 below, the percentage of Natura 2000 area affected by 2007 fire is describe for each type. The largest Natura 2000 sites affected is SCI over 173 million square metres or 52.77%, SPA area were the second largest with 35.65% of the whole Natura 2000 sites followed by SPA-SCI with 11.58% (**Table 6**).

Table 6: Natura 2000 Area Affected by 2007 Fire

Fire Perimeter	**Area (hectares)**	**%**
	189128.05	**100**
Natura2000 Area	**32849.25**	**17.36**
Natura 2000 – SPASCI (11.7%)	3804.674	
Natura 2000 – SPA (35.6%)	11710.678	
Natura 2000 – SCI (52.8%)	17333.904	
Other	**156279.89**	**82.63**

5.3 Fire severity among landcover classes

The following graphs, figure 7, are showing the percentage of area for two fire severity indices, dNBR and RdNBR, on affected land covers in Initial Assessment. Woody savannas and mixed forest were found under the fire perimeter area in both dNBR and RdNBR initial assessment (**Figure 7**).

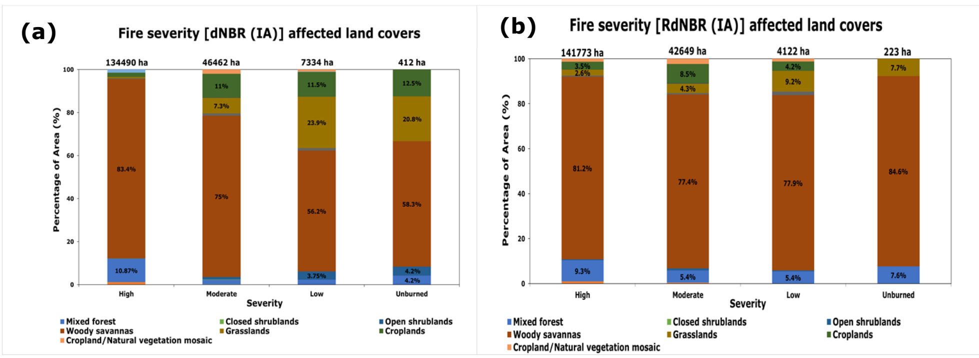

Figure 7: Fire Severity [dNBR (a) and RdNBR (b)] and affected land covers in Initial Assessment

Overall area included in high severity are decreasing to 22,776 hectare and 1,924 hectare respectively in dNBR and RdNBR extended assessment. The percentage of woody savannas in high severity of dNBR was higher (56.5%) than RdNBR (8.9%). Respectively of dNBR, mixed forest is 38.2% and 5.3% cropland and natural vegetation mosaic. Percentage of the rest areas in RdNBR index were 88.4% mixed forest and 8.9% of Woody Savannah.

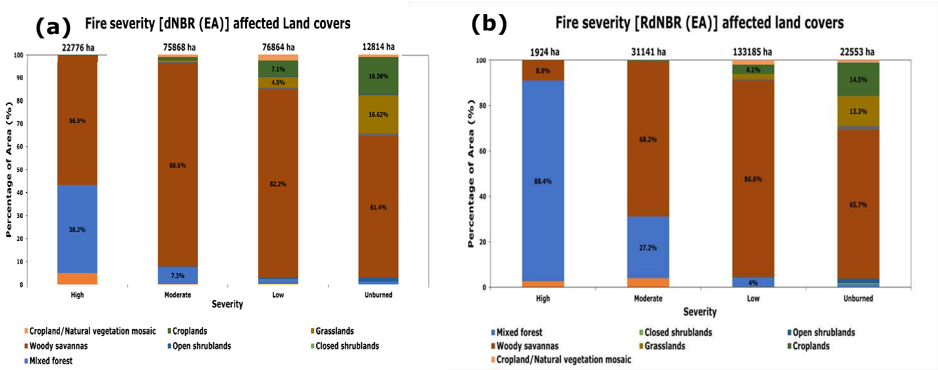

Figure 8: Fire Severity [dNBR (a) and RdNBR (b)] and affected land covers in Extended Assessment

Relative proportion of five severely affected land cover types under dNBR and RdNBR severity (IA and EA) showed that mixed forest and woody savannah were severely affected for both of the indices in the initial assessment. The extended assessment showed that grasslands, croplands were mostly under the low severity condition (**Figure 9**).

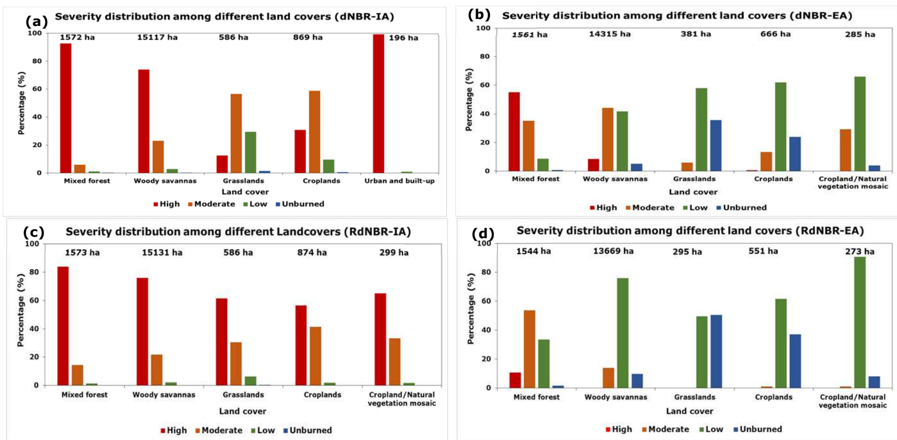

Figure 9: Severity distribution among different land covers for dNBR (a, b) and RdNBR (c, d) in IA and EA

5.4 Fire Severity in relation to Topography

Severity distribution with the elevation factors were investigated and the assumption for the slope gradient, the higher the slope the lower the severity, both of the burn indices (dNBR and RdNBR) for IA and EA showed the trend. There were no difference found for both of the indices, whereas, most fire occurred from low to moderate slope gradient (**Figure 10**).

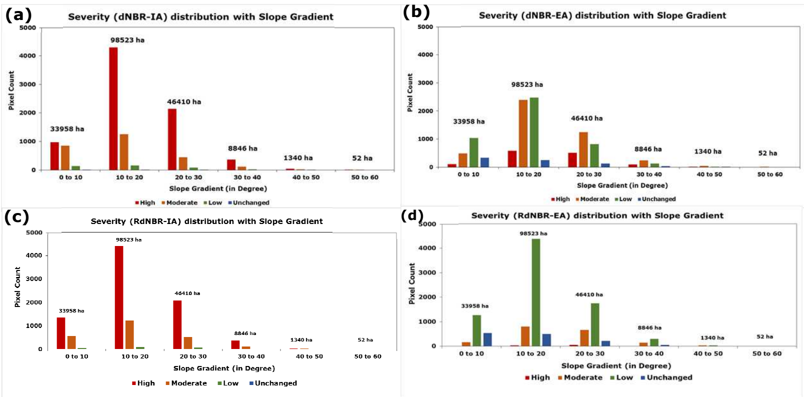

Figure 10: Severity distribution with slope gradient [dNBR (a, b) and RdNBR (c, d) in IA and EA]

Elevation also showed the similar trend as like slope. The mostly burned area found from 0 to 1250m range for both of the indices. Very little area were above this elevation range and no more than 55 hectares for any of the burn indices. The low-lying areas showed much faster change from high to moderate and low from initial to extended assessment (**Figure 11**).

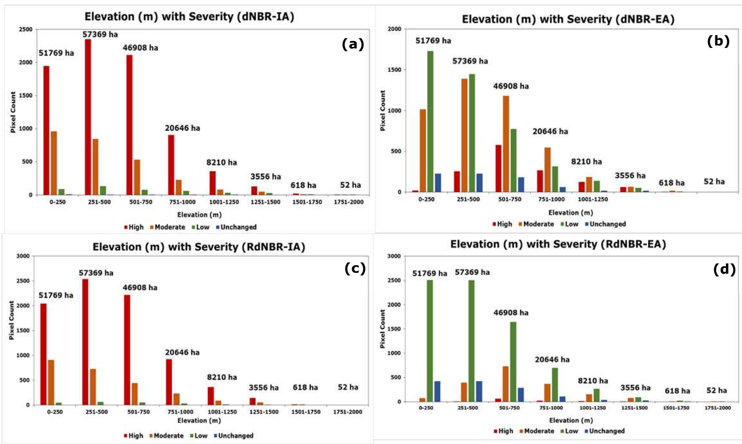

Figure 11: Elevation with Severity [a: dNBR-IA; b: dNBR-EA; c: RdNBR-IA; d: RdNBR-EA)]

The burned area is under the aspect of south, south-east, south-west and west direction. The flat and north-faced area showed the lowest burned area whereas south-west, south-east and south-west showed the highest burned area (**Figure 12**).

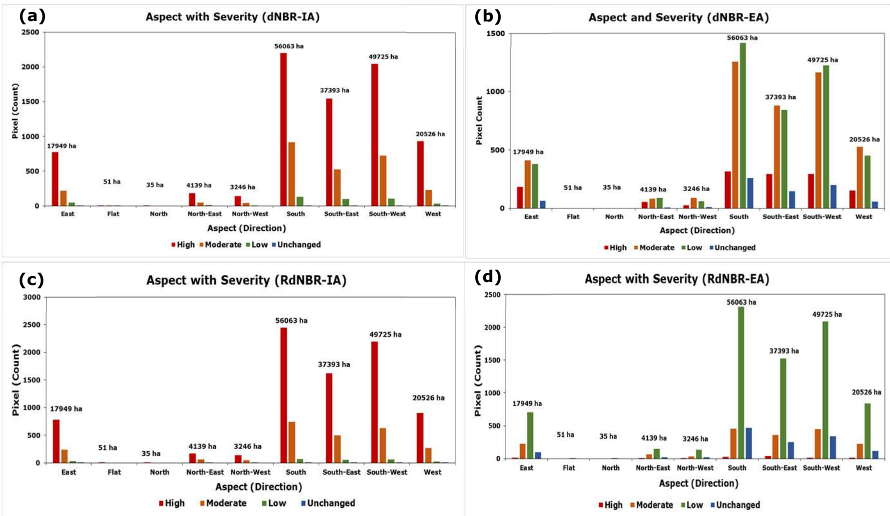

Figure 12: Aspect with Severity [a: dNBR-IA; b: dNBR-EA; c: RdNBR-IA; d: RdNBR-EA)]

5.5 Change in percentage of Tree Coverage with Severity

MODIS vegetation continuous field dataset (MOD44B) was used to identify the change in percentage of tree coverage under initial and extended assessment using both of the indices.

dNBR and RdNBR initial assessment showed that, the percentage was reduced down to 38% to 19% from 2006 to 2007. The extended assessment showed much more declining trend than to the initial assessment as it decrease from 51% to 21% from 2006 to 2007 and 21% to 12% from 2007 to 2008 (**Figure 13**).

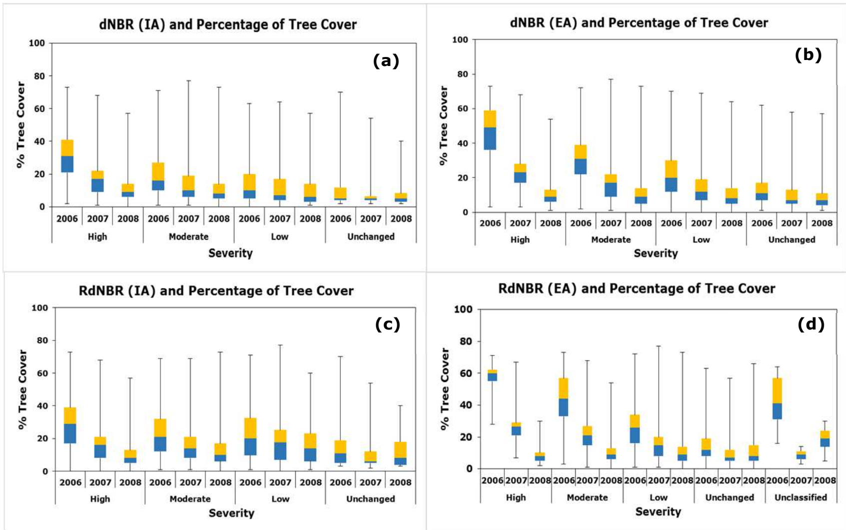

Figure 13: box plots of percentage of tree coverage in 2006, 2007 and 2008 under different severity

5.6 Estimation of Fire Radiative Energy and Fuel Consumption

MODIS calibrated radiances dataset from 10 July (191st day) to 30 September (273rd day) of 2007 were analyzed to detect and calculate fire radiative power (FRP), fire radiative energy (FRE) and fuel consumption (FC). Eight fire clusters were selected to derive the exact amount of fuel consumption in the study area.

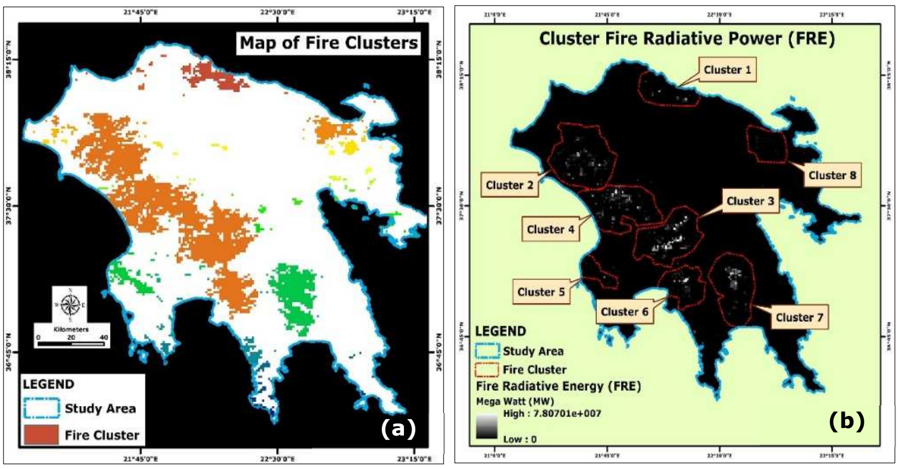

Figure 14: (a) Map of fire clusters from MODIS observations; (b) Map of eight fire clusters for estimation of fuel consumption

The estimated amount of FRE during the fire events was 8471217472 Mega Watt which showed 3.66 kg/m^2 of fuel consumption in MODIS detected burned areas. The total about of fuel consumption was 3.12 Teragram (Tg).

Table 7: Cluster-based fire radiative energy and fuel consumption during the fire (10th July to 30th September, 2007)

Cluster	FRE (MW)	FC (kg/m^2)	Total FC (Tg)
1	395,669,568	0.20	0.15
2	1,451,000,000	0.44	0.53
3	1,872,700,000	0.64	0.69
4	2,339,100,000	0.91	0.86
5	114,993,888	0.16	0.04
6	800,782,272	0.59	0.29
7	1,281,600,000	0.52	0.47
8	215,371,744	0.18	0.08
Total	**8471217472**	**3.66**	**3.18**

The MODIS active fire product (MCD14ML) captured 464782.3 MW of fire radiative energy from the pixels under fire perimeters (detected from 20th July to 2nd September, 2007). The fuel consumption was calculated using the equation of aboveground biomass estimation by Lefsky et al. (2005) using the forest canopy height dataset and was found that about 2.20 kg/m^2 of fuel consumed during the fire, whereas the temporal FRE analysis of eight clusters around fire perimeter showed that it was 3.66 kg/m^2 (Figure 14b).

5.7 Estimation of Summed Fire Radiative Power

The fire detection algorithm calculated per pixel based fire radiative power. The summed FRP thus is represented in **Figure 15**.

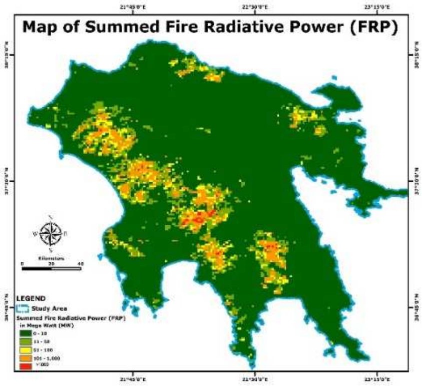

Figure 15: Map of Summed Fire Radiative Power (FRP)

The histograms showed that high severity area showed higher FRP and fuel consumption in the initial assessment, whereas in extended assessment the high severity shows the lowest values which is a notion of reducing the effects of fire severity after a year (**Figure 16**).

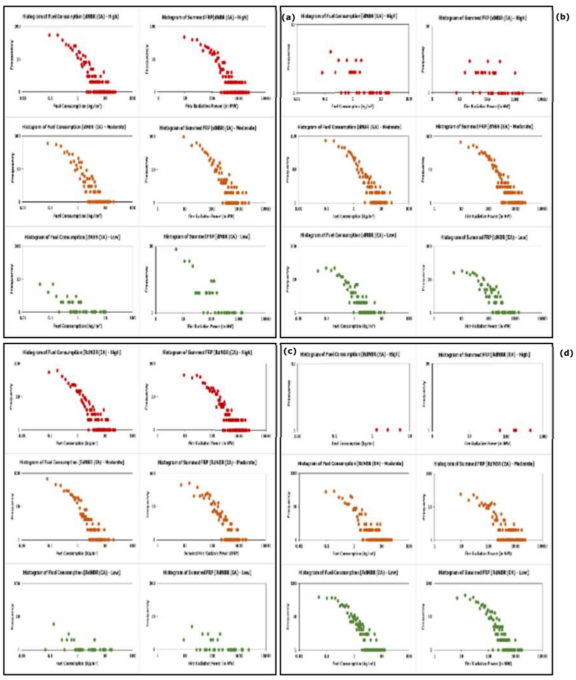

Figure 16: Histogram of Fuel Consumption and Summed FRP

5.8 Meteorological Factors and Fire Radiative Energy

Temperature, dew point temperature, humidity and wind speed of three closest weather station was plotted with the temporal fire radiative power. The highest FRP observed on 25th August, thus, at that time the temperature was comparatively high, humidity was very low and wind speed was high which reflects that the weather condition was a major factor of intense fire events (**Figure 17**).

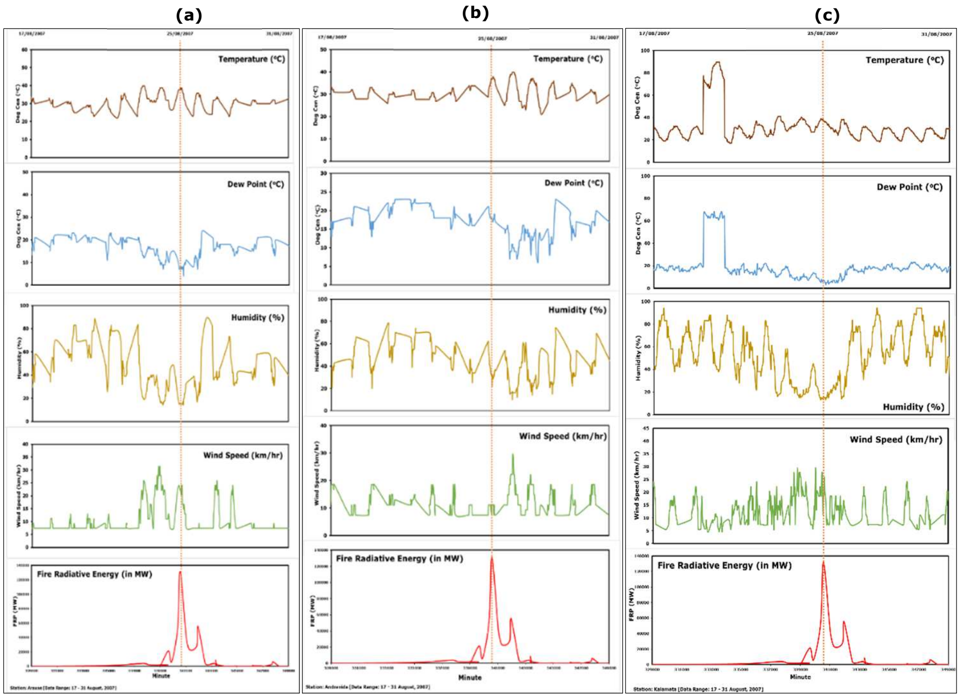

Figure 17: Meteorological factors [(a) Araxos, (b) Andravida and (c) Kalamata station] with Fire Radiative Power of closest fire cluster

5.9 Vegetation Regrowth and Fire Severity

Two different indicators, LAI (a biophysical parameter) and NDVI (vegetation index) were considered for vegetation regrowth analysis over time. The time series for three most affected landcover classes were generated to check the exact condition of vegetation before and after the fire.

5.9.1 Temporal LAI and Fire Severity

Time series analysis of MODIS-LAI for the top three affected land covers were conducted. The mean values for all the observation were considered and the variation of LAI value over the time after the fire event is significant for natural vegetation. Under the dNBR-IA assessment, the LAI profiles (under different severity categories) revealed that croplands and grasslands recovered much faster whereas woody savannah and mixed forest landcover shows a recovering trend over time (**Figure 18**). All of the LAI time-series for dNBR and RdNBR (IA & EA) were placed in **Appendix-A**.

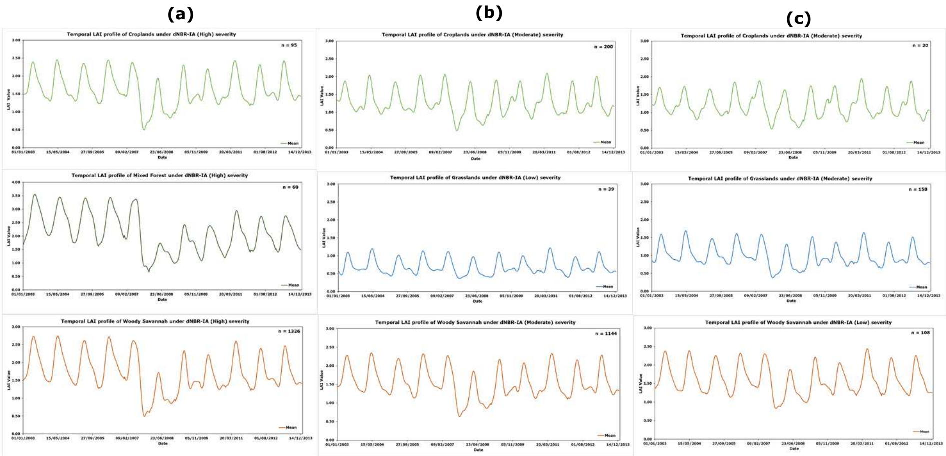

Figure 18: LAI (mean) temporal profile of three top land covers under dNBR [a: high; b: moderate, c: low] initial assessment

5.9.2 Temporal NDVI and Fire Severity

Time series analysis of MODIS-NDVI for the three most three affected land covers under different severity were conducted. The mean values for all the observation were considered and the variation of NDVI value over the time after the fire event is was not significant like the LAI time series. Under the dNBR-IA assessment, the NDVI profiles (under different severity categories) showed that woody savannah, croplands and grasslands showing no significant change in NDVI value before and after fire, whereas, mixed forest was trying to recover the after the fire (**Figure 19**). All of the NDVI time-series for dNBR and RdNBR (IA & EA) were placed in **Appendix-B**.

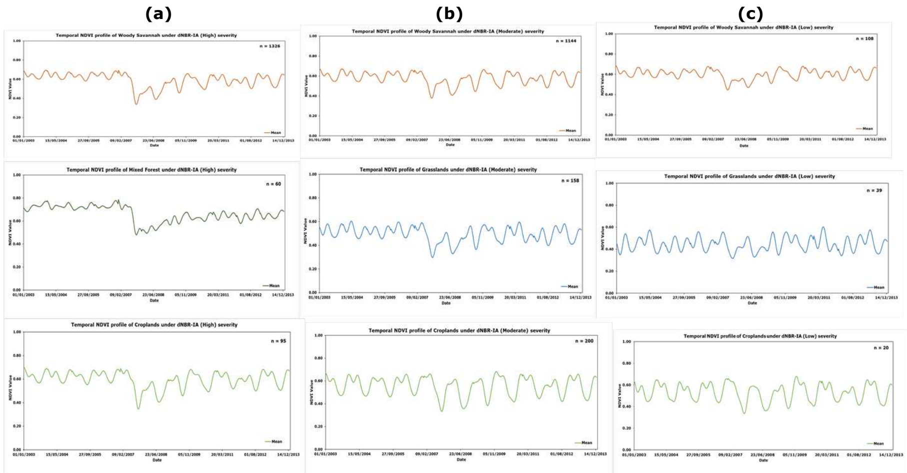

Figure 19: NDVI (mean) temporal profile of three temporal profile of three top land covers under dNBR [a: high; b: moderate, c: low] initial assessment

5.10 Phenology extraction using TIMESAT

TIMESAT were used to detect phenological profile using both unsmoothed LAI and NDVI dataset and the phenology was also tried to develop using the model developed by Dash et al., 2010. The start and ending dates were varied from one to another model. Three different smoothing filter were used (Gaussian, Logistic and Regression) in TIMESAT but there were much varied results for all the natural vegetation land covers (here, mixed forest and woody savannah). The varied results of different filters from TIMESAT and DST model developed by Dash et al., 2010, for mixed forest showed the variation in defining season days.

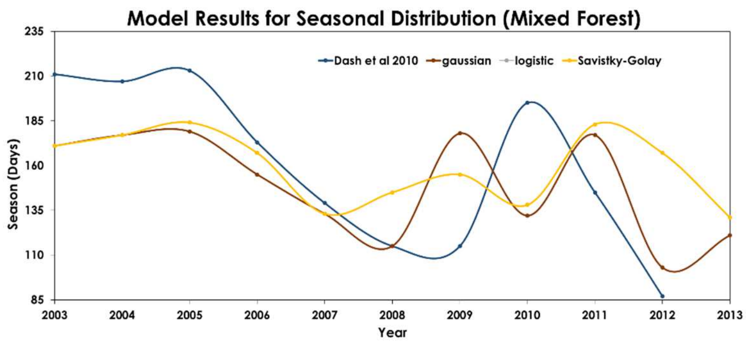

Figure 20: Variation in defining exact season days using phenology extraction models

5.11 Area under Curve Analysis for MODIS-LAI and MODIS-NDVI

The varied results from the phenology driven models indicated to use a widely used method, Area under Curve (AUC) to conduct to verify the change in phenological characteristics after the fire. The analysis was done for three most affected land cover classes for dNBR and RdNBR under initial and extended assessment.

The LAI-AUC graphs of top three land cover in dNBR-IA display in **Figure 21**. Except for grasslands under low severity class which dynamically curved before the valley, other land covers show the same pattern over different severity class with decreasing AUC value from high severity to low severity. Under high severity mixed forest has the highest AUC then woody savannah and croplands. Graphs of woody savannah in low severity have deeper than moderate severity curve with more dynamic change after increasing in 2009 (**Appendix-C**).

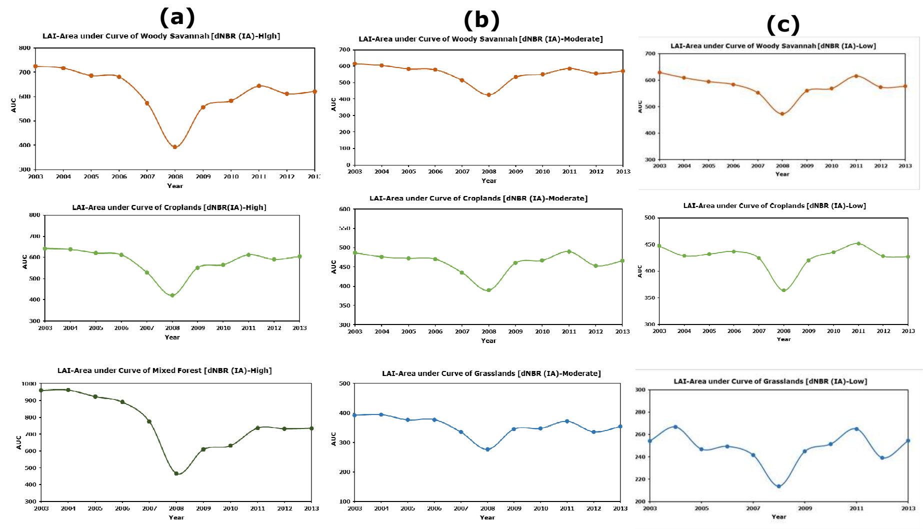

Figure 21: LAI-Area under Curve of each land cover types in three dNBR severity levels in Initial Assessment

The analysis of NDVI-AUC under dNBR-IA showed the lowest AUC in 2008 for woody savannah, mixed forest (**Figure 22**). In high severity class, mixed forest has the highest AUC over the year it is assumed because of the plant species which relatively dense than woody savannah and croplands. Unlike woody savannah and croplands which visually has same graph patter in moderate and low severity, grasslands graphs difference under those two severity class are clearer. Even though the line curve over land cover types and severity class are similar, grassland in low severity is the only one different (**Appendix-D**).

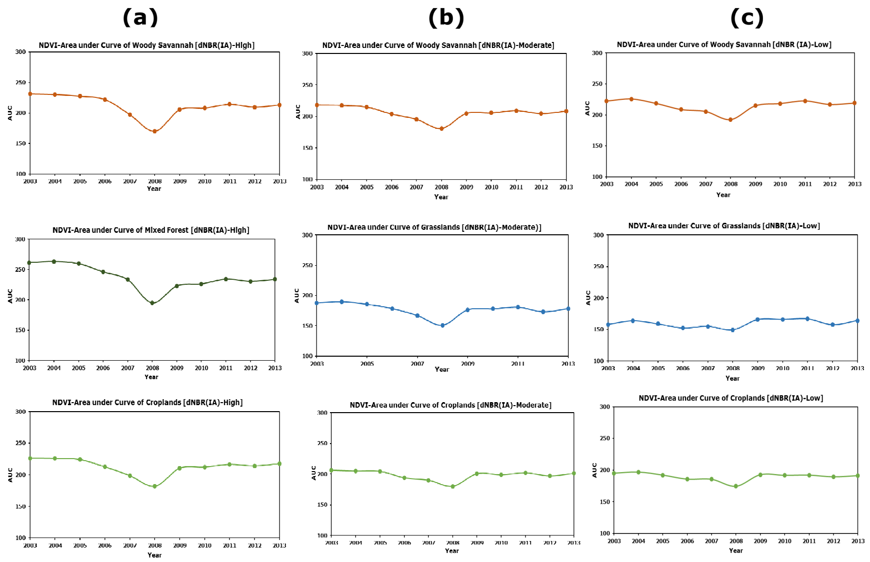

Figure 22: NDVI-Area under Curve of each land cover types in three dNBR severity levels in Initial Assessment

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Chapter 6
Discussion

6.1 Fire severity and affected land cover

To evaluate the fire severity we used two burn severity indices, differenced Normalized Burn Ratio (dNBR) and the Relative differenced Normalized Burn Ratio (RdNBR) to detect and assess the fire severity. dNBR measures the absolute resultant change between the pre- and post-fire images while the later one determines burn severity based on pre-fire reflectance and calculates the relative change caused by fire (Miller & Thode, 2007). Taking this definition (dNBR and RdNBR), a clear distinction appears between this two in relation to the aptness of using these two burn severity indices that is in the final remarks of whether algorithm's result will put extra value in severity assessment and the answer should be in favour of RdNBR. The results from the fire severity distribution showed almost similar results but RdNBR was showing a robust and consistent results for the natural land cover classes.

Considering the dNBR and RdNBR analysis for affected landcover classes, mixed forest in extended assessment showed much more higher (88.4%) value than to dNBR extended assessment, which revealed that the threshold value for RdNBR much robust for heterogeneous landscape (Miller & Thode, 2007). The five most affected landcover classes under the severity distribution showed that mixed forest was much more under high severity condition in extended assessment and after that woody savannah. Grasslands, croplands and mosaic of croplands and vegetation showed a significant recovery mostly from high to low and unburned area. The woody content is an indicator as mixed forest has much more woody content rather than woody savannah, grasslands and croplands. The recovery for grasslands are faster than any other landcover class.

6.2 Topographic factors influencing severity

The topographic factors were analysed to identify effects of topographic factors on severity distribution. Slope gradient, aspect and elevation were considered but there were no significant deviations found in all of the considered factors. For slope gradient, the RdNBR analysis showed that area under 10 to 30 degree of slope gradient showed much faster change from high to moderate, for dNBR (EA) analysis, it showed a reduced change to low severity from high severity category.

Elevation was considered for both of the burn severity indices (dNBR and RdNBR). Elevation were categorized to find out the effects of fire severity, but, there were no major effects found in this research. The results showed that RdNBR followed a shift from high to low where as in dNBR (EA) analysis area under the elevation from 0 – 1250m were in moderate severity category. Aspect followed the general trend, as, the wind direction and sun angle, south faced directions covered much more burned area than to the flat and north direction.

6.3 Change in tree percentage coverage

There was a decline in percentage of tree coverage from the year 2006 to 2008. The significant change were observed for both of the analysis. The extended assessment of dNBR and RdNBR showed a huge plummet of percentage of tree coverage from 2006 to 2008. This was the indication to observe the change spatially specially for fire affected area. The analysis was then conducted for the fire perimeter and it was found that about 91% area under the fire perimeter showed loss of tree percentage from the year 2006 to 2008, whereas from 2006 to 2007, the change in loss was 72% and from 2007 to 2008, it was 67%.

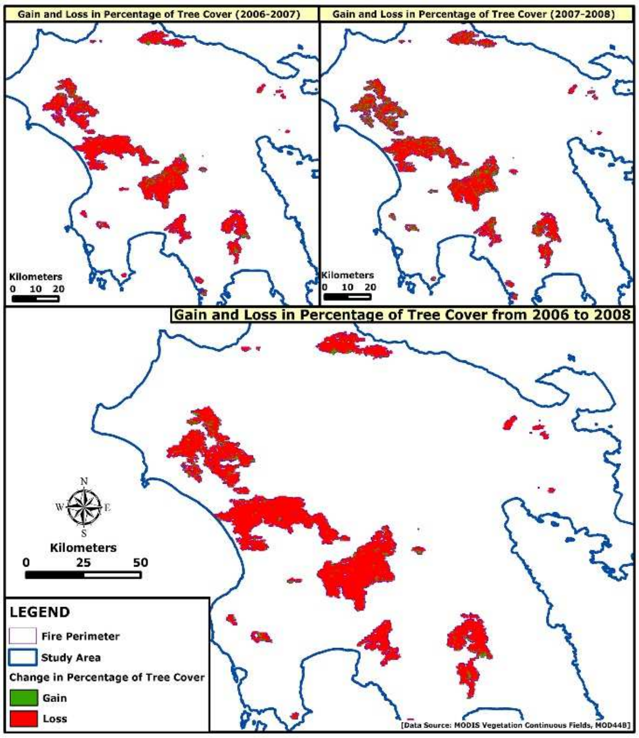


Figure 23: Gain and loss in percentage of tree coverage (2006 to 2008)

The used tree percentage data product (MOD44B) is a yearly data product, but, considering the change from 2006 to 2008, which encountered a huge loss of tree coverage for all the landcover types under the fire perimeter, it was a clear indication that the Greek fires of 2007 had a great influence on reducing percentage of tree coverage (**Figure 23**).

6.4 Estimation of Fire Radiative Power and Fuel Consumption

Estimation of fire radiative power and fuel consumption using MODIS sensor has constraints, as, MODIS derived pixels appear larger near the edge of the satellite ground swath, that is the background region of the pixel becomes larger (Peterson et al., 2013; Wooster et al., 2012). The overall estimation of FRE and Fuel consumption was compared with the MODIS active fire products. The difference of the two analysis was 1.46 kg/m^2 of fuel consumption which was not a robust results. The method used to calculate aboveground biomass for the active burn product dataset was only considered the forest canopy height (Lefsky et al., 2005). Both of the methods were not free of constraints, though, the MODIS estimation considered a prolonged period (10th July to 30th September, 2007) of observations, also the fire detection algorithm used in the assessment used spectral and spatial filters to correct the atmospheric and background noises (Wooster et al., 2012).

The histogram analysis of fire radiative power for the area under dNBR and RdNBR (IA & EA) showed a positive trend of distribution of fire radiative power in high, moderate and low category. Under the initial assessment, high severity area (under dNBR and RdNBR) classification showed higher frequency of FRP than to moderate and moderate severity was higher than the low severity, which, showed the compatibility of using the dNBR and RdNBR classification developed by Miller and Thode (2007). Meteorological parameters were observed with the FPR and the peak value of FRP showed during the fire and before the fire humidity was low, wind speed and temperature was high which revealed that weather condition was a strong driving force for the massive fires.

6.5 Vegetation Regrowth and Fire Severity

MODIS-LAI and MODIS-NDVI time series were generated and three most affected landcover classes were taken into consideration for this study, mainly woody savannah, mixed forest, croplands and grasslands. After resampling only two land cover classes showed most consistent in RdNBR (IA and EA) assessment, whereas, in dNBR (IA and EA) analysis only woody savannah was common (**Figure 24**). Further analysis were conducted mainly on these two natural vegetation cover classes (mixed forest and woody savannah).

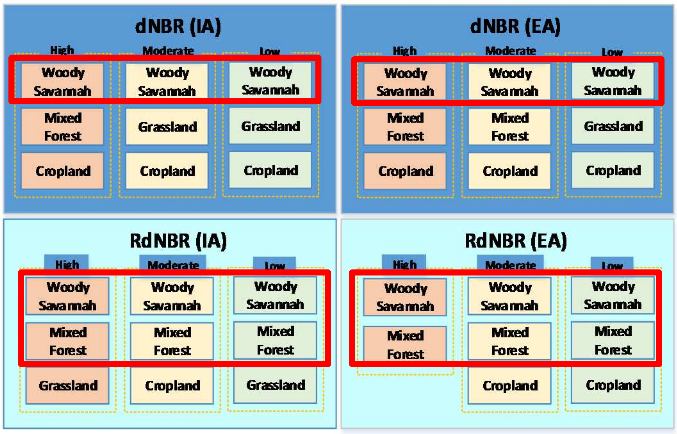
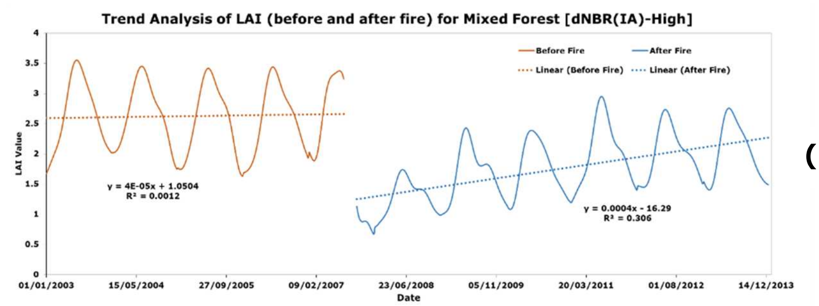
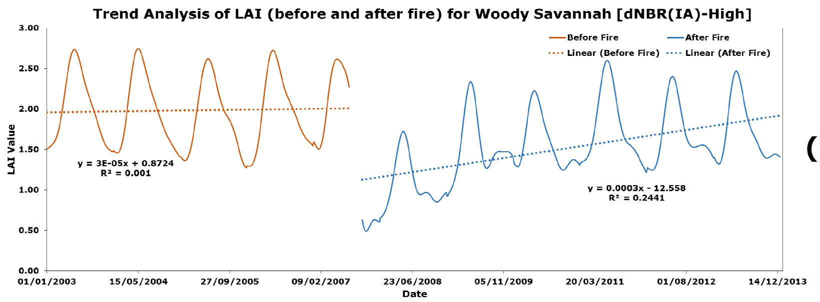


Figure 24: Land cover classes after resampling from 500m to 1km

MODIS-LAI time series under different severity (dNBR and RdNBR) showed that woody savannah and mixed forest were the most affected landcover classes. The time-series graphs showed a clear reduction of spectral signature during the forest fires and mainly natural vegetation cover classes were trying to recover the spectral signature. Grasslands showed faster recovery of LAI value after the fire, croplands were also recovered after one year, but, woody savannah and mixed forest were never recovered the before LAI signature. The trend analysis for before and after fire LAI cycle for mixed forest and woody savannah showed a significant sign of vegetation recovery over time (**Figure 25**).



(a)



(b)

Figure 25: Trend analysis of LAI (before and after fire) for (a) mixed forest and (b) woody savannah under dNBR(IA)-High severity

The temporal analysis of MODIS-NDVI also showed the dropdown of NDVI value during fire, but, the landcover classes in a whole didn't show sharp decline like LAI (**Appendix-E & F**). Though the trend analysis of natural vegetation cover classes, mixed forest and woody savannah, showed a recovery trend (**Figure 26**).

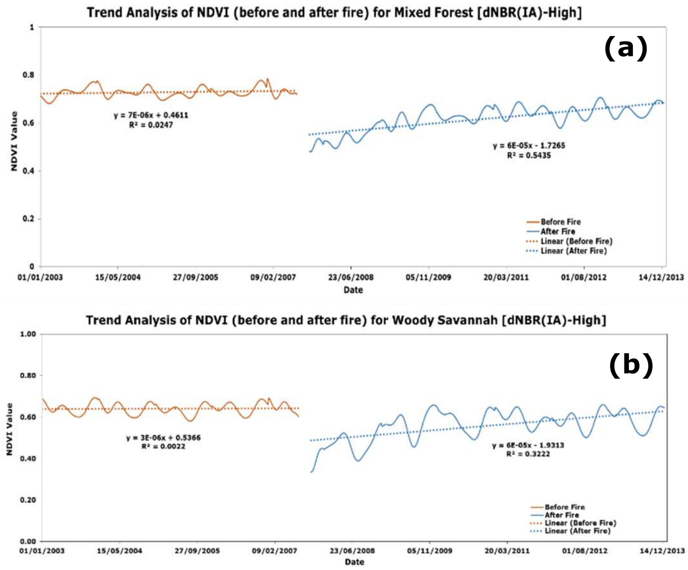
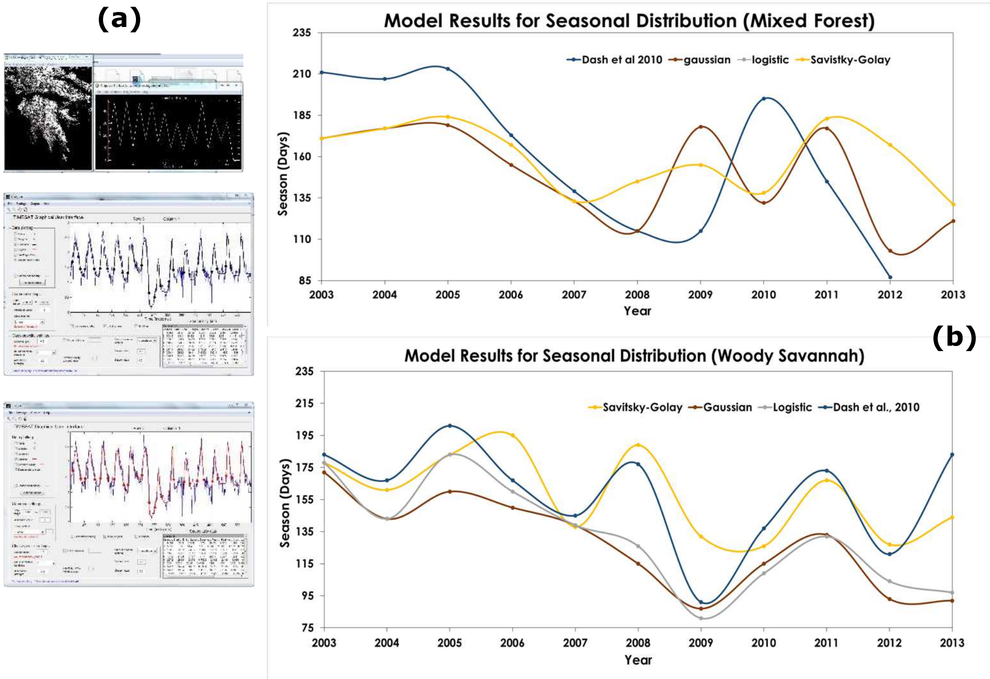


Figure 26: Trend analysis of NDVI (before and after fire) for (a) mixed forest and (b) woody savannah under dNBR (IA)-High severity

6.6 Vegetation Phenological Cycle

The start and end date of the seasons is an important factor to define the seasonal variability (Zhang et al., 2006; Jeganathan et al., 2010). TIMESAT and Model developed by Dash et al. (2010) were used and the results from different filters showed different results (**Figure 27**). The different start and end dates from different filters directed to use an alternative option,

(a)



	Dash et al., 2010	Gaussian Distribution	Logistic Distribution
Year	Season Start	Season Start	Season Start
2003	25/01/2003	22/03/2003	22/03/2003
2004	10/02/2004	05/03/2004	05/03/2004
2005	25/01/2005	14/03/2005	06/03/2005
2006	22/03/2006	30/03/2006	30/03/2006
2007	06/03/2007	14/03/2007	14/03/2007
2008	25/01/2008	13/03/2008	18/02/2008
2009	17/01/2009	18/02/2009	26/02/2009
2010	26/02/2010	14/03/2010	14/03/2010
2011	17/01/2011	26/02/2011	26/02/2011
2012	13/03/2012	21/03/2012	29/03/2012
2013	-	22/03/2013	22/03/2013

	Dash et al., 2010	Gaussian Distribution	Logistic Distribution
Year	Season End	Season End	Season End
2003	17/11/2003	17/11/2003	17/11/2003
2004	24/11/2004	08/11/2004	08/11/2004
2005	17/11/2005	17/11/2005	17/11/2005
2006	17/11/2006	01/11/2006	17/11/2006
2007	14/09/2007	14/09/2007	14/09/2007
2008	03/07/2008	20/08/2008	05/09/2008
2009	26/06/2009	24/10/2009	30/09/2009
2010	25/11/2010	14/09/2010	22/09/2010
2011	05/08/2011	01/11/2011	09/11/2011
2012	11/07/2012	12/08/2012	16/11/2012
2013	-	06/09/2013	22/09/2013

(c)

Figure 27: (a) Different model fits and phenology extraction; (b) model results for seasonal distribution for mixed forest and woody savannah; (c) season start and end date varies for different years

One of the major limitations not to get the exact date of season start and end was the spikes in the datasets of MODIS-LAI and MODIS-NDVI. The overall fit and the raw data showed that the data was noisy to define any definite season start and end date (**Figure 28**).

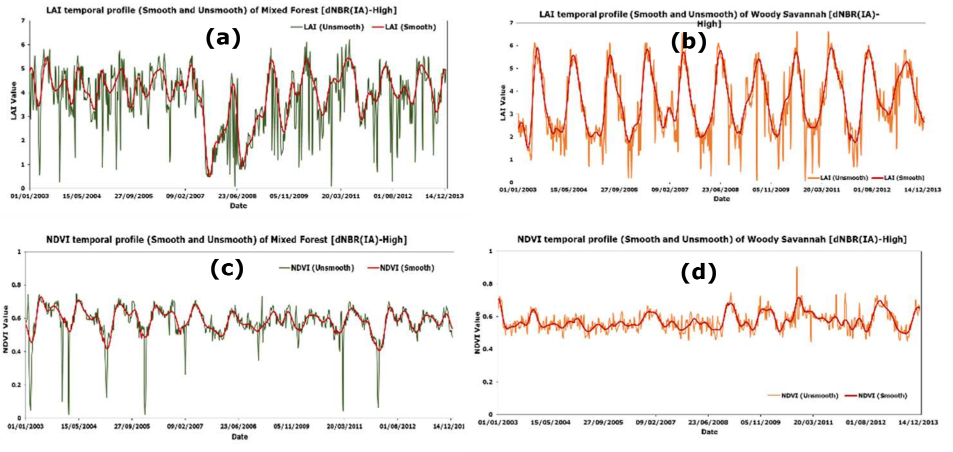


Figure 28: LAI (a,b) and NDVI (c,d) temporal profile for mixed forest and woody savannah under dNBR(IA)-High severity

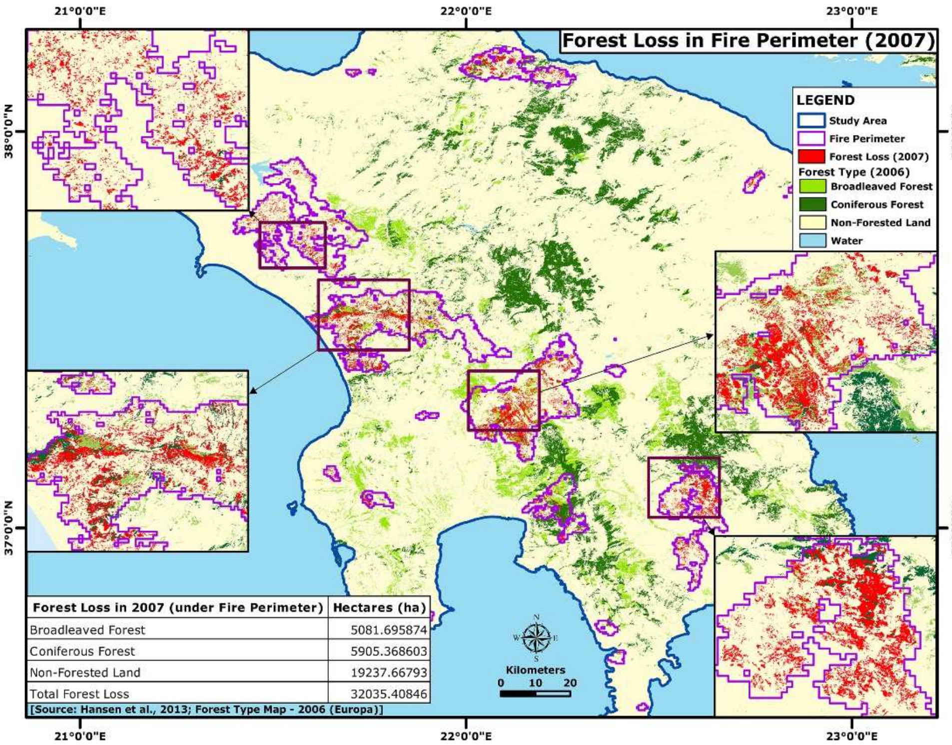
6.7 Area under Curve analysis for MODIS-LAI and MODIS-NDVI

The year wise area under curve analysis of MODIS-LAI and MODIS-NDVI showed that there is a sharp decline for the year of 2007, which indirectly showed that the fire had an influence on vegetation structure. Grasslands and croplands showed fast recovery of AUC value rather than mixed forest and woody savannah (**Appendix-C & D**). From the MODIS-LAI Area under Curve analysis, it was evident that the massive forest fires had a profound impacts on the forest ecosystems of Peloponnese.

6.8 Justification with Forest Loss Dataset

The results of fire severity and its impacts on vegetation was justified with the forest loss dataset developed by Hansen et al. (2013). The forest loss dataset for the year of 2007 were considered and it was found that 32045 hectares of forest loss was recorded in the fire perimeter for 2007. The forest type data product also used to verify the loss of forest type and according to the analysis, it was found that coniferous forest (5905 ha) and broadleaved forest (5082 ha) were severely damaged under the fire perimeter.

The dNBR and RdNBR analysis with the forest loss area by Hansen et al. (2013) showed that high severity area occupied high forest loss, which proved the applicability of using coarse resolution MODIS sensor to detect fire severity (**Figure 29**).



Forest Loss in 2007 (under Fire Perimeter)	Hectares (ha)
Broadleaved Forest	5081.695874
Coniferous Forest	5905.368603
Non-Forested Land	19237.66793
Total Forest Loss	32035.40846

Figure 29: Forest loss (in 2007) in fire perimeter

Chapter 7
Conclusions

This research was conducted using two fire severity indices, dNBR and RdNBR, to assess the impact of fire severity on vegetation regrowth. All the free available MODIS data products were used to detect burned area, fire severity, fire radiative power and energy estimation and for the time-series analysis of spectral signature of different vegetation cover types. Woody savannah and mixed forest were the two most affected natural vegetation coverage, although grasslands and croplands were also destroyed during the forest fire in 2007. There were no significant impacts found with the elevation factors (slope, elevation and aspect) and fire severity, but, the moderate slope areas were under high severity condition in the initial assessment.

MODIS fire products were used to detect the fire radiative power and fire radiative energy and the fuel consumption was calculated during the fire events. The meteorological factors had a significant impacts on fire ignition, as, all the adjacent weather stations showed high wind speed, low humidity and high temperature before and during the massive forest fires. The detected fire radiative power and radiative energy were found different from different assessment, but, the fire detection algorithm revealed the more reliable results, as, it incorporated land and cloud mask, spatial and spectral filtering, background characterisation, sun-glint identification, to detect fire pixels. The estimated summed fire radiative power thus showed the competent results with the fire severity classification used in this study. The high severity area showed higher fire radiative power and the results for both initial and extended assessment followed the general assumption of fire severity distribution.

MODIS derived bio-physical parameter, MODIS-LAI, and MODIS derived vegetation index, MODIS-NDVI were analysed for thirteen years (2003–2013) to derive the impacts of fire severity on vegetation structure. The environmental conditions are a factor for onset of greenness and end of senescence, so, the fire perimeter was consider to do the analysis. The natural vegetation cover classes (mixed forest and woody savannah) showed a significant drop down and slow recovery rather than grasslands and croplands. The trend analysis of the LAI signature was remarkable for the natural vegetation cover classes. MODIS-NDVI revealed the impacts of fire severity on vegetation cover classes. The yearly cycle of MODIS-NDVI was not distinct as MODIS-LAI, as NDVI only considers greenness. In some cases, MODIS-NDVI and MODSI-LAI did not come up with the same result, but, for mixed forest and woody savannah land cover class, the results were very close. There was an earnest try in this study to derive the phenological profile for the natural land cover classes under fire affected area, but, different filters were generating different start and end date of season. Therefore, year-based area under curve analysis was conducted for the most affected land cover classes. The Area under curve analysis revealed a significant dropdown of the value for the year of 2008, and it was common for all the landcover classes affected due to the fire. The natural vegetation cover classes, mixed forest and woody savannah showed a sharp decline but the recovery over the year was found rather slow than to the grasslands and croplands.

The results derived from the MODIS products were then validated with a forest loss dataset from tiles of Landsat images developed by Hansen et al. (2013). The outcomes from the MODIS images showed the similar results, as, the high severity area occupied the highest forest loss, moderate and low showed the moderate and low coverage of forest loss. The similar results from the MODIS analysis with the Landsat dataset showed that MODIS sensor can be used to regional to local scale for fire severity and post-fire impact assessment.

The MODIS sensors offers many different data products with a high temporal resolution, but, the algorithms used in these data products is not free from noises. In this study, one of the main constraints to derive vegetation phenology was the data quality of the MODIS-LAI and MODIS-NDVI. The temporal dataset had so many spikes which was difficult to define exact seasonal start and end date.

The future studies related to fire severity and vegetation regrowth should be concerned with the data quality of the MODIS-LAI and MODIS-NDVI product. An enhanced algorithm for phenology extraction will make the MODIS-derived vegetation indices more useful for the ecologists and environmental researchers.

References

Barrett, K., & Kasischke, E. S. (2013). Controls on variations in MODIS fire radiative power in Alaskan boreal forests: Implications for fire severity conditions. *Remote Sensing of Environment, 130*, 171-181.

Bassi, S., Kettunen, M., Kampa, E., & Cavalieri, S. (2008). FOREST FIRES: Causes and contributing factors in Europe. *European Parliament, Brussels*.

Blake, W. H., Theocharopoulos, S. P., Skoulikidis, N., Clark, P., Tountas, P., Hartley, R., & Amaxidis, Y. (2008). Wildfire, soil erosion and the risk to aquatic resources: evidence from the burnt Evrotas River basin, southern Peloponnese, Greece. *10*.

Brewer, C. K., Winne, J. C., Redmond, R. L., Opitz, D. W., & Mangrich, M. V. (2005). Classifying and mapping wildfire severity: a comparison of methods. *Photogrammetric Engineering and Remote Sensing, 71*(11), 1311-1320.

Chuvieco, E., Santis, A. d., Riaño, D., & Halligan, K. (2007). Simulation approaches for burn severity estimation using remotely sensed images. *Fire ecology, 2007*.

Chuvieco, E., Ventura, G., Martín, M. P., & Gómez, I. (2005). Assessment of multitemporal compositing techniques of MODIS and AVHRR images for burned land mapping. *Remote Sensing of Environment, 94*(4), 450-462.

Díaz-Delgado, R., Lloret, F., & Pons, X. (2003). Influence of fire severity on plant regeneration by means of remote sensing imagery. *International Journal of Remote Sensing, 24*(8), 1751-1763.

Ellicott, E., & Vermote, E. (2012). The Science and Application of Satellite Based Fire Radiative Energy. In D. L. Fatoyinbo (Ed.), *Remote Sensing of Biomass - Principles and Applications* (pp. 178-192): InTech.

Ellicott, E., Vermote, E., Giglio, L., & Roberts, G. (2009). Estimating biomass consumed from fire using MODIS FRE. *Geophysical Research Letters, 36*(13).

Epting, J., Verbyla, D., & Sorbel, B. (2005). Evaluation of remotely sensed indices for assessing burn severity in interior Alaska using Landsat TM and ETM+. *Remote Sensing of Environment, 96*(3), 328-339.

Escuin, S., Navarro, R., & Fernandez, P. (2008). Fire severity assessment by using NBR (Normalized Burn Ratio) and NDVI (Normalized Difference Vegetation Index) derived from LANDSAT TM/ETM images. *International Journal of Remote Sensing, 29*(4), 1053-1073.

French, N. H. F., Kasischke, E. S., Hall, R. J., Murphy, K. A., Verbyla, D. L., Hoy, E. E., & Allen, J. L. (2008). Using Landsat data to assess fire and burn severity in the North American boreal forest region: an overview and summary of results. *International Journal of Wildland Fire, 17*(4), 443-462.

Gitas, I., Mitri, G., Veraverbeke, S., & Polychronaki, A. (2012). Advances in remote sensing of post-fire vegetation recovery monitoring–a review. *Remote Sensing of Biomass–Principles and Applications'.(Ed. L Fatoyinbo)(InTech) Available at http://www.intechopen.com/books/remote-sensing-of-biomass-principles-and-applications/advances-in-remote-sensing-of-post-fire-monitoring-a-review [Verified 20 June 2013]*.

Hall, R. J., Freeburn, J. T., De Groot, W. J., Pritchard, J. M., Lynham, T. J., & Landry, R. (2008). Remote sensing of burn severity: experience from western Canada boreal fires. *International Journal of Wildland Fire, 17*(4), 476-489.

Harris, S., Veraverbeke, S., & Hook, S. (2011). Evaluating spectral indices for assessing fire severity in Chaparral Ecosystems (Southern California) Using MODIS/ASTER (MASTER) airborne simulator data. *Remote Sensing, 3*(11), 2403-2419.

Holden, Z. A. (2008). Twenty Year (1984-2004) Temporal and Spatial Burn Severity Patterns Inferred from Satellite Imagery in the Gila National Forest, New Mexico.

Hoy, E. E. (2007). Evaluating the potential of the Normalized Burn Ratio and other spectral indices for assessment of fire severity in Alaskan Black Spruce forests.

Jakubauskas, M. E., Lulla, K. P., & Mausel, P. W. (1990). Assessment of vegetation change in a fire-altered forest landscape. *PE&RS, Photogrammetric Engineering & Remote Sensing, 56*(3), 371-377.

JRC. (2008). Forest Fires in Europe 2007 *JRC Scientific and Technical Reports* (Vol., pp. 77).

Justice, C. O., Townshend, J. R. G., Vermote, E. F., Masuoka, E., Wolfe, R. E., Saleous, N., Roy, D. P., & Morisette, J. T. (2002). An overview of MODIS Land data processing and product status. *Remote sensing of Environment, 83*(1), 3-15.

Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J. J., Razinger, M., Schultz, M. G., & Suttie, M. (2012). Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power. *Biogeosciences, 9*(1).

Kaufman, Y. J., Kleidman, R. G., & King, M. D. (1998). SCAR-B fires in the tropics: Properties and remote sensing from EOS-MODIS.

Journal of Geophysical Research: Atmospheres (1984–2012), 103(D24), 31955-31968.

Key, C. H., & Benson, N. C. (1999). The Normalized Burn Ratio, a Landsat TM radiometric index of burn severity incorporating multi-temporal differencing. *US Geological Survey*.

Lhermitte, S., Verbesselt, J., Verstraeten, W. W., Veraverbeke, S., & Coppin, P. (2011). Assessing intra-annual vegetation regrowth after fire using the pixel based regeneration index. *ISPRS Journal of Photogrammetry and Remote Sensing, 66*(1), 17-27.

Loboda, T. V., Giglio, L., Boschetti, L., & Justice, C. O. (2012). Regional fire monitoring and characterization using global NASA MODIS fire products in dry lands of Central Asia. *Frontiers of Earth Science, 6*(2), 196-205.

Lunetta, R. S., Knight, J. F., Ediriwickrema, J., Lyon, J. G., & Worthy, L. D. (2006). Land-cover change detection using multi-temporal MODIS NDVI data. *Remote sensing of environment, 105*(2), 142-154.

Merino-de-Miguel, S., Huesca, M., & González-Alonso, F. (2010). Modis reflectance and active fire data for burn mapping and assessment at regional level. *Ecological Modelling, 221*(1), 67-74.

Miller, J. D., & Thode, A. E. (2007). Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). *Remote Sensing of Environment, 109*(1), 66-80.

Mitri, G. H., & Gitas, I. Z. (2004). A semi-automated object-oriented model for burned area mapping in the Mediterranean region using Landsat-TM imagery. *International Journal of Wildland Fire, 13*(3), 367-376.

Pereira, J. M. C., Sousa, A. M. O., Sá, A. C. L., Martín, M. P., & Chuvieco, E. (1999). Regional-scale burnt area mapping in Southern Europe using NOAA-AVHRR 1 km data *Remote Sensing of Large Wildfires* (pp. 139-155): Springer.

Petropoulos, G. P., Griffiths, H. M., & Kalivas, D. P. (2014). Quantifying spatial and temporal vegetation recovery dynamics following a wildfire event in a Mediterranean landscape using EO data and GIS. *Applied Geography, 50*, 120-131.

Ridder, R. M. (2007). Global forest resources assessment 2010: options and recommendations for a global remote sensing survey of forests. *FAO For. Resour. Assess. Programme Work. Pap, 141*.

Roberts, G., Wooster, M. J., Freeborn, P. H., & Xu, W. (2011). Integration of geostationary FRP and polar-orbiter burned area datasets for an enhanced biomass burning inventory. *Remote Sensing of Environment, 115*(8), 2047-2061.

Röder, A., Hill, J., Duguy, B., Alloza, J. A., & Vallejo, R. (2008). Using long time series of Landsat data to monitor fire events and post-fire dynamics and identify driving factors. A case study in the Ayora region (eastern Spain). *Remote Sensing of Environment, 112*(1), 259-273. doi: http://dx.doi.org/10.1016/j.rse.2007.05.001

Rogan, J., & Franklin, J. (2001). Mapping wildfire burn severity in southern California forests and shrublands using Enhanced Thematic Mapper imagery. *Geocarto International, 16*(4), 91-106.

Roy, D. P., Frost, P. G. H., Justice, C. O., Landmann, T., Le Roux, J. L., Gumbo, K., Makungwa, S., Dunham, K., Du Toit, R., & Mhwandagara, K. (2005). The Southern Africa Fire Network (SAFNet) regional burned-area product-validation protocol. *International Journal of Remote Sensing, 26*(19), 4265-4292.

Running, S. W. (2008). Ecosystem disturbance, carbon, and climate. *Science, 321*(5889), 652-653.

San-Miguel-Ayanz, J., Pereira, J. M. C., Boca, R., Strobl, P., Kucera, J., & Pekkarinen, A. (2009). Forest fires in the European Mediterranean region: mapping and analysis of burned areas *Earth observation of wildland fires in Mediterranean ecosystems* (pp. 189-203): Springer.

ScienceDaily. (2012). Science Reference: Bushfire. Retrieved 5 June, 2013, from http://www.sciencedaily.com/articles/b/bushfire.htm.

Tanase, M., de la Riva, J., Santoro, M., Pérez-Cabello, F., & Kasischke, E. (2011). Sensitivity of SAR Data to Post-fire Forest Regrowth in Mediterranean and Boreal Forests. *Remote Sensing of Environment, 115*(8), 2075-2085. doi: http://dx.doi.org/10.1016/j.rse.2011.04.009.

van der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Mu, M., Kasibhatla, P. S., Morton, D. C., DeFries, R. S., Jin, Y. v., & van Leeuwen, T. T. (2010). Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009). *Atmospheric Chemistry and Physics, 10*(23), 11707-11735.

Veraverbeke, S., Lhermitte, S., Verstraeten, W. W., & Goossens, R. (2010a). The temporal dimension of differenced Normalized Burn Ratio (dNBR) fire/burn severity studies: the case of the large 2007 Peloponnese wildfires in Greece. *Remote Sensing of Environment, 114*(11), 2548-2563.

Veraverbeke, S., Lhermitte, S., Verstraeten, W. W., & Goossens, R. (2011). A time-integrated MODIS burn severity assessment using the multi-temporal differenced normalized burn ratio.

International Journal of Applied Earth Observation and Geoinformation, 13(1), 52-58.

Veraverbeke, S., Van De Kerchove, R., Verstraeten, W., Lhermitte, S., & Goossens, R. (2010b, 2010). *Fire-induced changes in vegetation, albedo and land surface temperature assessed with MODIS*.

Vermote, E., Ellicott, E., Dubovik, O., Lapyonok, T., Chin, M., Giglio, L., & Roberts, G. J. (2009). An approach to estimate global biomass burning emissions of organic and black carbon from MODIS fire radiative power. *Journal of Geophysical Research: Atmospheres (1984–2012), 114*(D18).

Walz, Y., Maier, S. W., Dech, S. W., Conrad, C., & Colditz, R. R. (2007). Classification of burn severity using Moderate Resolution Imaging Spectroradiometer (MODIS): A case study in the jarrah-marri forest of southwest Western Australia. *Journal of Geophysical Research: Biogeosciences (2005–2012), 112*(G2).

White, J. D., Ryan, K. C., Key, C. C., & Running, S. W. (1996). Remote sensing of forest fire severity and vegetation recovery. *International Journal of Wildland Fire, 6*(3), 125-136.

Wooster, M. J., Roberts, G., Perry, G. L. W., & Kaufman, Y. J. (2005). Retrieval of biomass combustion rates and totals from fire radiative power observations: FRP derivation and calibration relationships between biomass consumption and fire radiative energy release. *Journal of Geophysical Research: Atmospheres (1984–2012), 110*(D24).

Wooster, M. J., Zhukov, B., & Oertel, D. (2003). Fire radiative energy for quantitative study of biomass burning: Derivation from the BIRD experimental satellite and comparison to MODIS fire products. *Remote Sensing of Environment, 86*(1), 83-107.

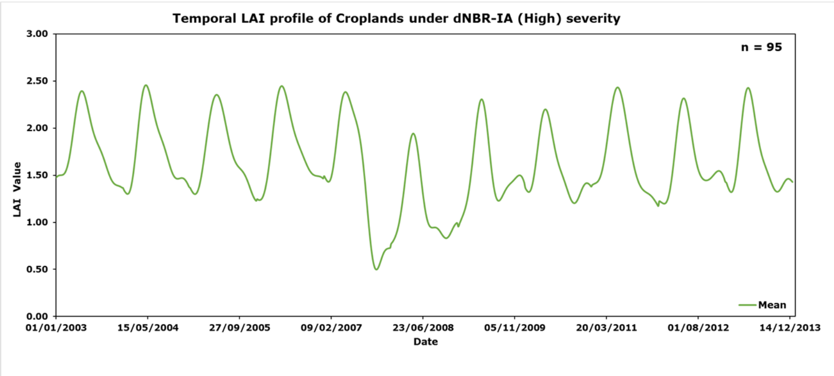
WWF. (2007). Ecological assessment of the wildfires of August 2007 in the Peloponnese, Greece. Athens: WWF Greece.

Zhu, Z., Key, C., Ohlen, D., & Benson, N. (2006). Evaluate sensitivities of burn-severity mapping algorithms for different ecosystems and fire histories in the United States *Final Report to the Joint Fire Science Program* (pp. 35).

Appendix -A: Time series of LAI (mean) profile

Graphics show in this appendix, sequentially are:

- dNBR-IA and dNBR-EA in high severity, moderate, and low class
- RdNBR-IA and RdNBR-EA in high severity, moderate, and low class
- All in top three land cover, except for RdNBR-EA in high severity class



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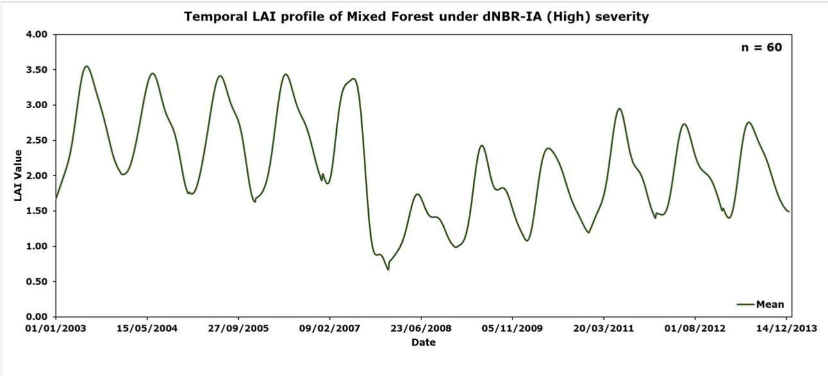
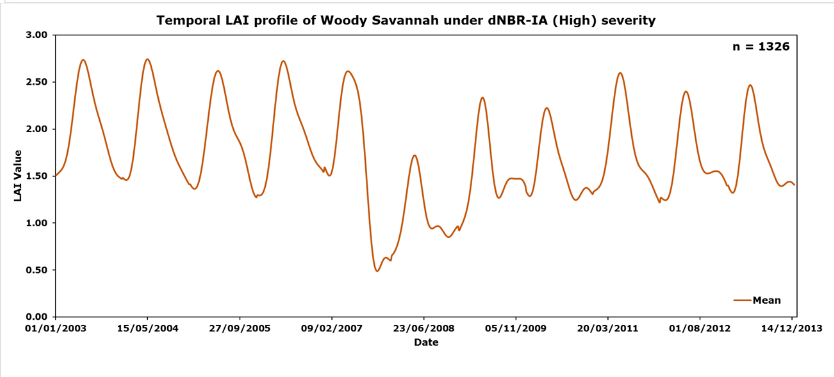
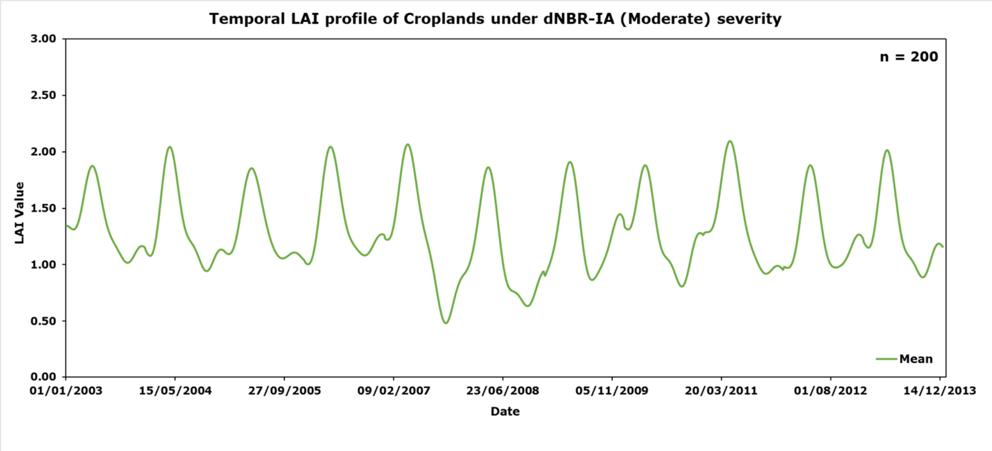
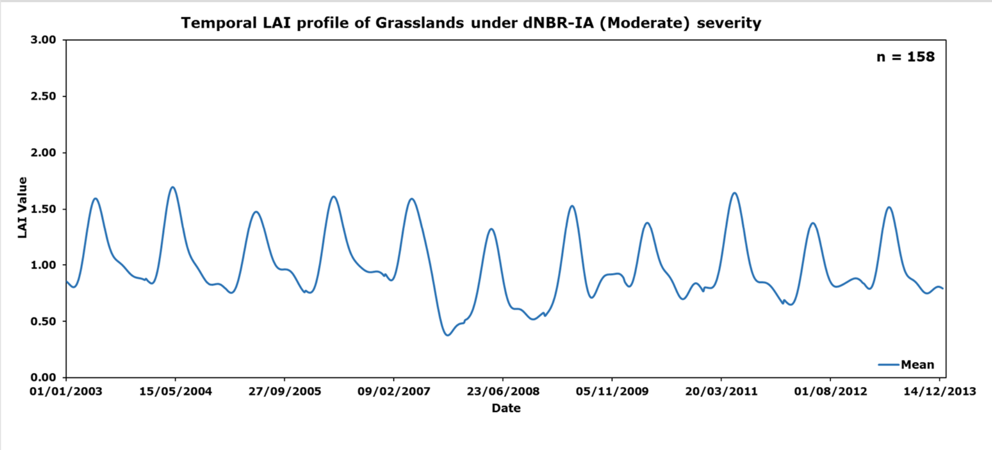


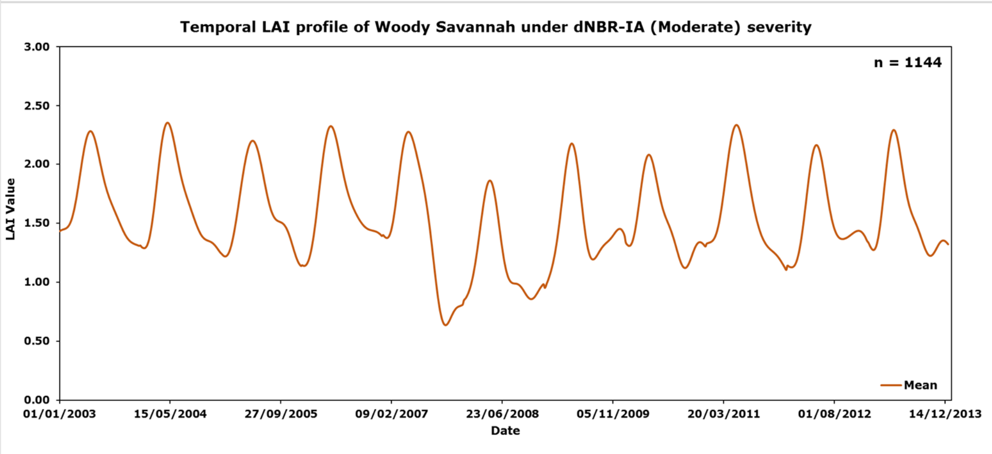




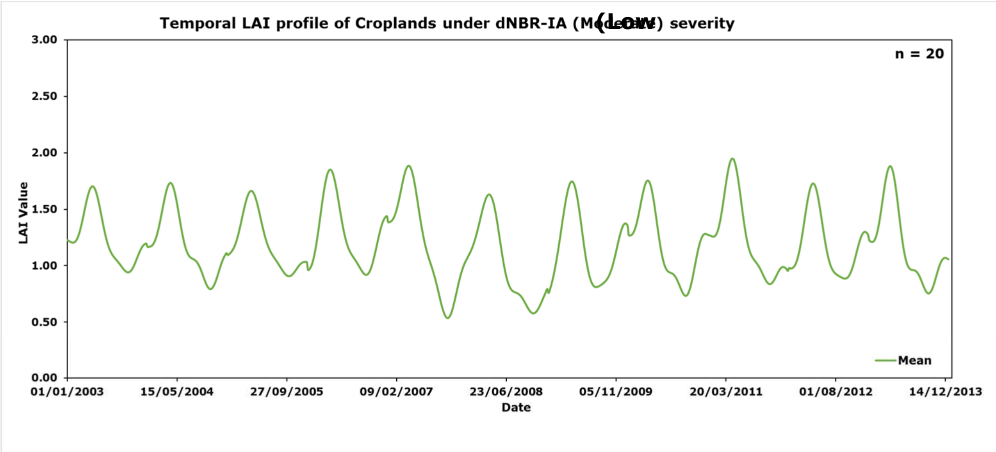
Temporal LAI profile of Croplands under dNBR-IA (Moderate) severity
n = 200
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

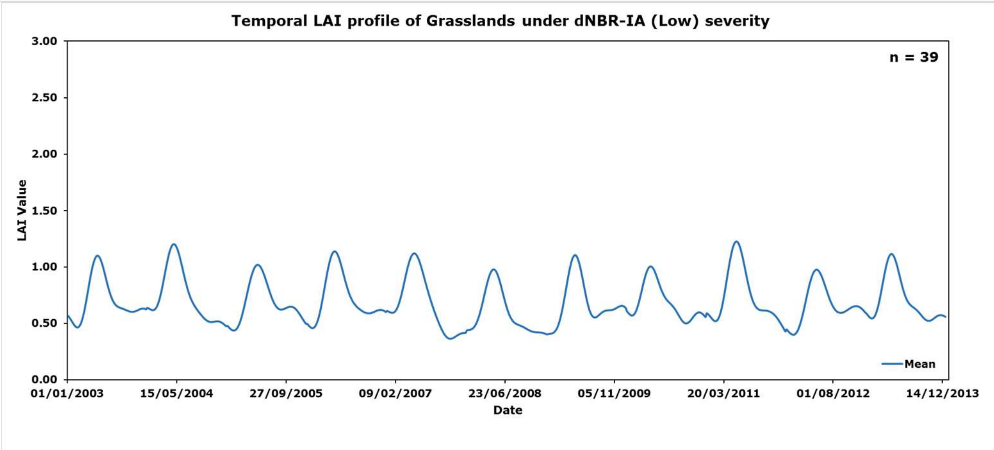


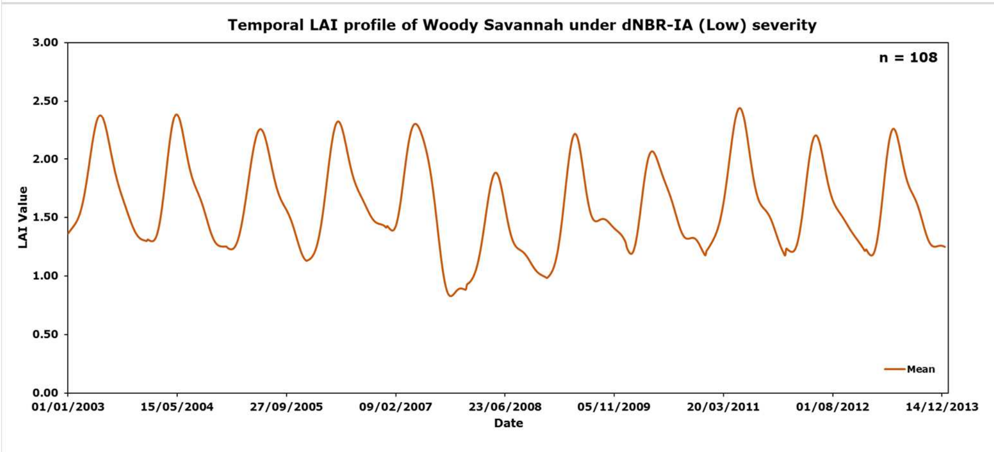
Temporal LAI profile of Grasslands under dNBR-IA (Moderate) severity
n = 158
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

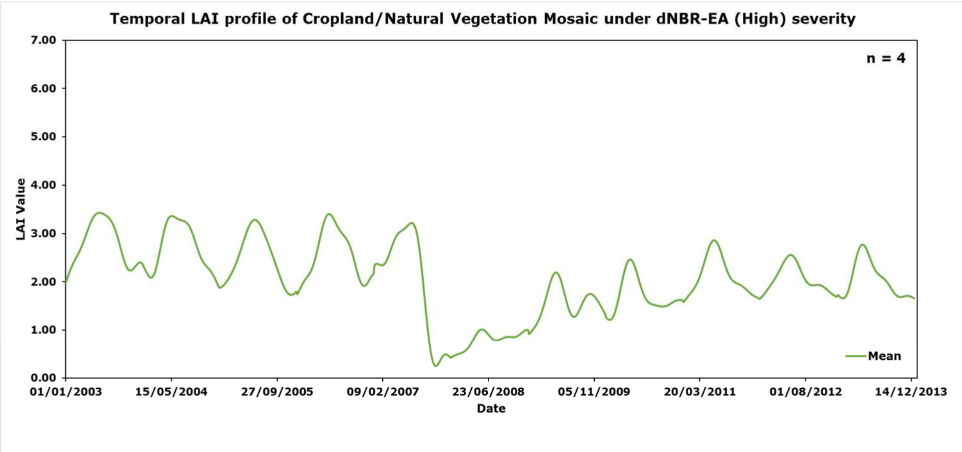


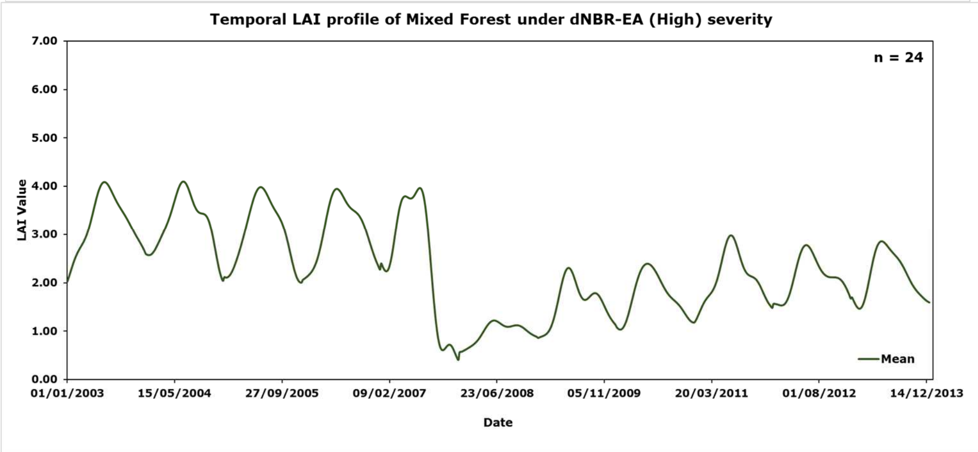
Temporal LAI profile of Woody Savannah under dNBR-IA (Moderate) severity
n = 1144
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

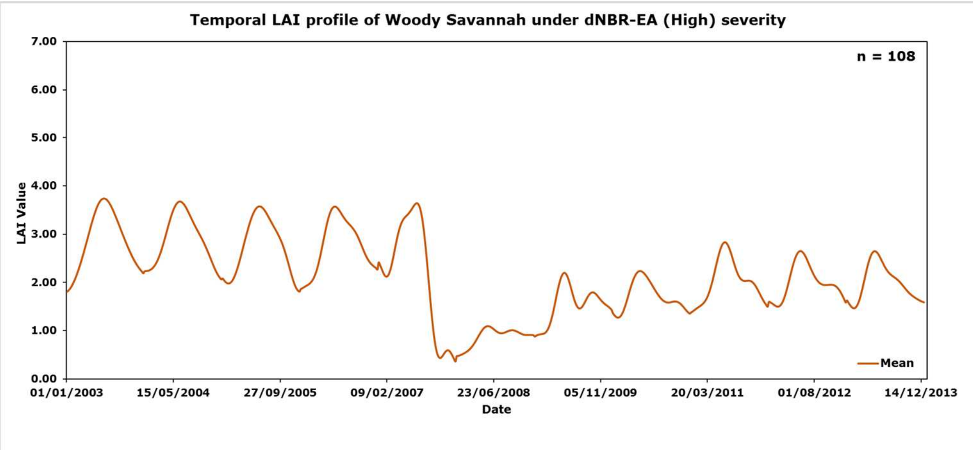

Temporal LAI profile of Croplands under dNBR-IA (Moderate) severity
(Low
n = 20
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

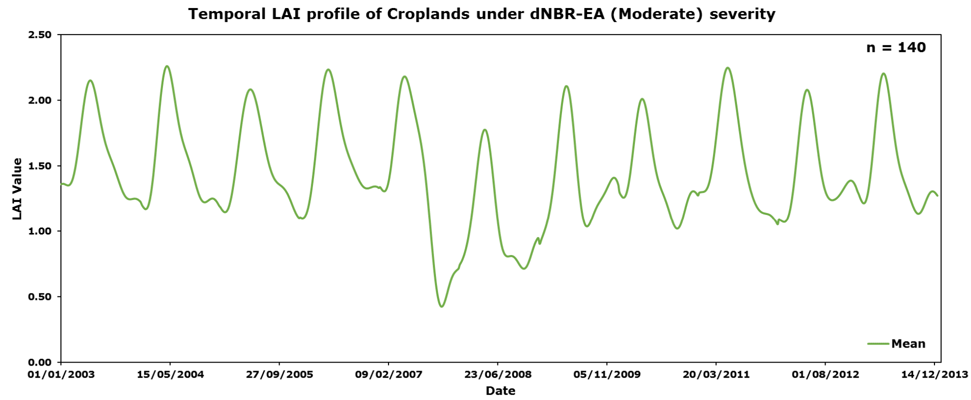

Temporal LAI profile of Grasslands under dNBR-IA (Low) severity
n = 39
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

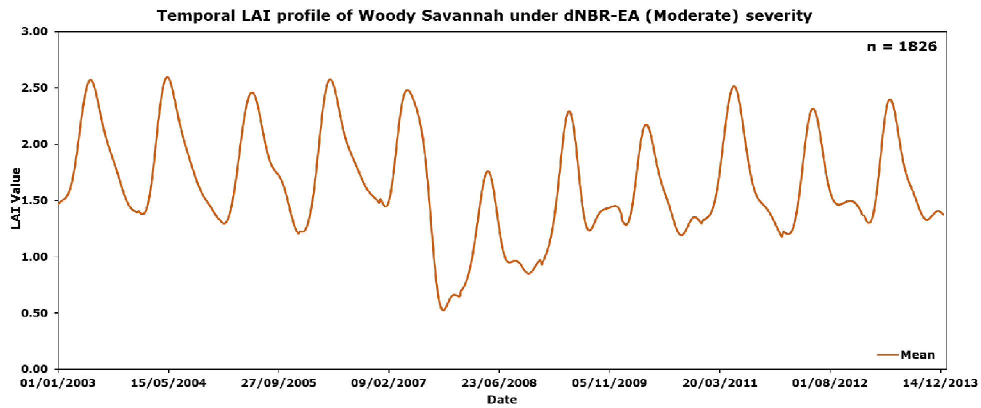

Temporal LAI profile of Woody Savannah under dNBR-IA (Low) severity
n = 108
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

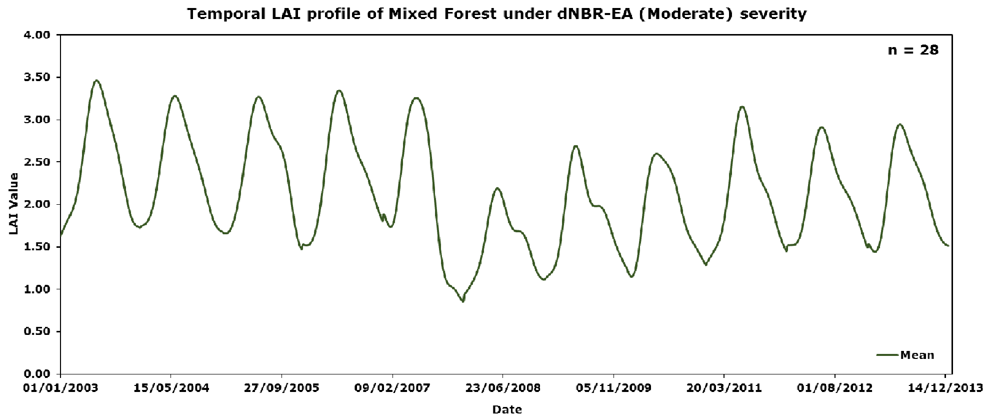

Temporal LAI profile of Cropland/Natural Vegetation Mosaic under dNBR-EA (High) severity
n = 4
LAI Value
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

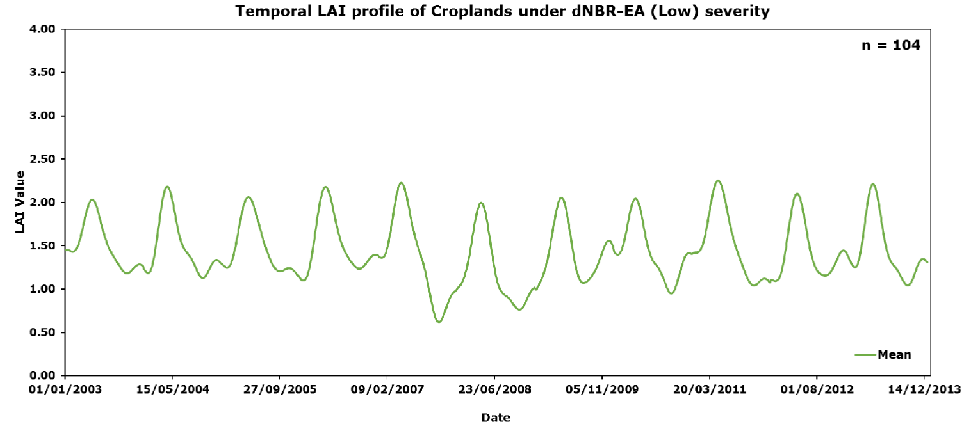

Temporal LAI profile of Mixed Forest under dNBR-EA (High) severity
n = 24
LAI Value
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

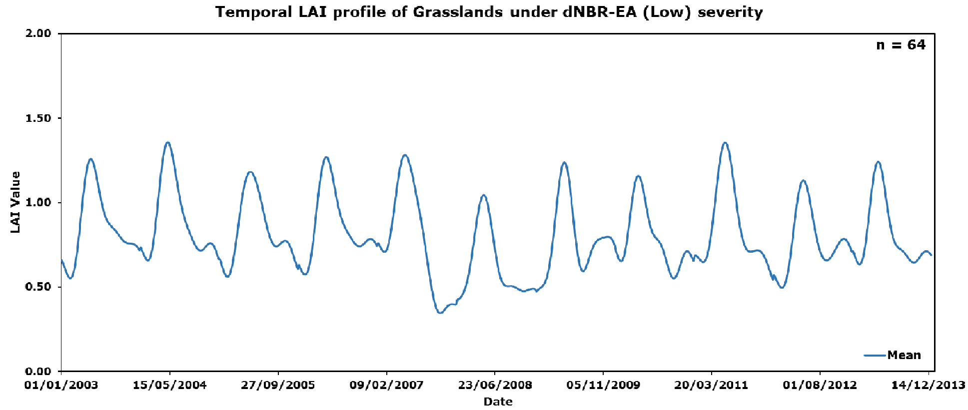

Temporal LAI profile of Woody Savannah under dNBR-EA (High) severity
n = 108
LAI Value
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

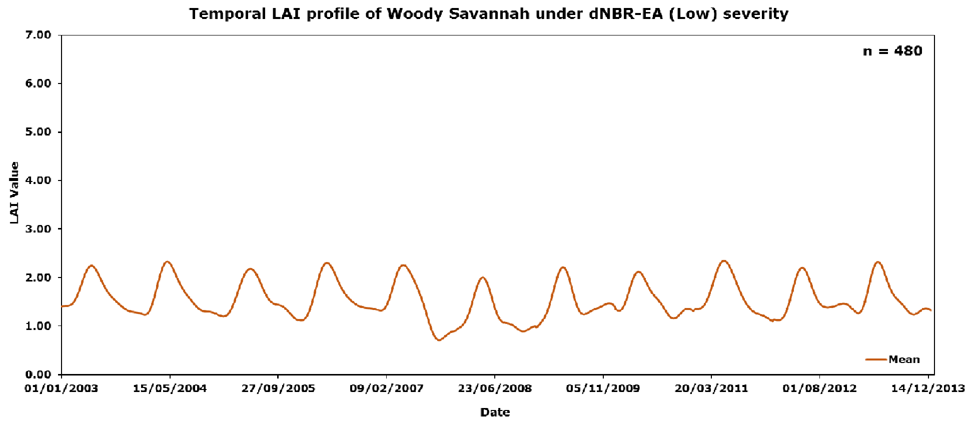

Temporal LAI profile of Croplands under dNBR-EA (Moderate) severity
n = 140
LAI Value
2.50
2.00
1.50
1.00
0.50
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

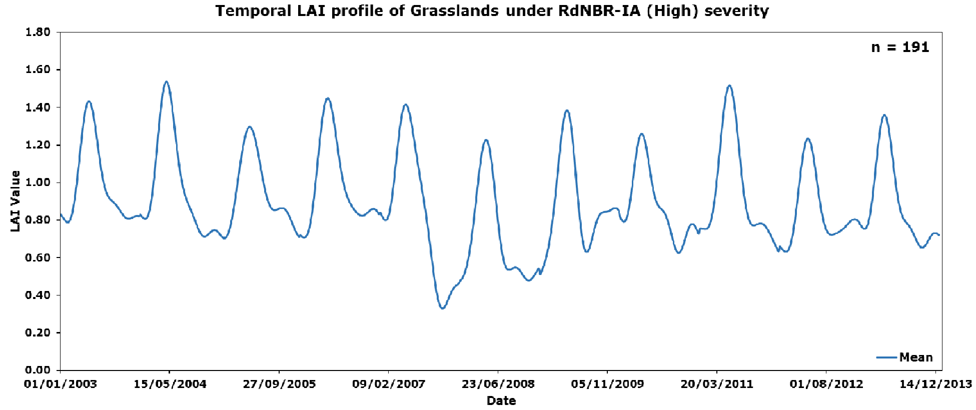

Temporal LAI profile of Woody Savannah under dNBR-EA (Moderate) severity
n = 1826
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

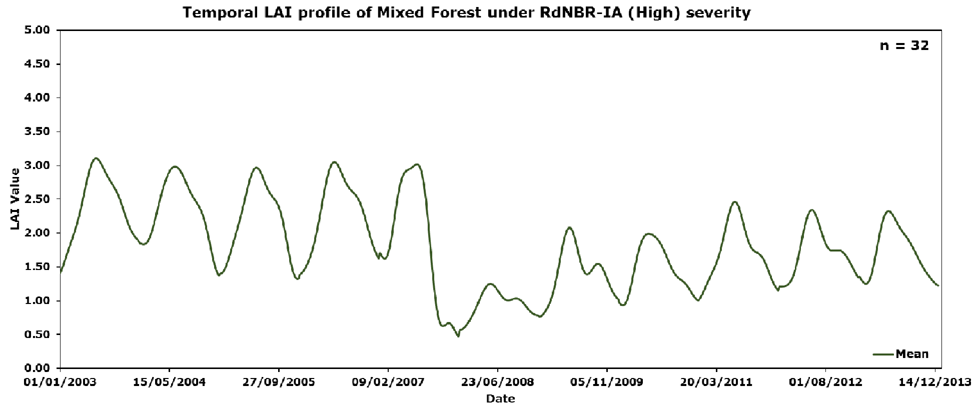

Temporal LAI profile of Mixed Forest under dNBR-EA (Moderate) severity
n = 28
LAI Value
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

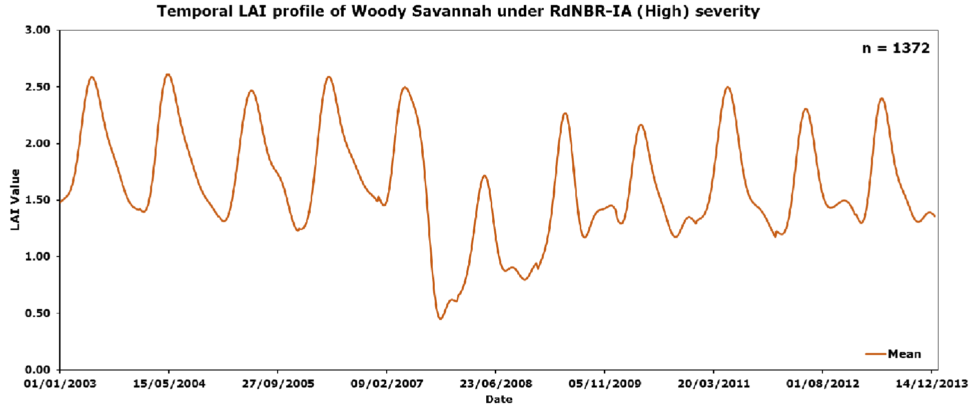

Temporal LAI profile of Croplands under dNBR-EA (Low) severity
n = 104
LAI Value
Mean
Date
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013

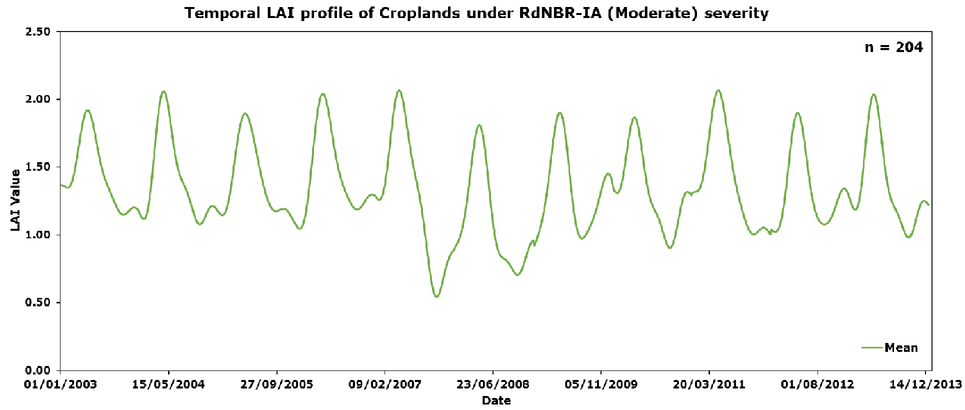

Temporal LAI profile of Grasslands under dNBR-EA (Low) severity
n = 64
LAI Value
Mean
Date
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013

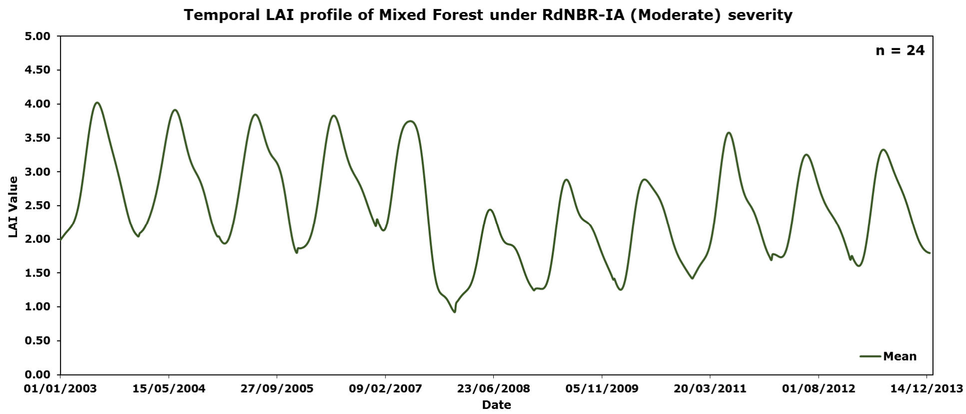

Temporal LAI profile of Woody Savannah under dNBR-EA (Low) severity
n = 480
LAI Value
Mean
Date
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013

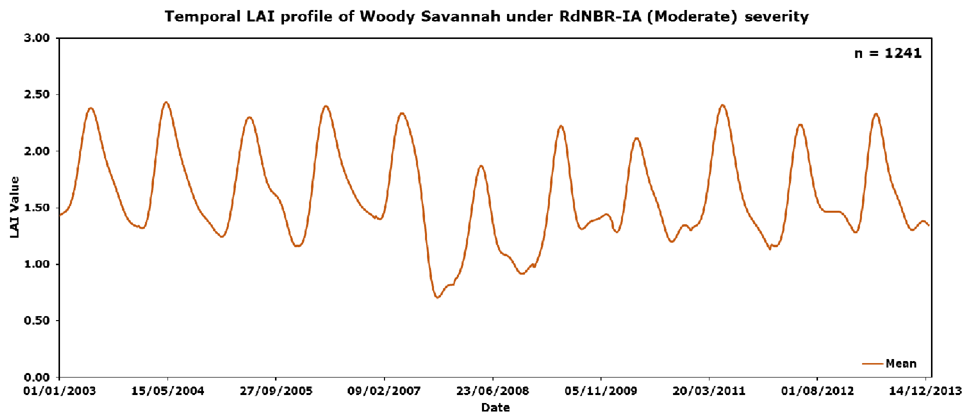

Temporal LAI profile of Grasslands under RdNBR-IA (High) severity
n = 191
LAI Value
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

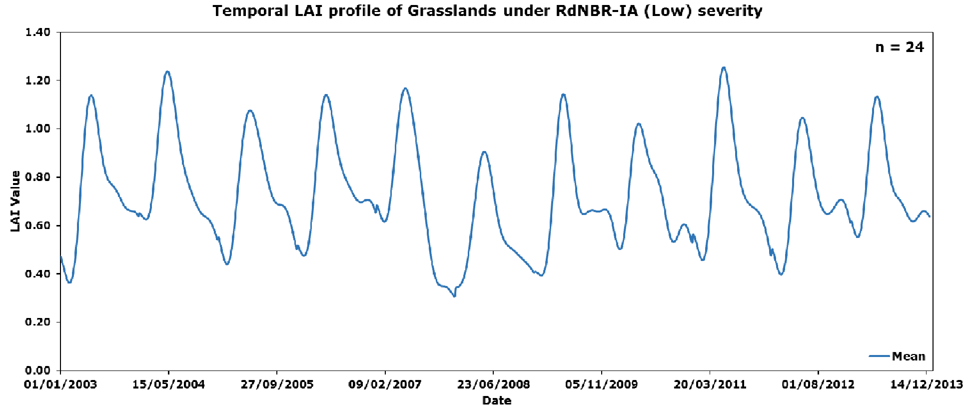

Temporal LAI profile of Mixed Forest under RdNBR-IA (High) severity
n = 32
LAI Value
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

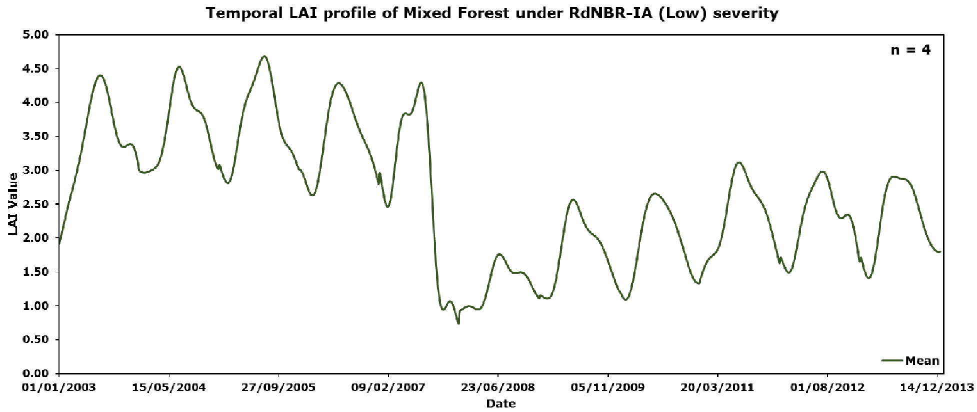

Temporal LAI profile of Woody Savannah under RdNBR-IA (High) severity
n = 1372
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

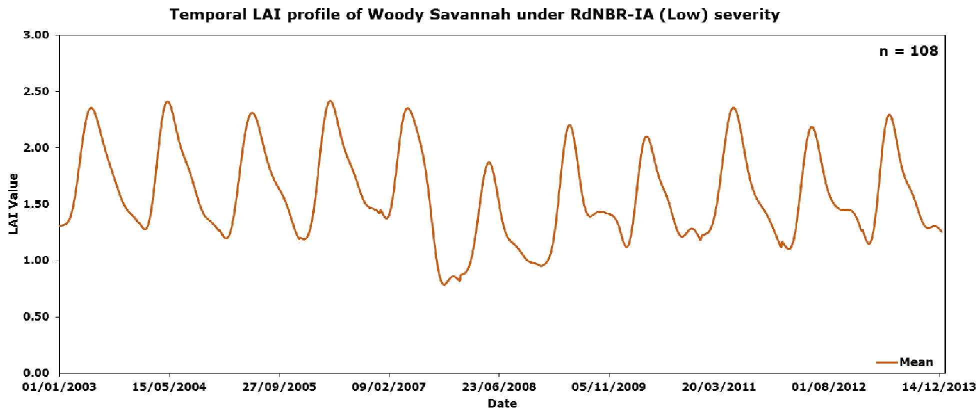

Temporal LAI profile of Croplands under RdNBR-IA (Moderate) severity
n = 204
LAI Value
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

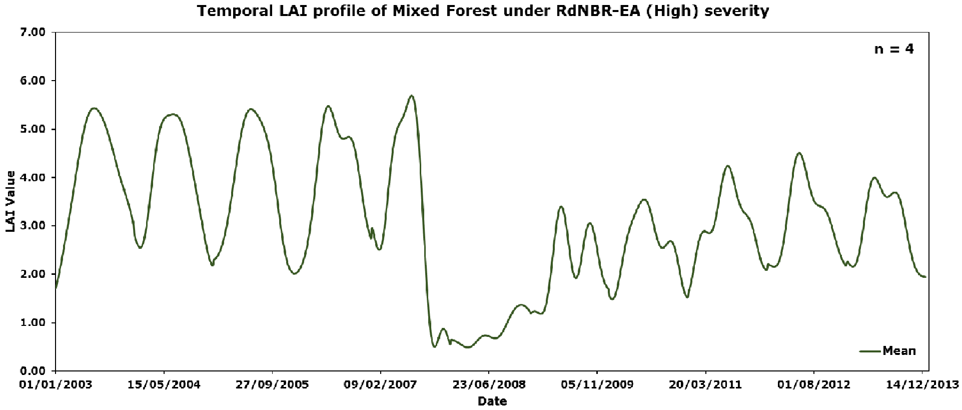

Temporal LAI profile of Mixed Forest under RdNBR-IA (Moderate) severity
n = 24
LAI Value
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

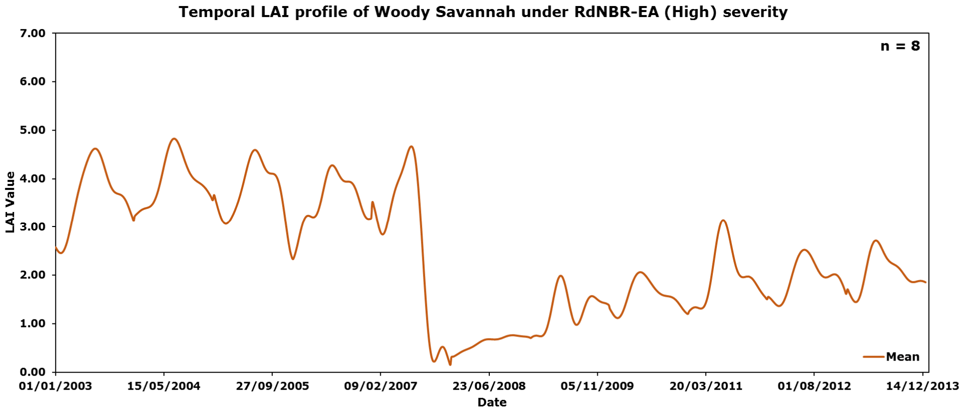

Temporal LAI profile of Woody Savannah under RdNBR-IA (Moderate) severity
n = 1241
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

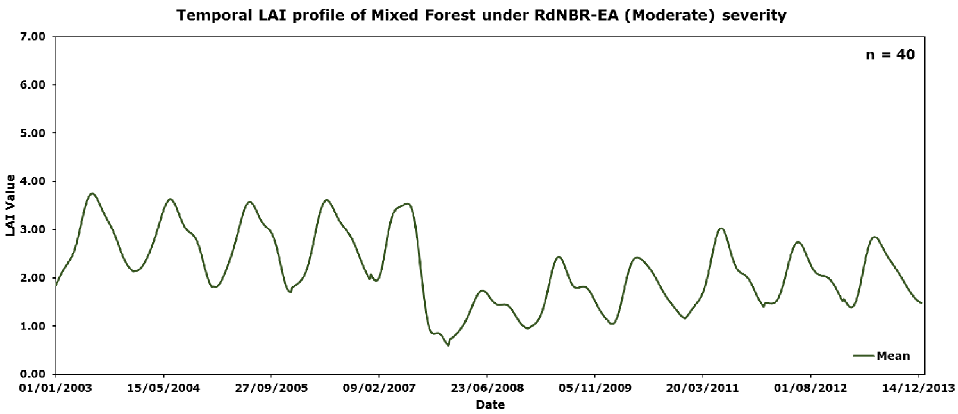

Temporal LAI profile of Grasslands under RdNBR-IA (Low) severity
n = 24
LAI Value
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean


Temporal LAI profile of Mixed Forest under RdNBR-IA (Low) severity
n = 4
LAI Value
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

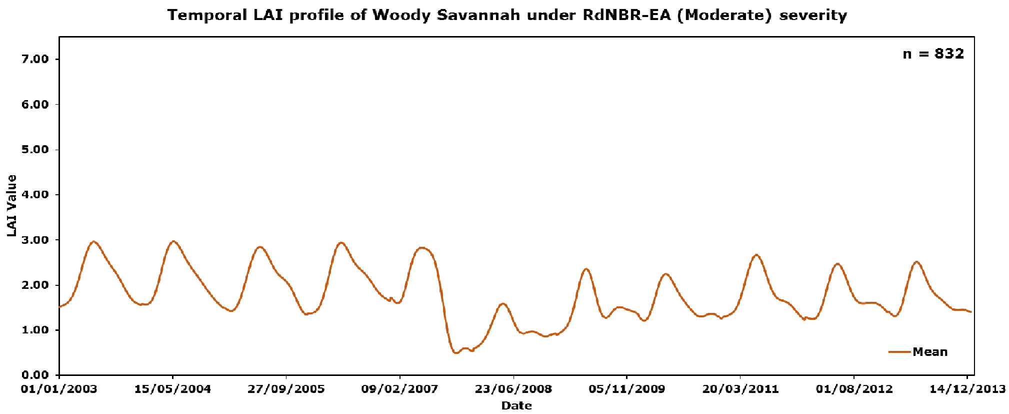

Temporal LAI profile of Woody Savannah under RdNBR-IA (Low) severity
n = 108
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean


Temporal LAI profile of Mixed Forest under RdNBR-EA (High) severity
n = 4
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LAI Value
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

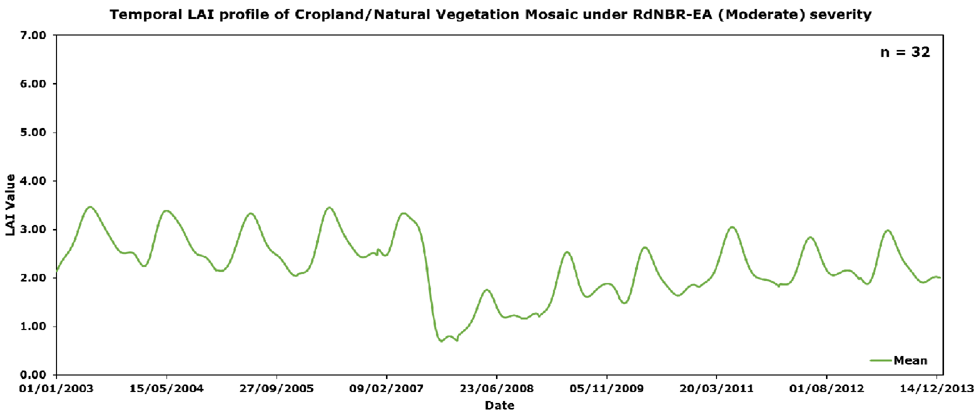

Temporal LAI profile of Woody Savannah under RdNBR-EA (High) severity
n = 8
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LAI Value
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date



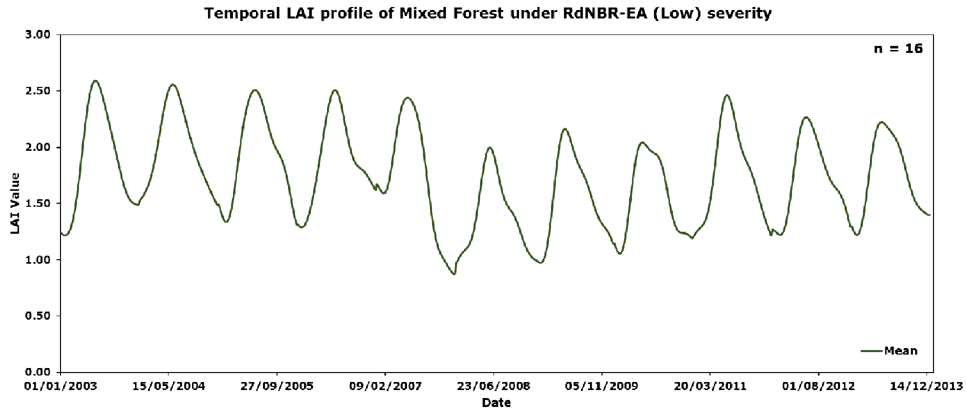
Temporal LAI profile of Mixed Forest under RdNBR-EA (Moderate) severity
n = 40
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LAI Value
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

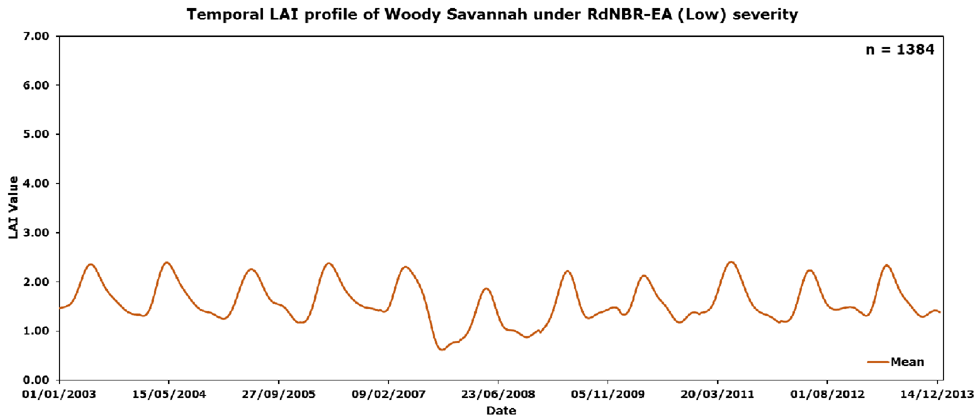


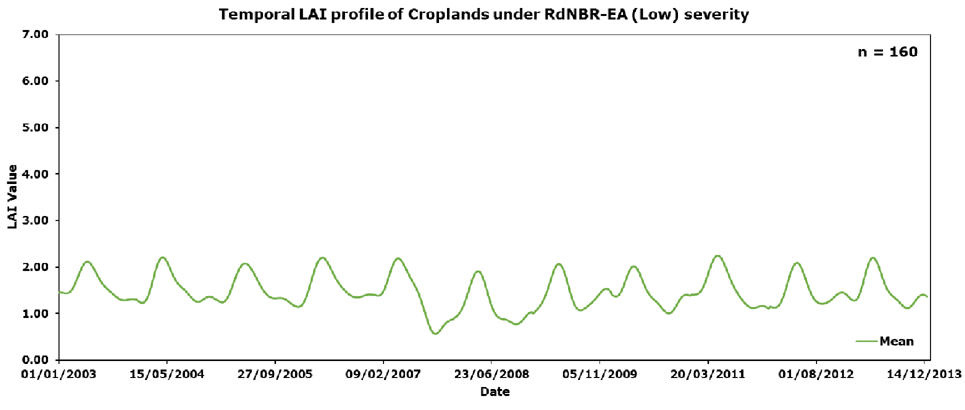
Temporal LAI profile of Woody Savannah under RdNBR-EA (Moderate) severity
n = 832
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LAI Value
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date



Temporal LAI profile of Cropland/Natural Vegetation Mosaic under RdNBR-EA (Moderate) severity
n = 32
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
LAI Value
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date


Temporal LAI profile of Mixed Forest under RdNBR-EA (Low) severity
n = 16
LAI Value
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

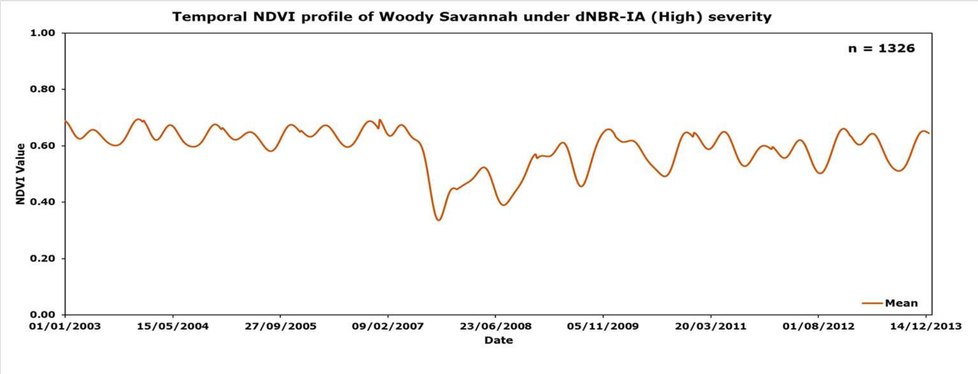

Temporal LAI profile of Woody Savannah under RdNBR-EA (Low) severity
n = 1384
LAI Value
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

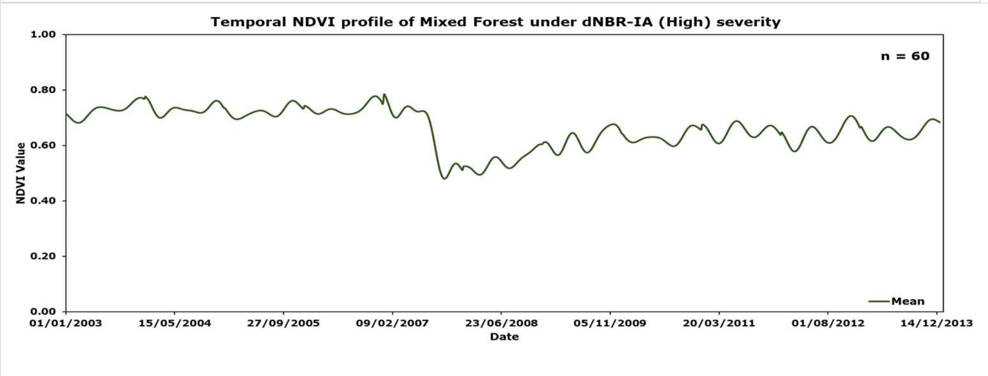

Temporal LAI profile of Croplands under RdNBR-EA (Low) severity
n = 160
LAI Value
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

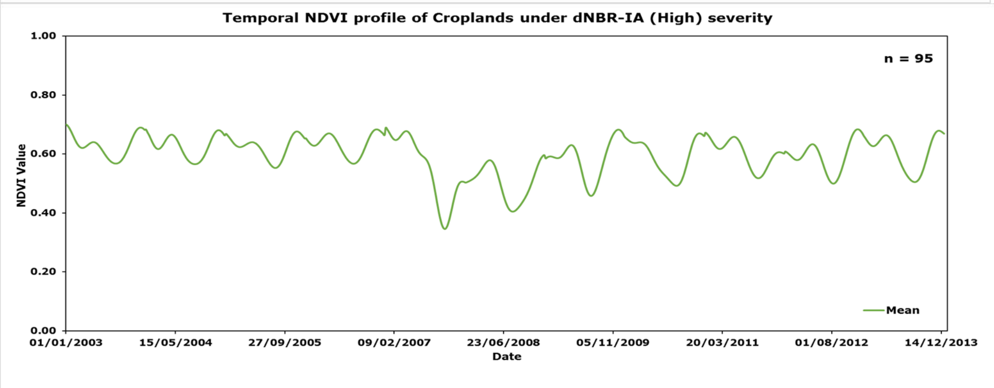
Appendix -B: Time series of NDVI (mean) profile

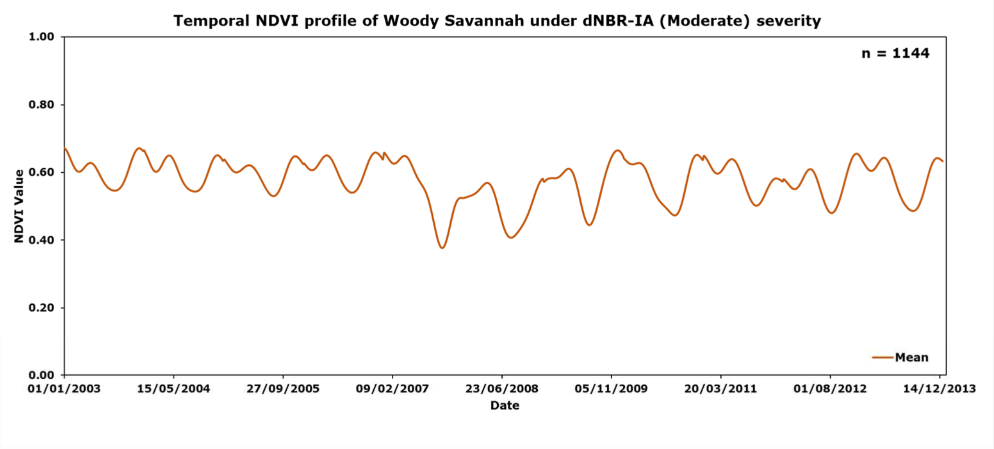
Graphics show in this appendix, sequentially are:

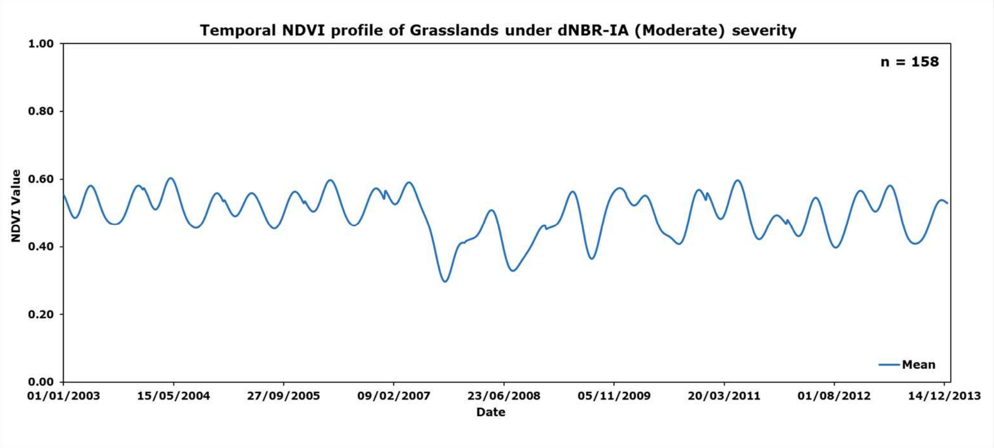
- dNBR-IA and dNBR-EA in high severity, moderate, and low class
- RdNBR-IA and RdNBR-EA in high severity, moderate, and low class
- All in top three land cover, except for RdNBR-EA in high severity class

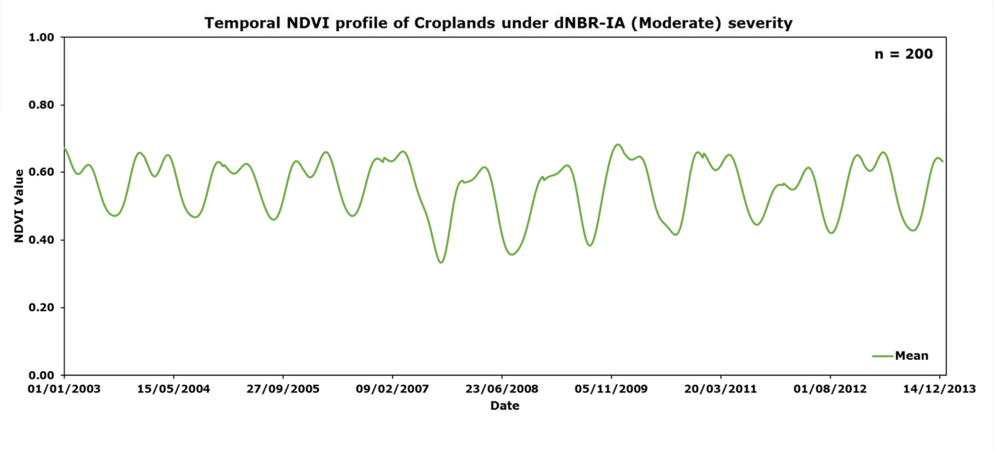


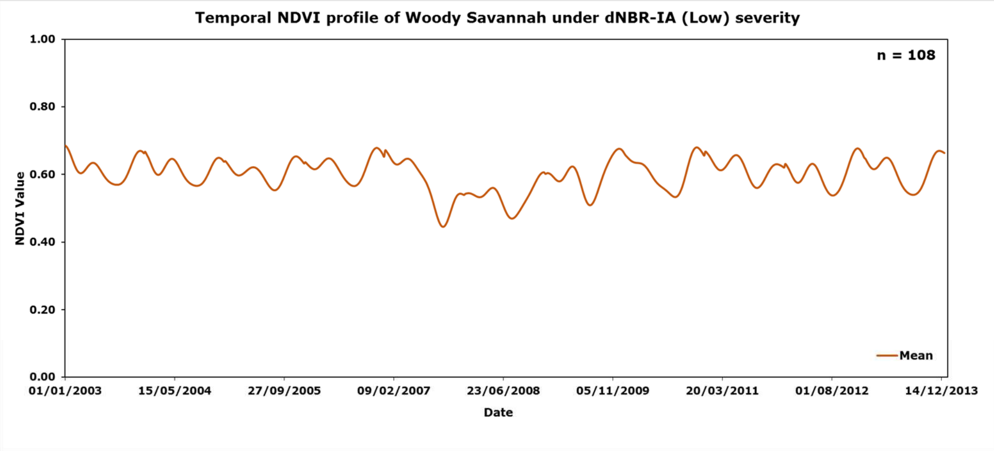


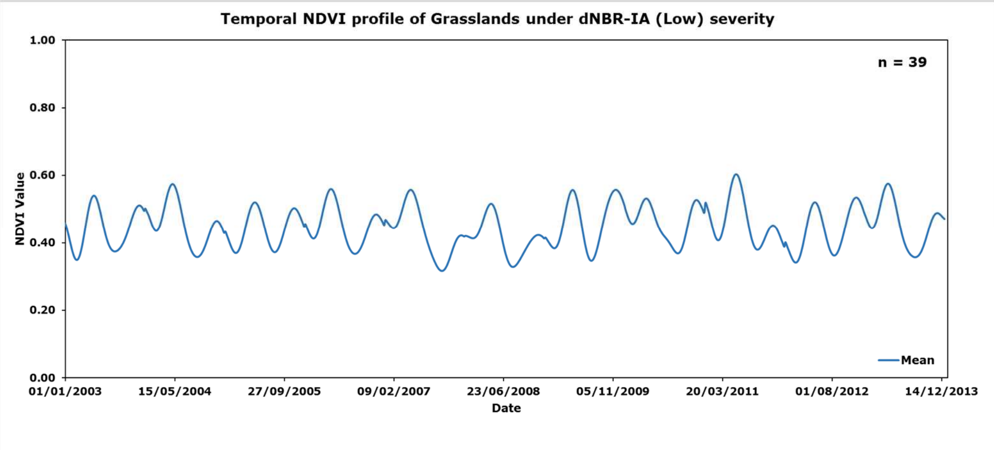


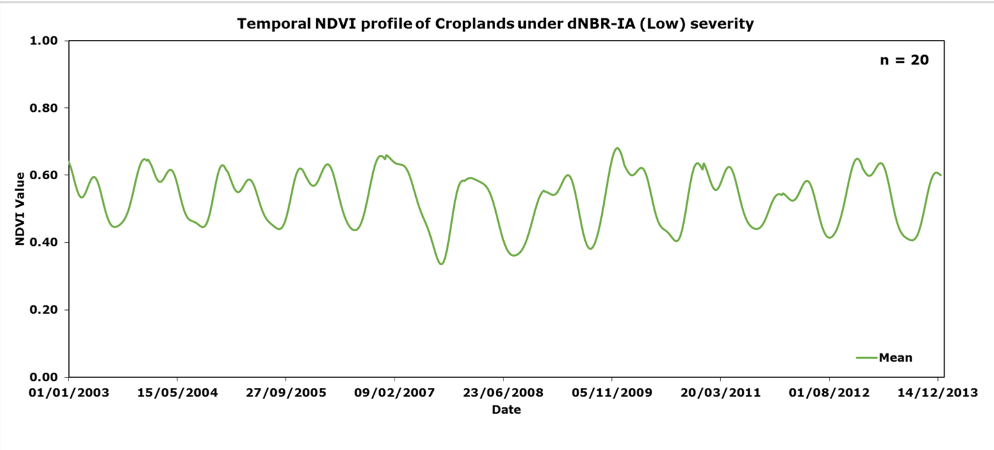

Temporal NDVI profile of Woody Savannah under dNBR-IA (Moderate) severity
n = 1144
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

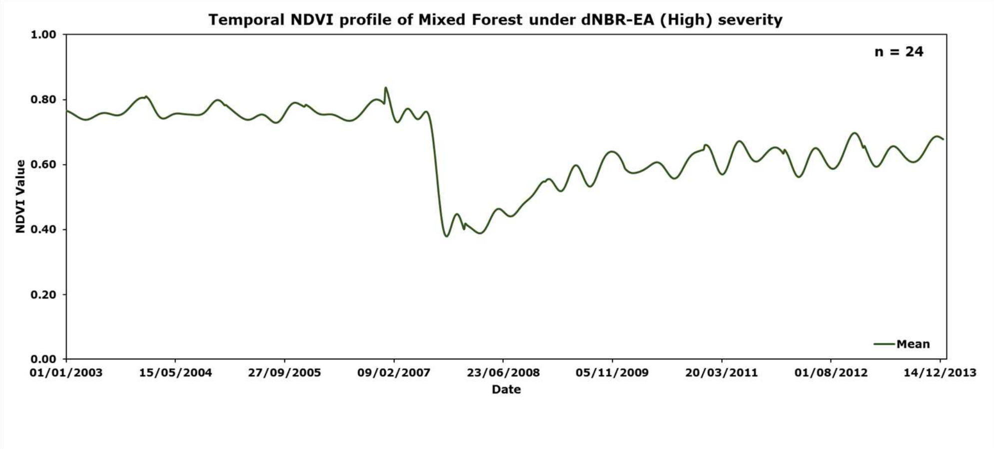

Temporal NDVI profile of Grasslands under dNBR-IA (Moderate) severity
n = 158
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

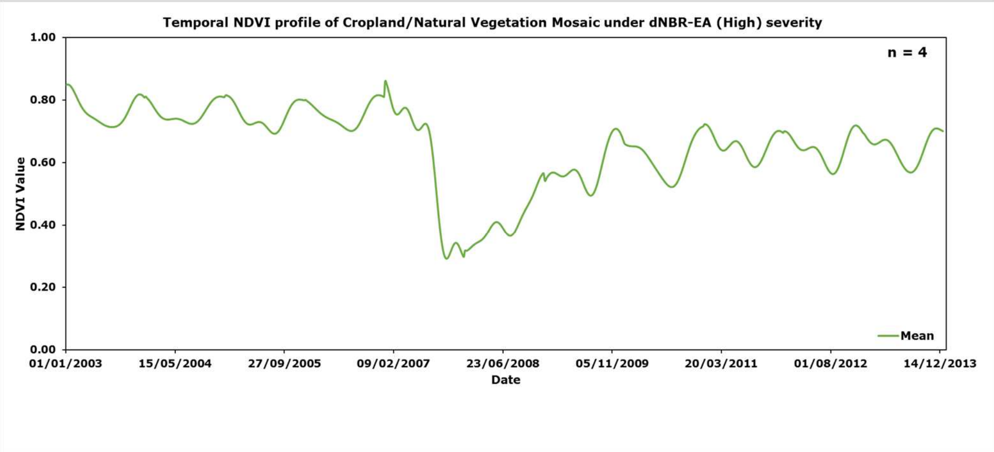

Temporal NDVI profile of Croplands under dNBR-IA (Moderate) severity
n = 200
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

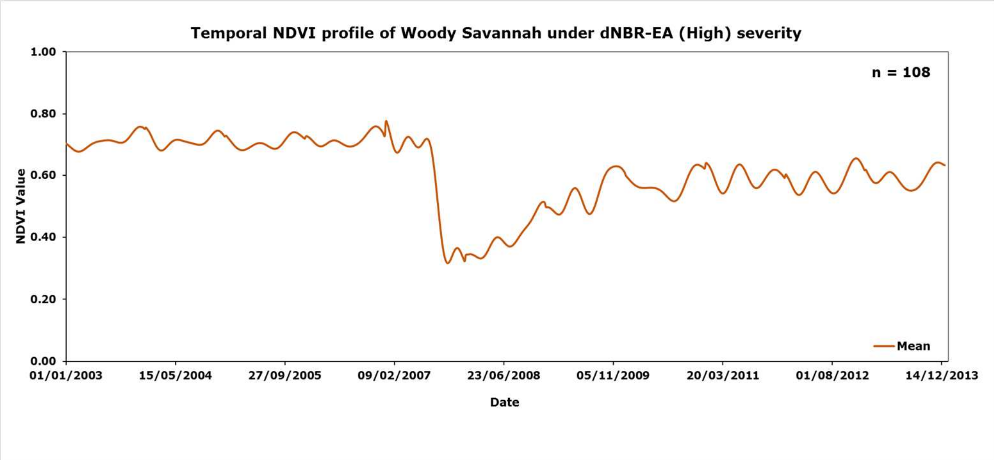

Temporal NDVI profile of Woody Savannah under dNBR-IA (Low) severity
n = 108
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

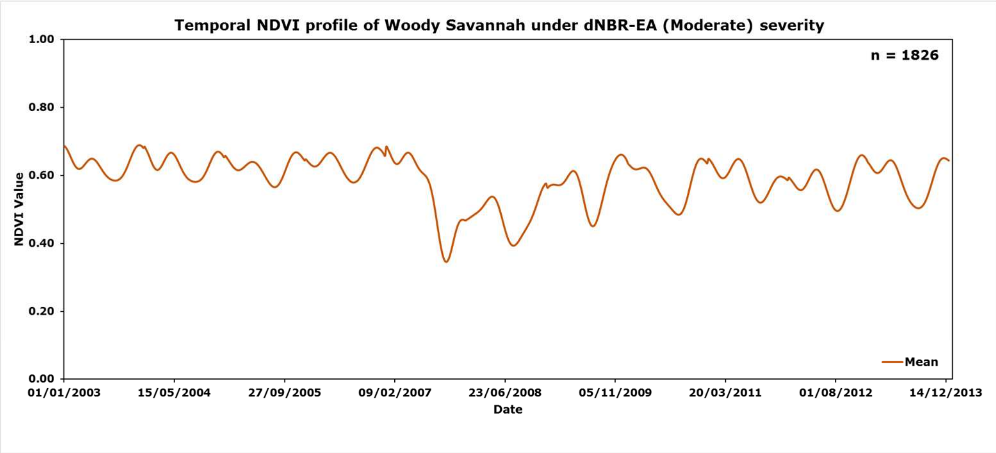

Temporal NDVI profile of Grasslands under dNBR-IA (Low) severity
n = 39
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

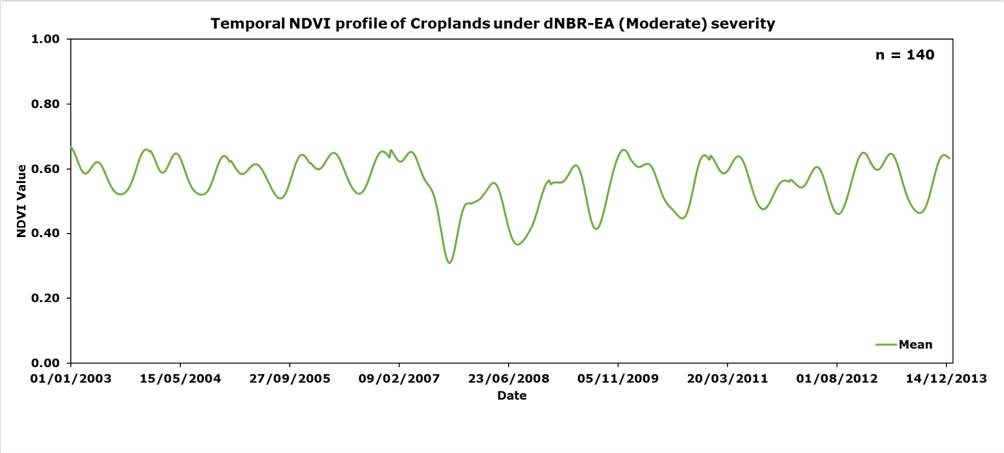

Temporal NDVI profile of Croplands under dNBR-IA (Low) severity
n = 20
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

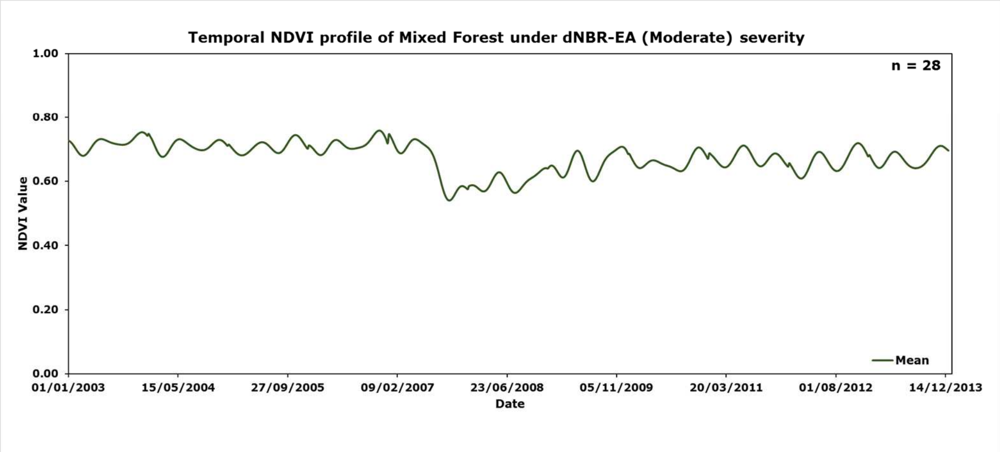

Temporal NDVI profile of Mixed Forest under dNBR-EA (High) severity
n = 24
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

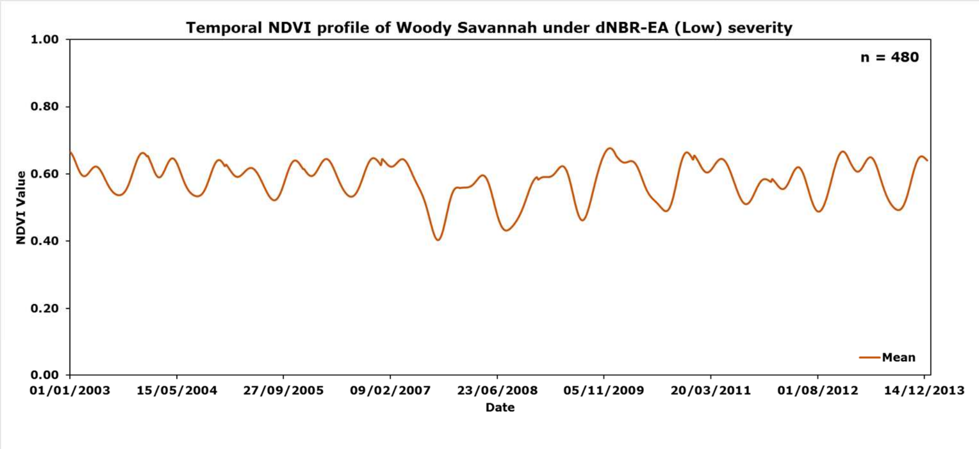

Temporal NDVI profile of Cropland/Natural Vegetation Mosaic under dNBR-EA (High) severity
n = 4
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

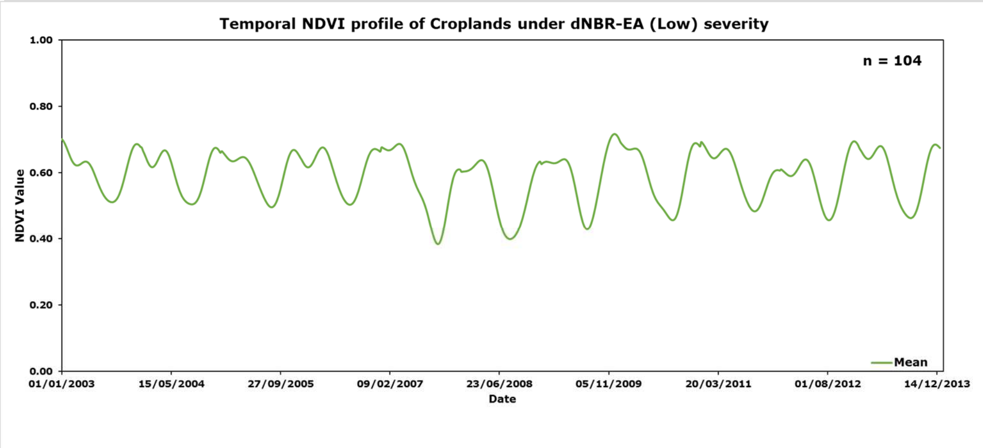

Temporal NDVI profile of Woody Savannah under dNBR-EA (High) severity
n = 108
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

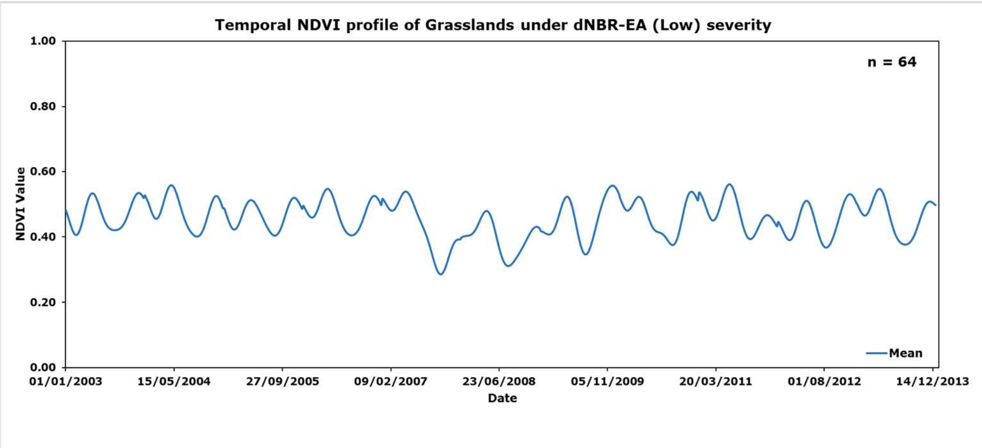

Temporal NDVI profile of Woody Savannah under dNBR-EA (Moderate) severity
n = 1826
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

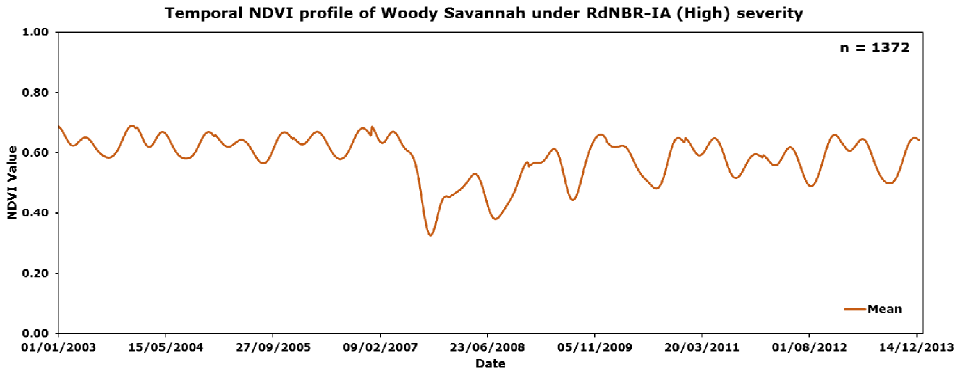

Temporal NDVI profile of Croplands under dNBR-EA (Moderate) severity
n = 140
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

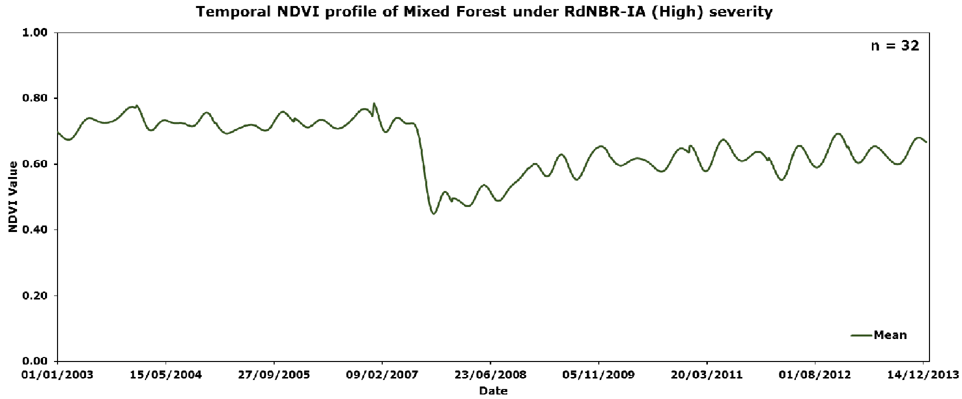

Temporal NDVI profile of Mixed Forest under dNBR-EA (Moderate) severity
n = 28
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

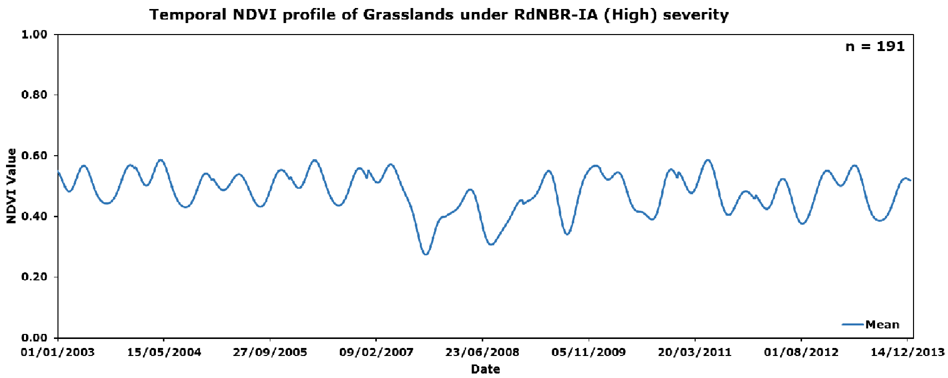

Temporal NDVI profile of Woody Savannah under dNBR-EA (Low) severity
n = 480
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

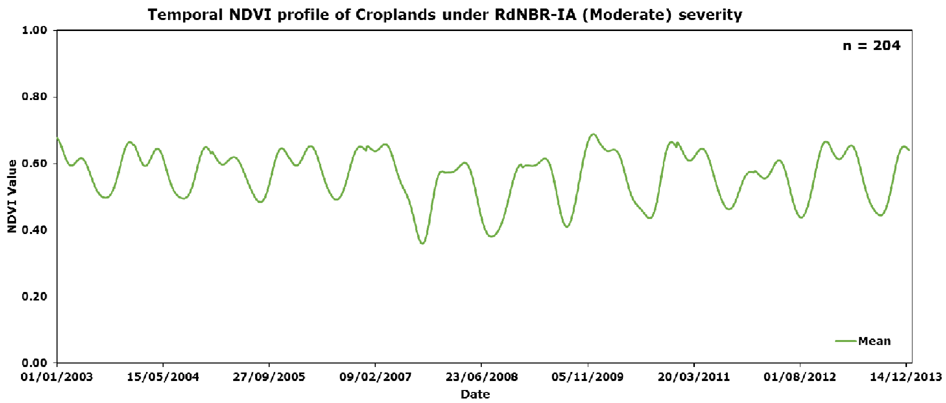

Temporal NDVI profile of Croplands under dNBR-EA (Low) severity
n = 104
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean


Temporal NDVI profile of Grasslands under dNBR-EA (Low) severity
n = 64
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

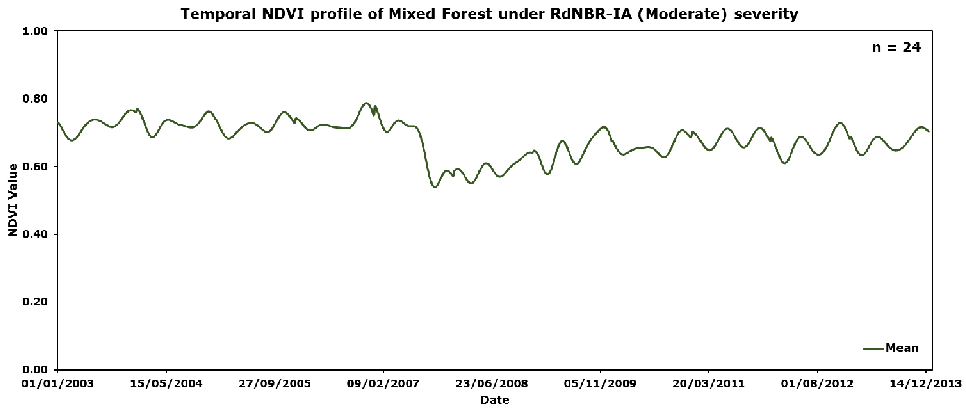

Temporal NDVI profile of Woody Savannah under RdNBR-IA (High) severity
n = 1372
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean


Temporal NDVI profile of Mixed Forest under RdNBR-IA (High) severity
n = 32
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

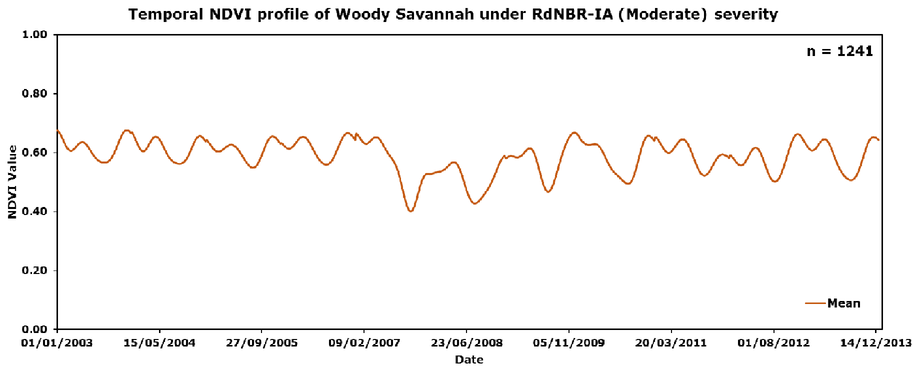

Temporal NDVI profile of Grasslands under RdNBR-IA (High) severity
n = 191
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean



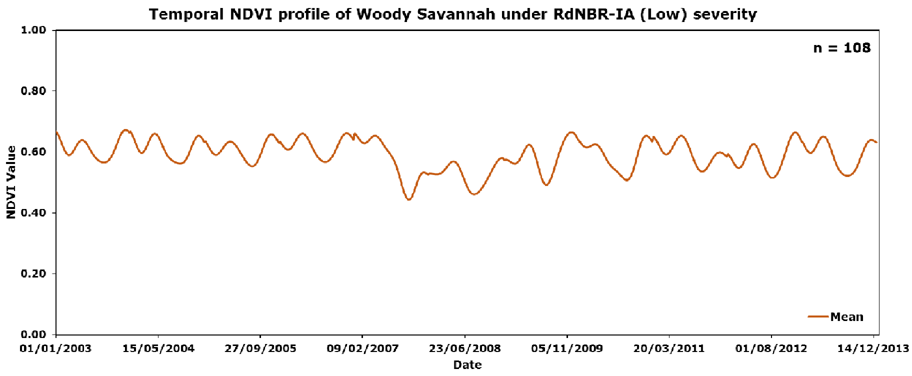
Temporal NDVI profile of Croplands under RdNBR-IA (Moderate) severity
n = 204
NDVI Value
Mean
Date

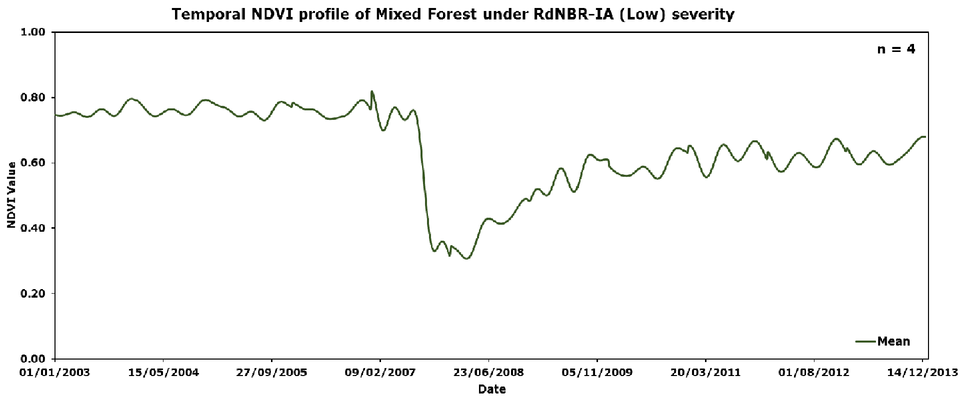


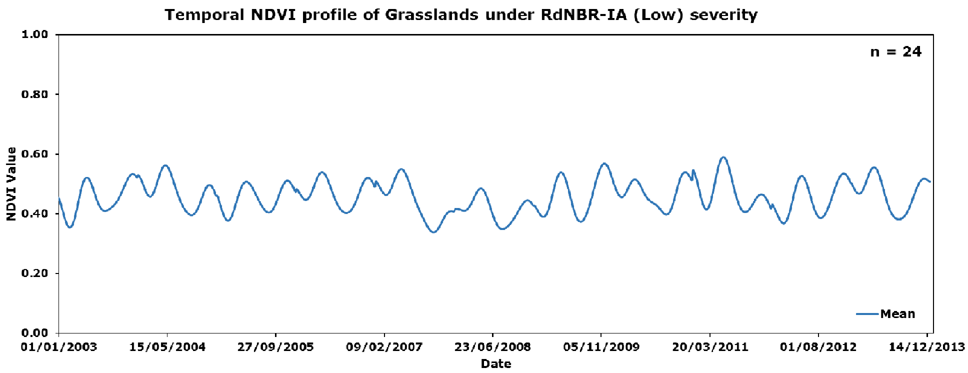
Temporal NDVI profile of Mixed Forest under RdNBR-IA (Moderate) severity
n = 24
NDVI Value
Mean
Date

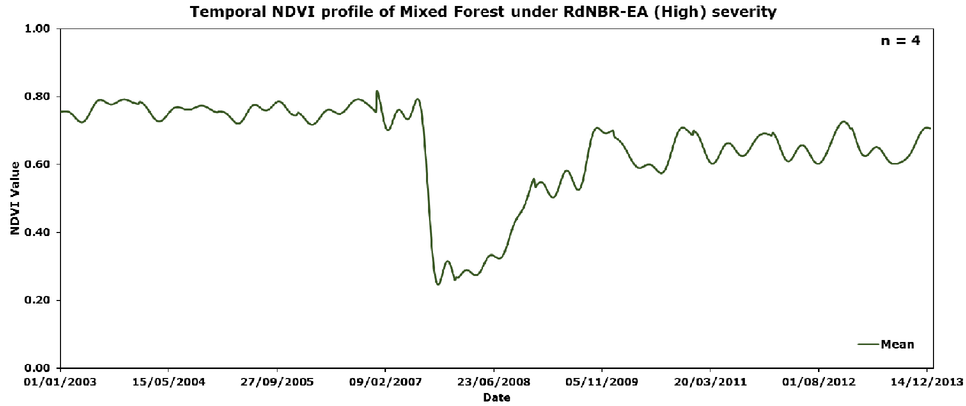


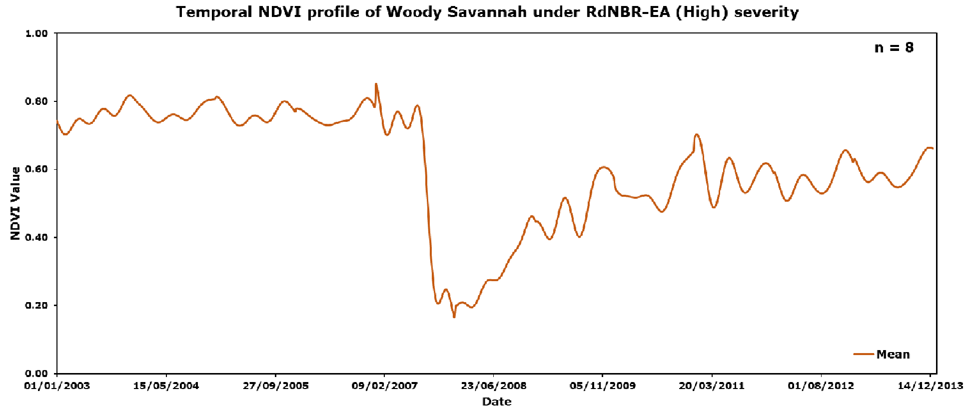
Temporal NDVI profile of Woody Savannah under RdNBR-IA (Moderate) severity
n = 1241
NDVI Value
Mean
Date

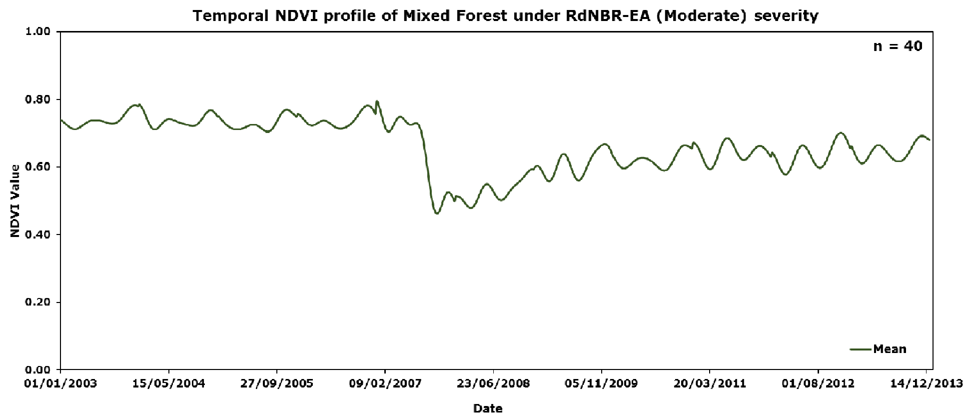

Temporal NDVI profile of Woody Savannah under RdNBR-IA (Low) severity
n = 108
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

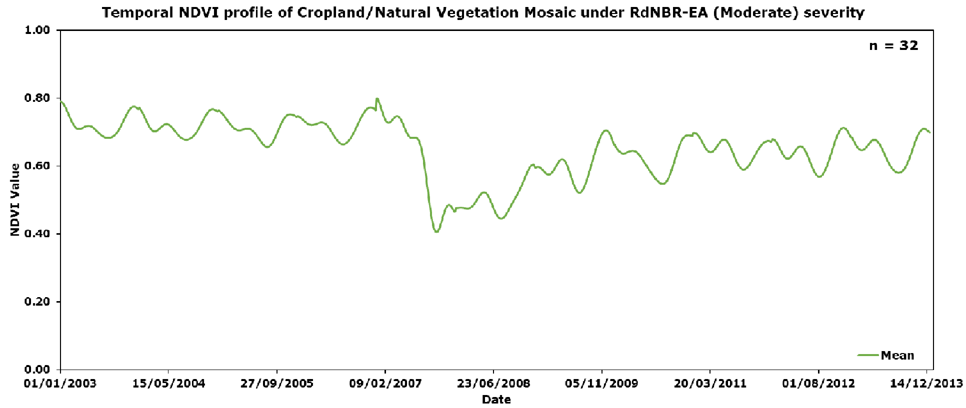

Temporal NDVI profile of Mixed Forest under RdNBR-IA (Low) severity
n = 4
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

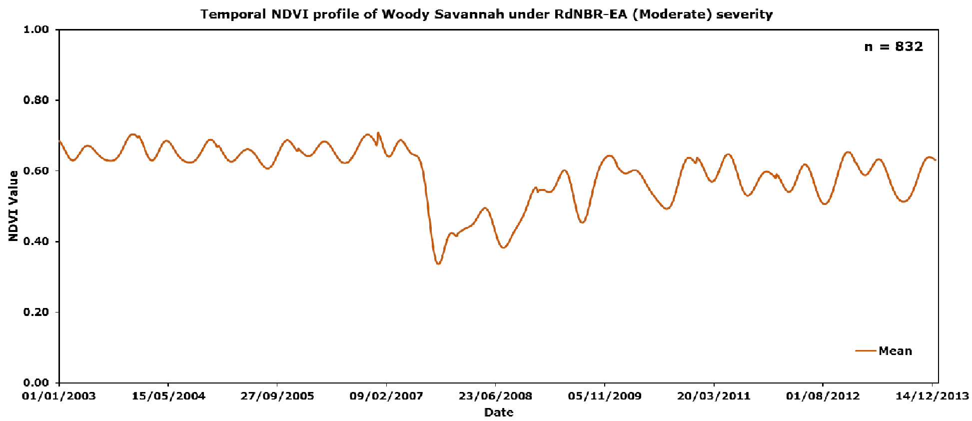

Temporal NDVI profile of Grasslands under RdNBR-IA (Low) severity
n = 24
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

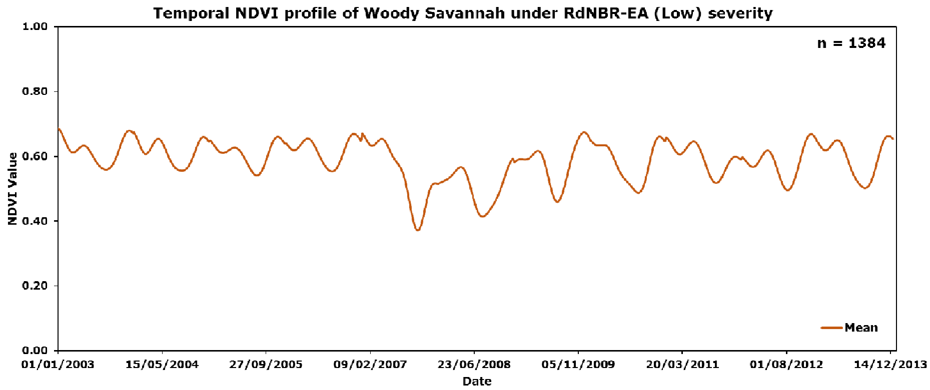

Temporal NDVI profile of Mixed Forest under RdNBR-EA (High) severity
n = 4
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean


Temporal NDVI profile of Woody Savannah under RdNBR-EA (High) severity
n = 8
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean

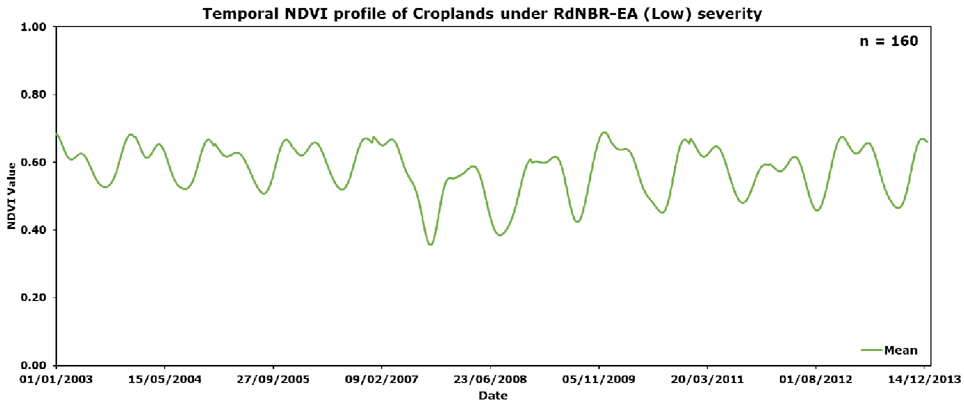

Temporal NDVI profile of Mixed Forest under RdNBR-EA (Moderate) severity
n = 40
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date
Mean


Temporal NDVI profile of Cropland/Natural Vegetation Mosaic under RdNBR-EA (Moderate) severity
n = 32
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

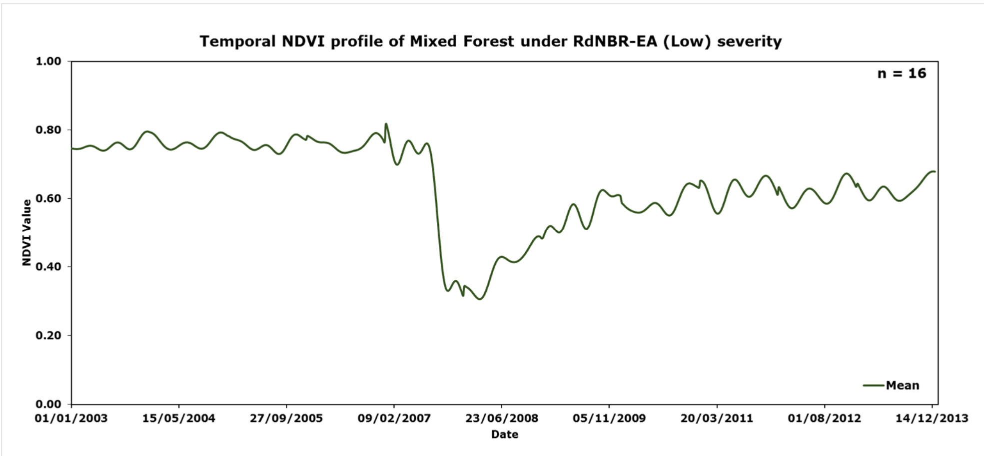

Temporal NDVI profile of Woody Savannah under RdNBR-EA (Moderate) severity
n = 832
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date



Temporal NDVI profile of Woody Savannah under RdNBR-EA (Low) severity
n = 1384
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date



Temporal NDVI profile of Croplands under RdNBR-EA (Low) severity
n = 160
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

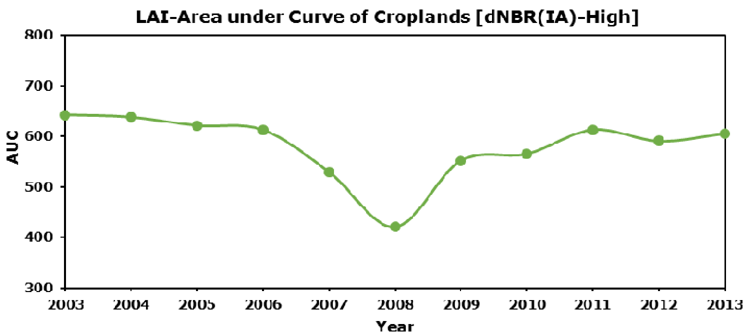


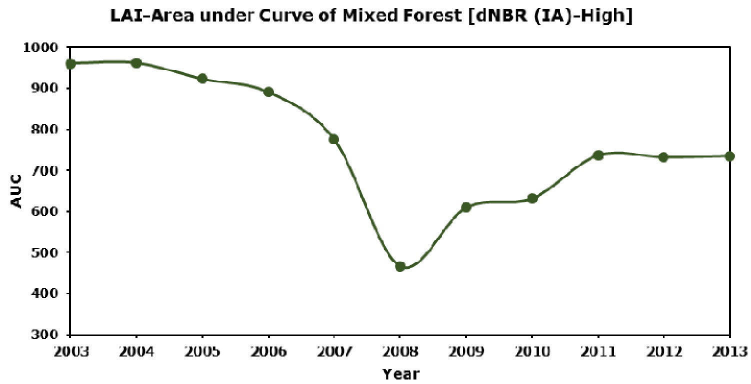
Temporal NDVI profile of Mixed Forest under RdNBR-EA (Low) severity
n = 16
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
Mean
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

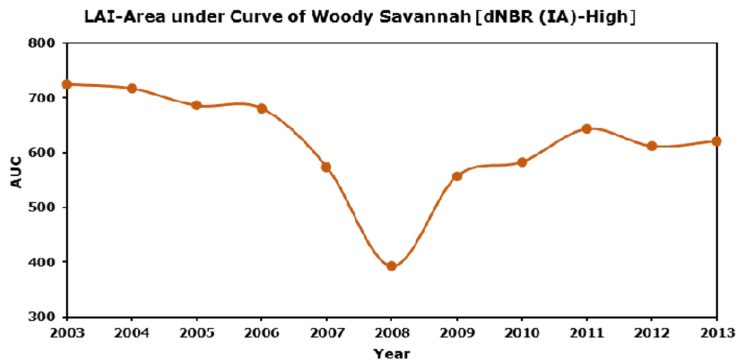
Appendix-C: AUC-LAI profiles

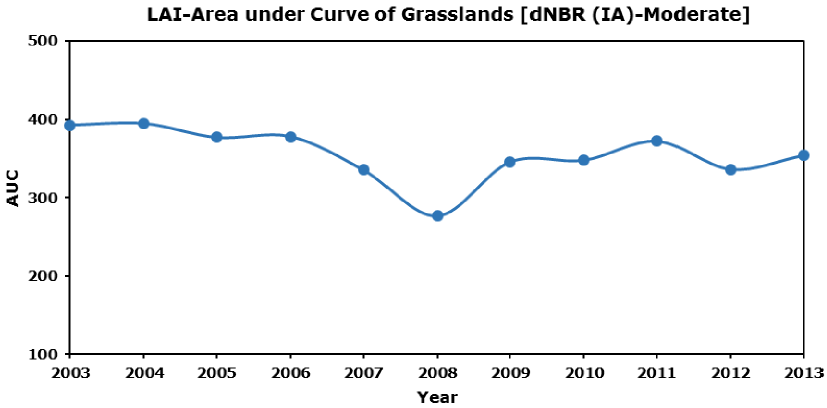
Graphics show in this appendix, sequentially are:

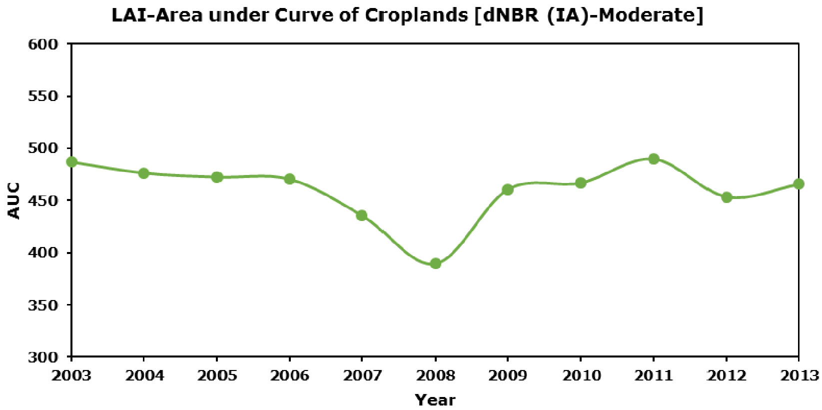
- dNBR-IA and dNBR-EA in high severity, moderate, and low class
- RdNBR-IA and RdNBR-EA in high severity, moderate, and low class
- All in top three land cover, except for RdNBR-EA in high severity class

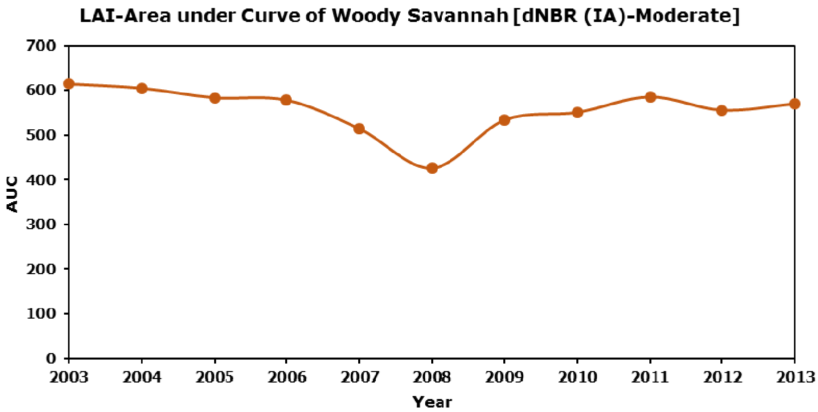


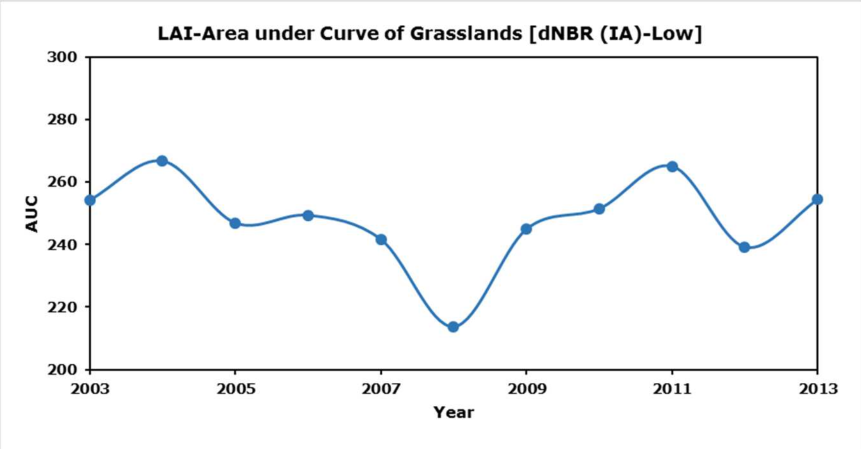


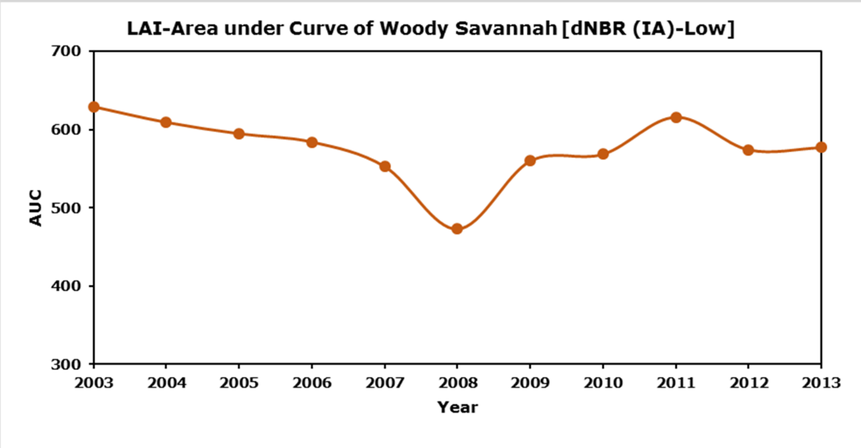


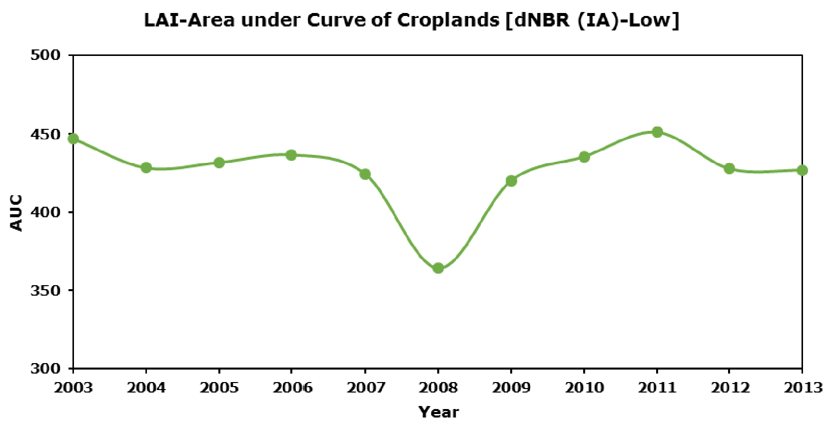

LAI-Area under Curve of Grasslands [dNBR (IA)-Moderate]
AUC
100
200
300
400
500
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

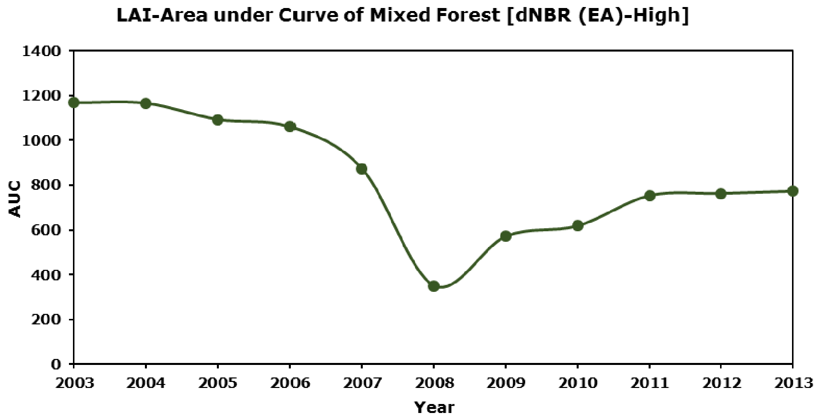

LAI-Area under Curve of Croplands [dNBR (IA)-Moderate]
AUC
300
350
400
450
500
550
600
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

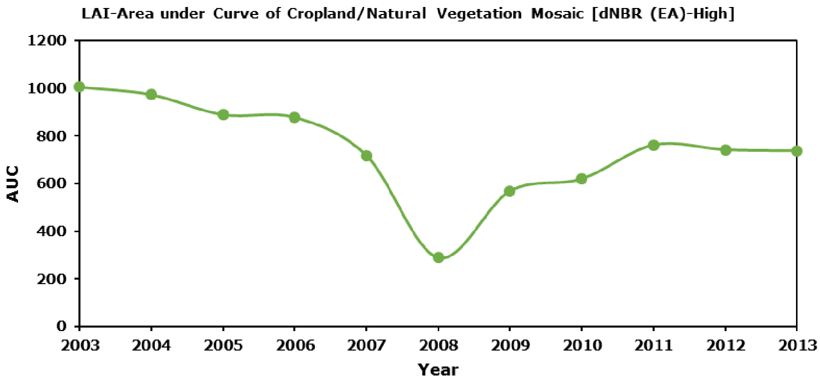

LAI-Area under Curve of Woody Savannah [dNBR (IA)-Moderate]
AUC
0
100
200
300
400
500
600
700
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

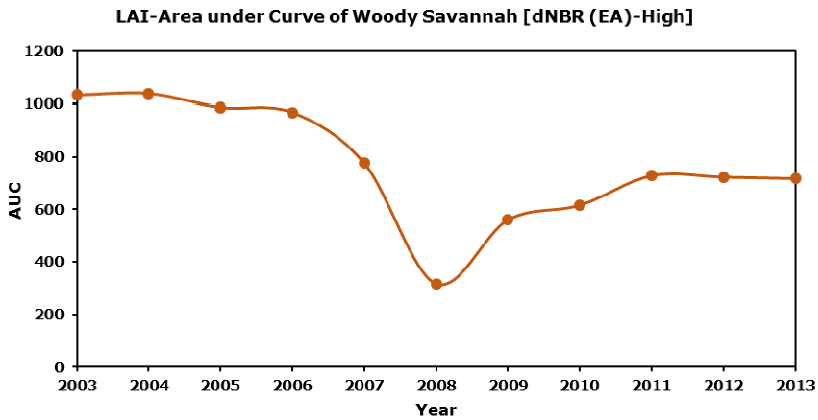

LAI-Area under Curve of Grasslands [dNBR (IA)-Low]
AUC
300
280
260
240
220
200
2003
2005
2007
2009
2011
2013
Year

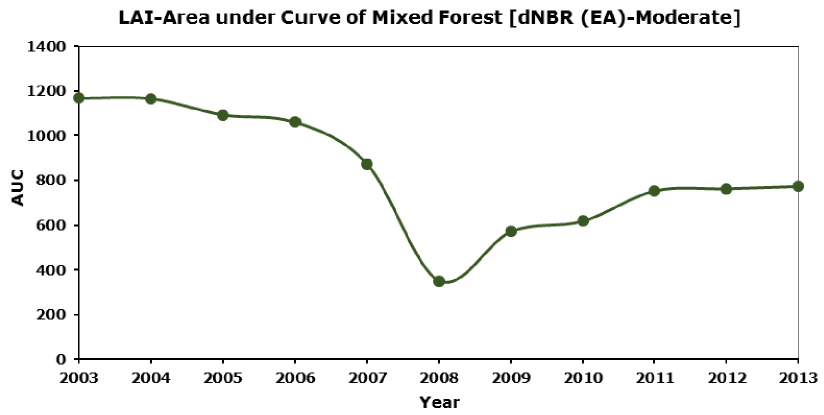

LAI-Area under Curve of Woody Savannah [dNBR (IA)-Low]
AUC
700
600
500
400
300
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

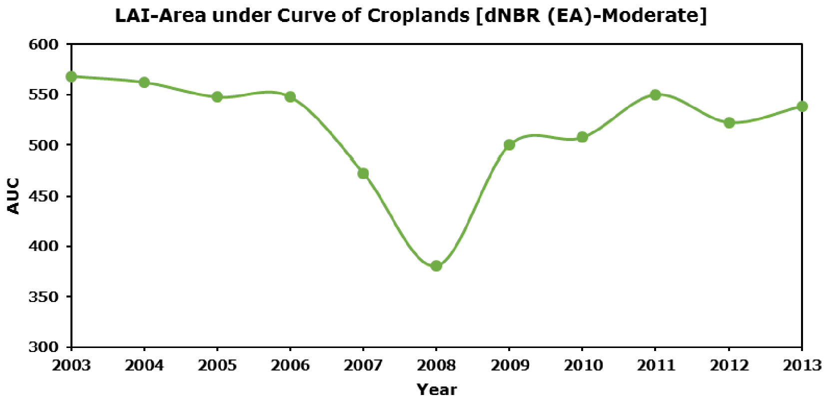

LAI-Area under Curve of Croplands [dNBR (IA)-Low]
AUC
500
450
400
350
300
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

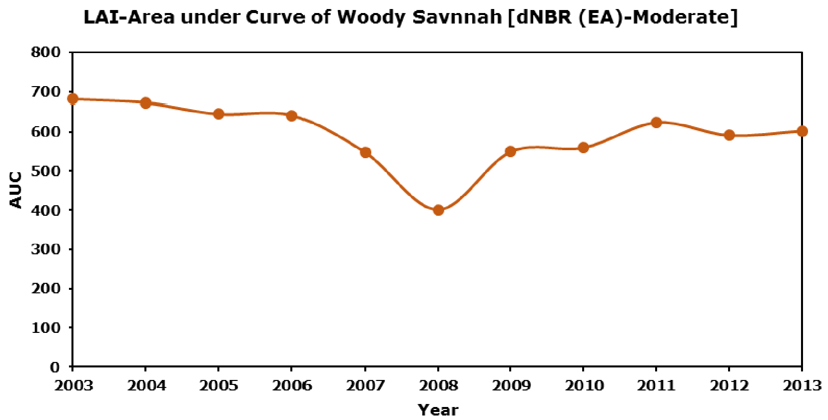

LAI-Area under Curve of Mixed Forest [dNBR (EA)-High]
AUC
Year
0
200
400
600
800
1000
1200
1400
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013


LAI-Area under Curve of Cropland/Natural Vegetation Mosaic [dNBR (EA)-High]
AUC
Year
0
200
400
600
800
1000
1200
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

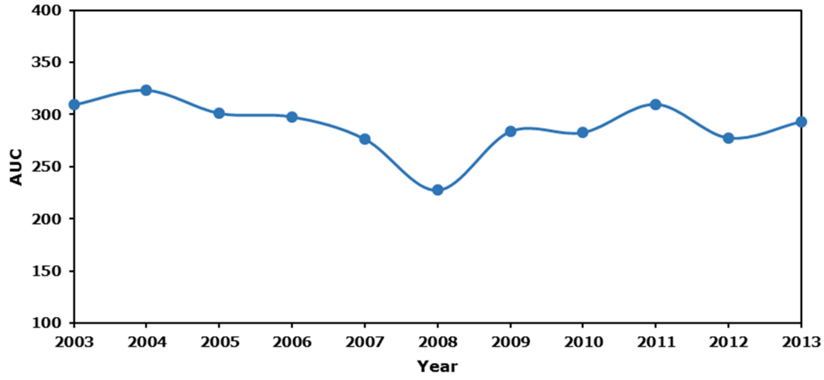

LAI-Area under Curve of Woody Savannah [dNBR (EA)-High]
AUC
Year
0
200
400
600
800
1000
1200
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013


LAI-Area under Curve of Mixed Forest [dNBR (EA)-Moderate]
1400
1200
1000
800
600
400
200
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

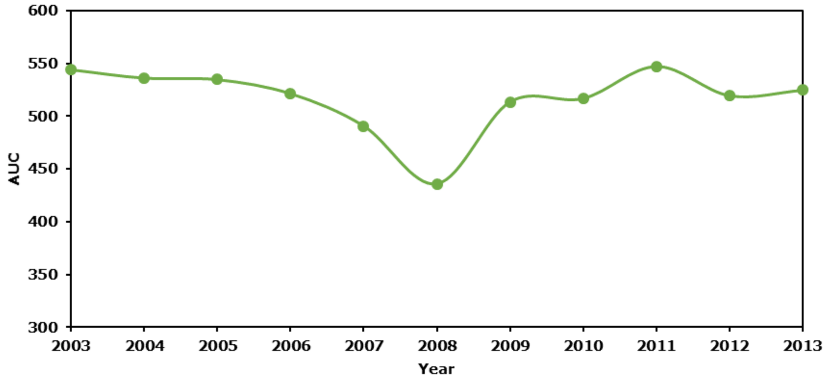

LAI-Area under Curve of Croplands [dNBR (EA)-Moderate]
600
550
500
450
400
350
300
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


LAI-Area under Curve of Woody Savnnah [dNBR (EA)-Moderate]
800
700
600
500
400
300
200
100
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

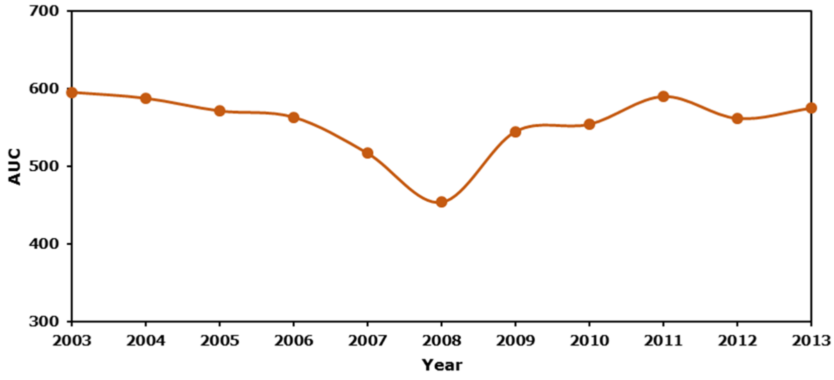
LAI-Area under Curve of Grasslands [dNBR (EA)-Low]

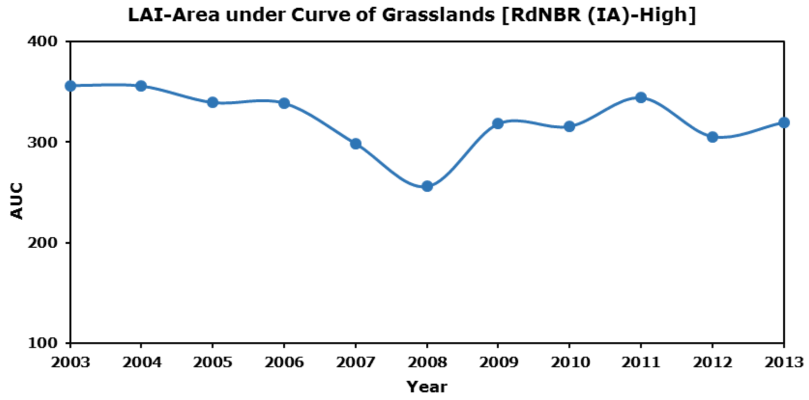


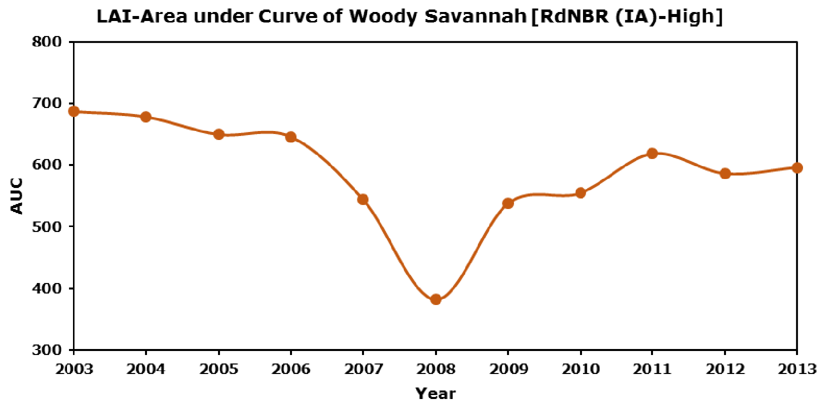
LAI-Area under Curve of Croplands [dNBR (EA)-Low]

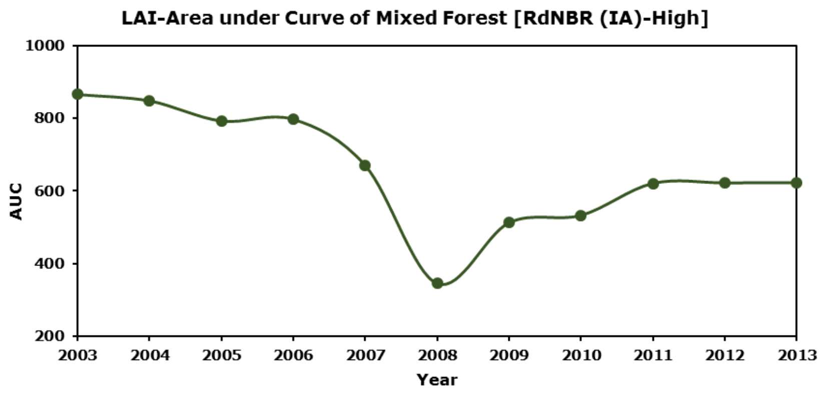


LAI-Area under Curve of Woody Savannah [dNBR (EA)-Low]

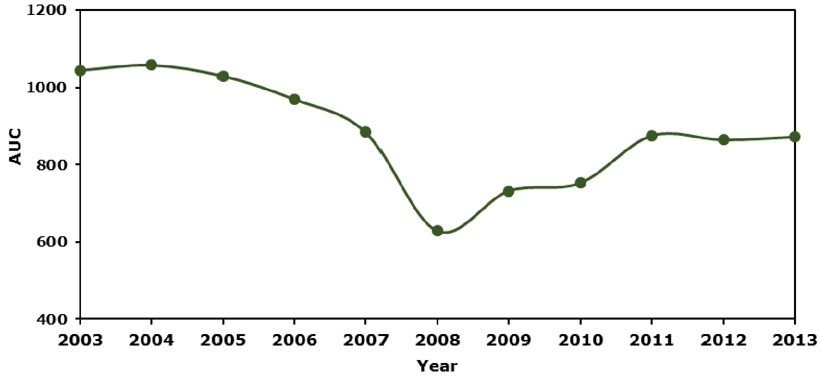



LAI-Area under Curve of Grasslands [RdNBR (IA)-High]
400
300
200
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

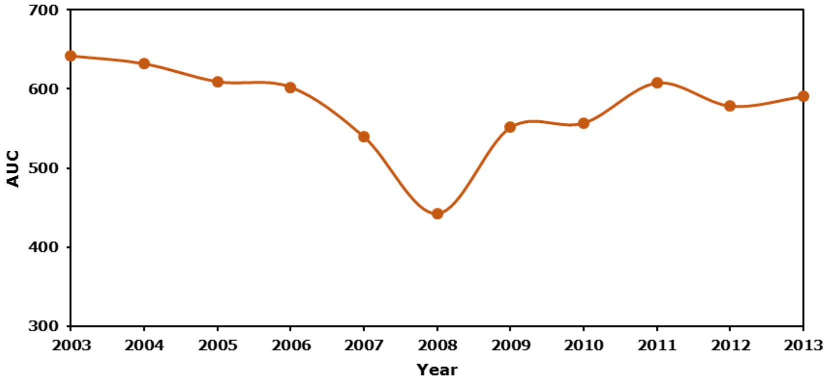

LAI-Area under Curve of Woody Savannah [RdNBR (IA)-High]
800
700
600
500
400
300
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


LAI-Area under Curve of Mixed Forest [RdNBR (IA)-High]
1000
800
600
400
200
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

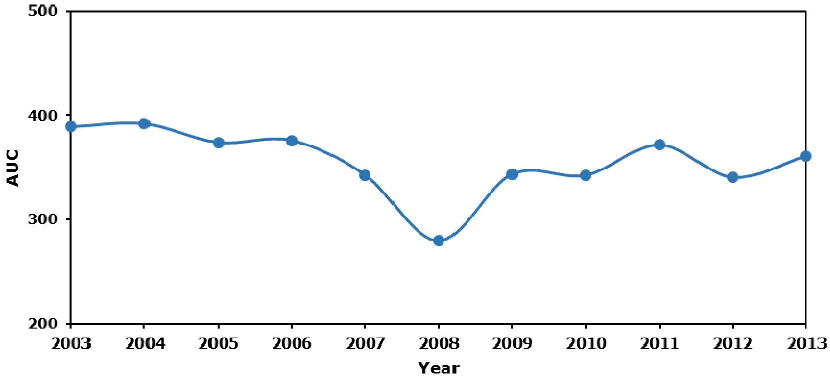
LAI-Area under Curve of Mixed Forest [RdNBR (IA)-Moderate]

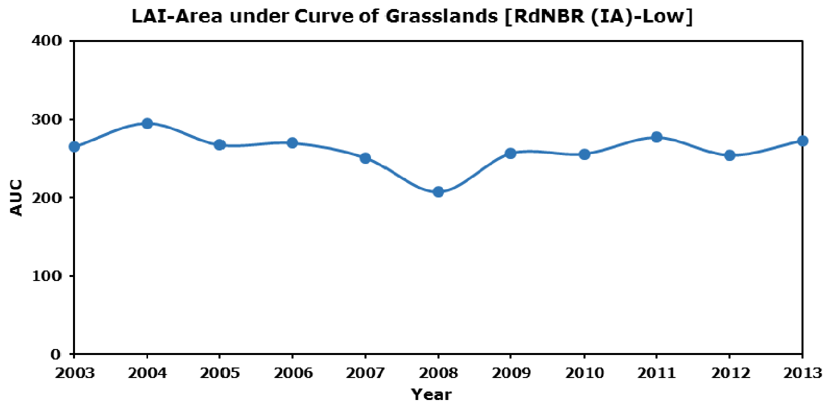


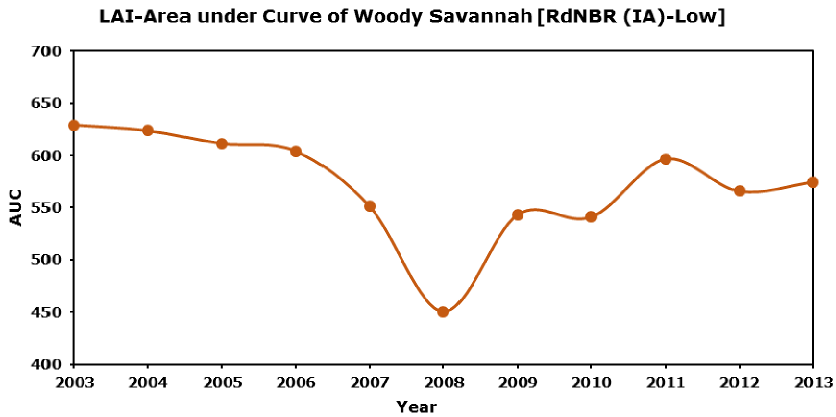
Area under Curve of Woody Savannah [RdNBR (IA)-Moderate]

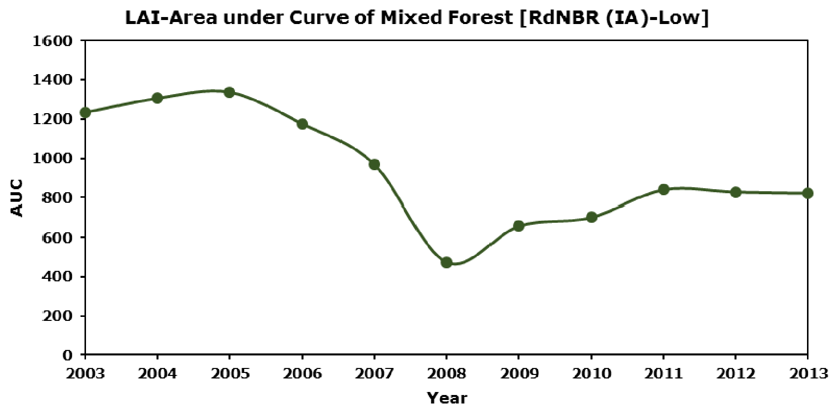


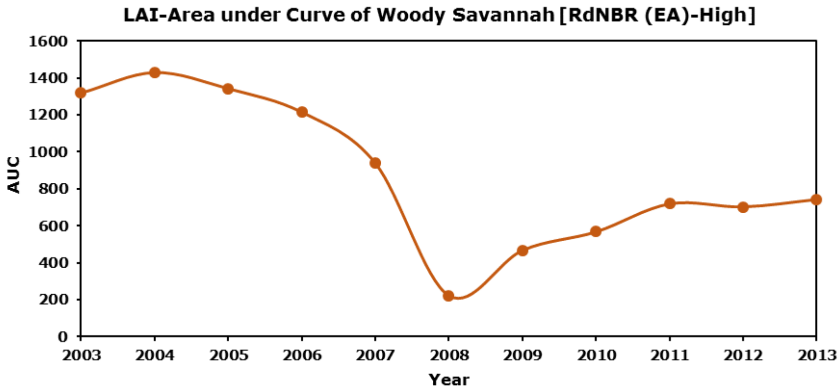
LAI-Area under Curve of Grasslands [RdNBR (IA)-Moderate]

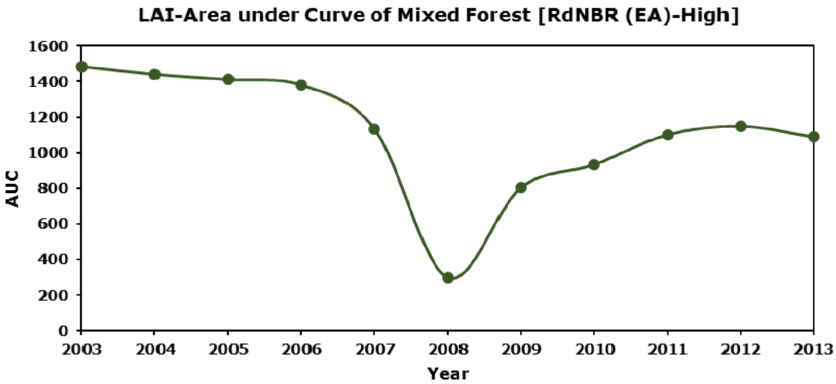


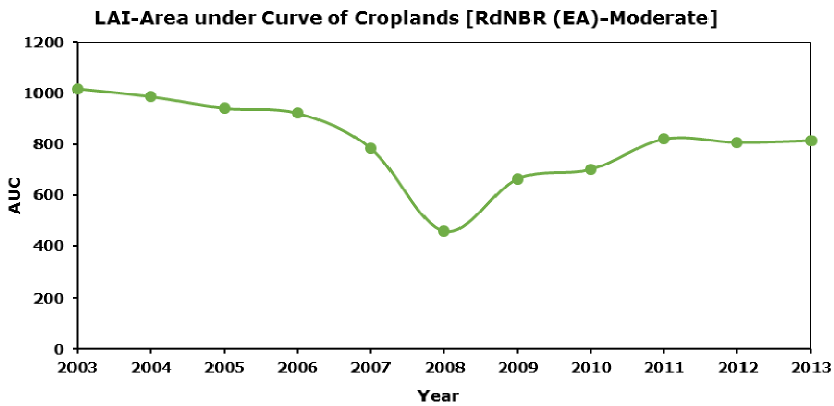

LAI-Area under Curve of Grasslands [RdNBR (IA)-Low]
400
300
200
100
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

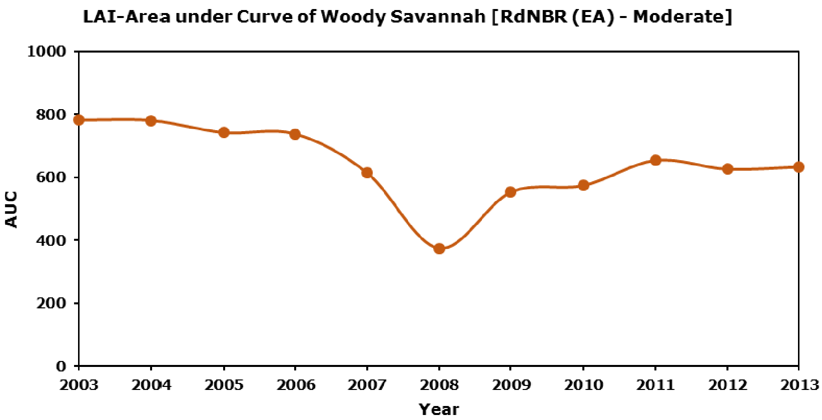

LAI-Area under Curve of Woody Savannah [RdNBR (IA)-Low]
700
650
600
550
500
450
400
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

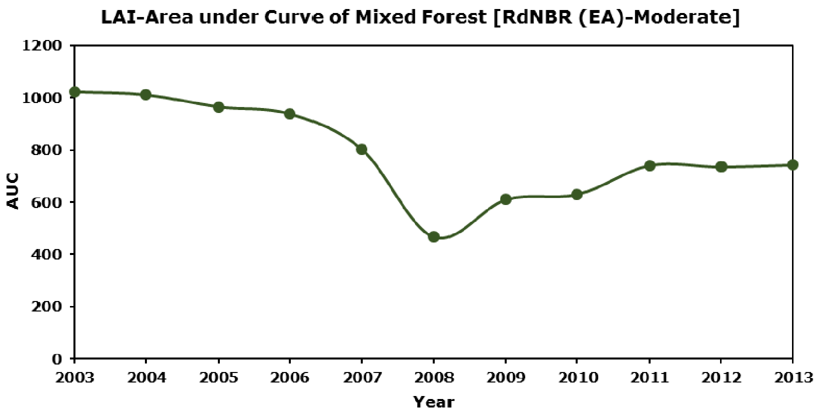

LAI-Area under Curve of Mixed Forest [RdNBR (IA)-Low]
1600
1400
1200
1000
800
600
400
200
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

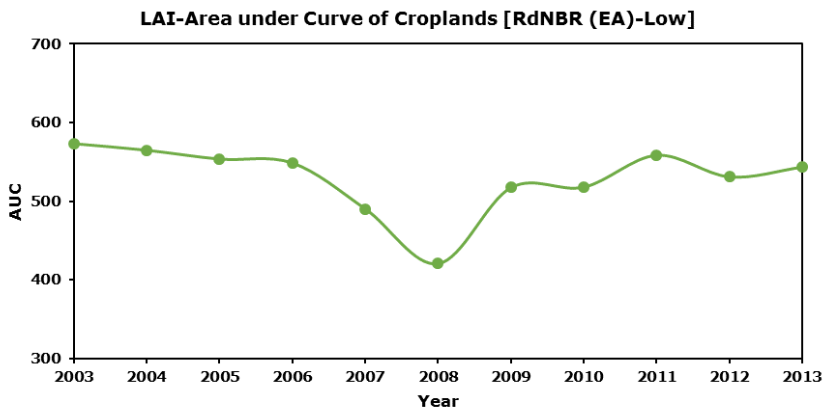

LAI-Area under Curve of Woody Savannah [RdNBR (EA)-High]
AUC
Year
1600
1400
1200
1000
800
600
400
200
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

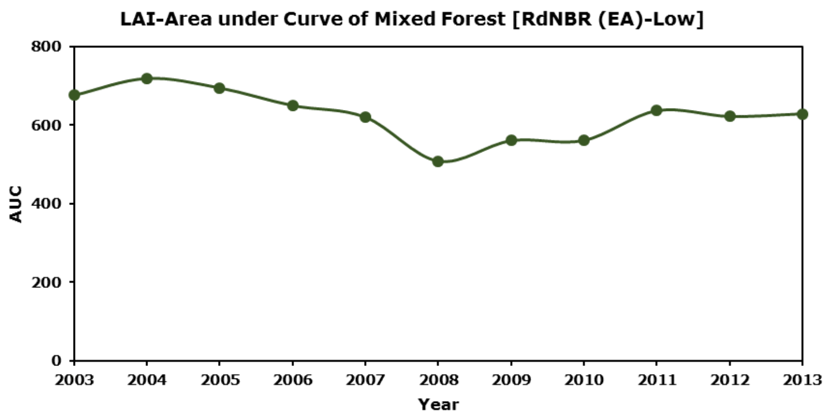

LAI-Area under Curve of Mixed Forest [RdNBR (EA)-High]
AUC
Year
1600
1400
1200
1000
800
600
400
200
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

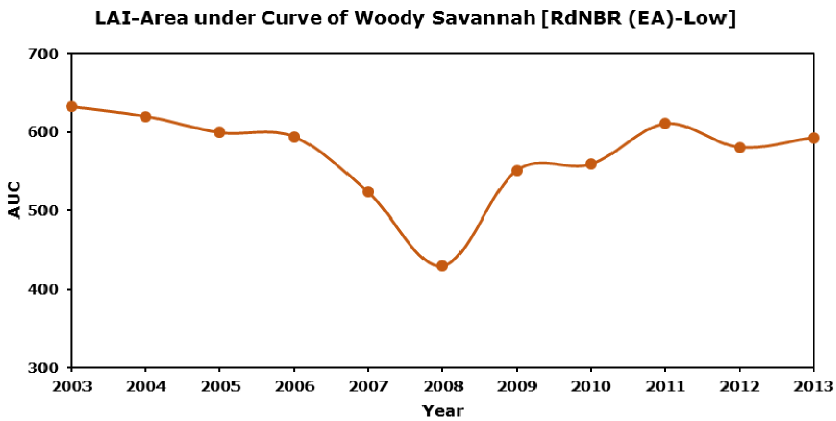

LAI-Area under Curve of Croplands [RdNBR (EA)-Moderate]
AUC
Year
1200
1000
800
600
400
200
0
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013


LAI-Area under Curve of Woody Savannah [RdNBR (EA) - Moderate]
1000
800
600
400
200
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


LAI-Area under Curve of Mixed Forest [RdNBR (EA)-Moderate]
1200
1000
800
600
400
200
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


LAI-Area under Curve of Croplands [RdNBR (EA)-Low]
700
600
500
400
300
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

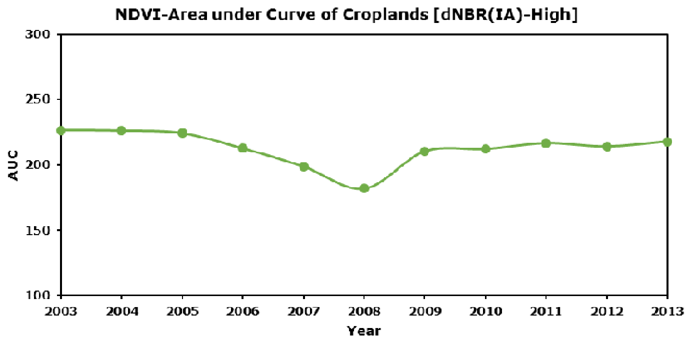

LAI-Area under Curve of Mixed Forest [RdNBR (EA)-Low]
800
600
400
200
0
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

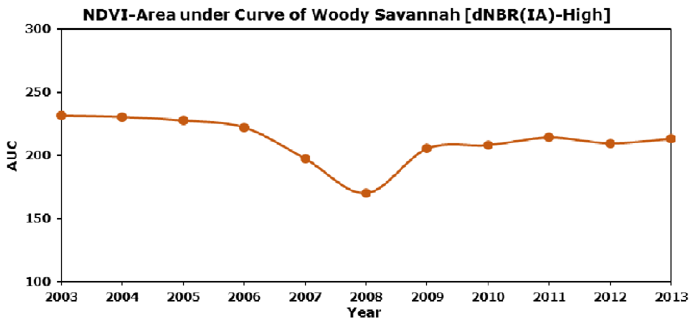

LAI-Area under Curve of Woody Savannah [RdNBR (EA)-Low]
700
600
500
400
300
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

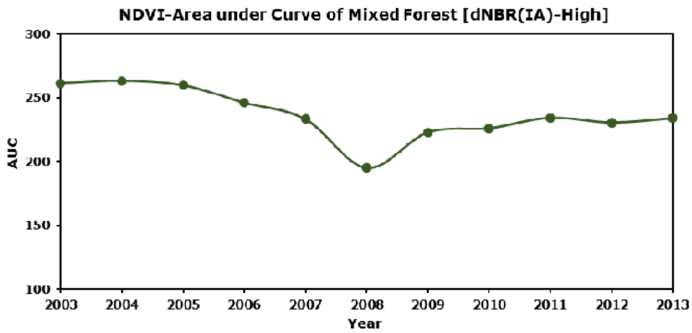
Appendix-D: AUC-NDVI profiles

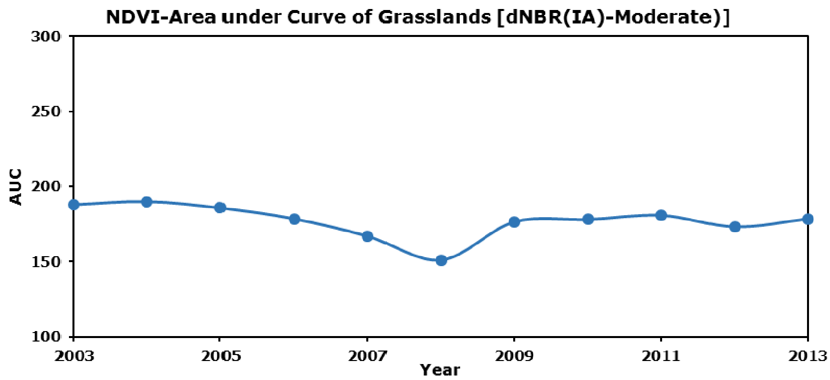
Graphics show in this appendix, sequentially are:

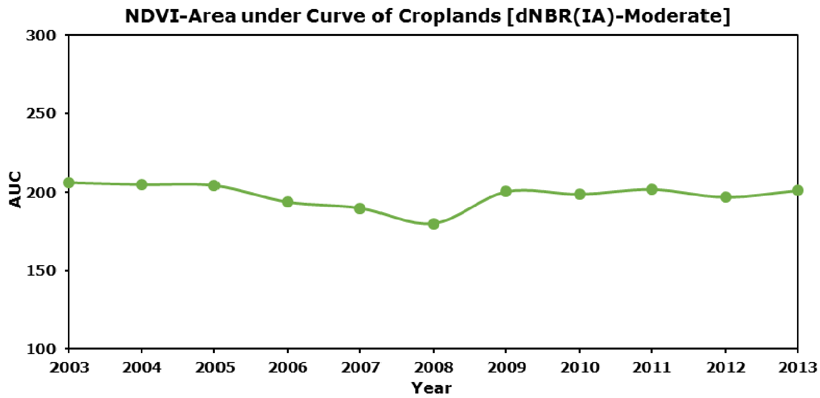
- dNBR-IA and dNBR-EA in high severity, moderate, and low class
- RdNBR-IA and RdNBR-EA in high severity, moderate, and low class
- All in top three land cover, except for RdNBR-EA in high severity class

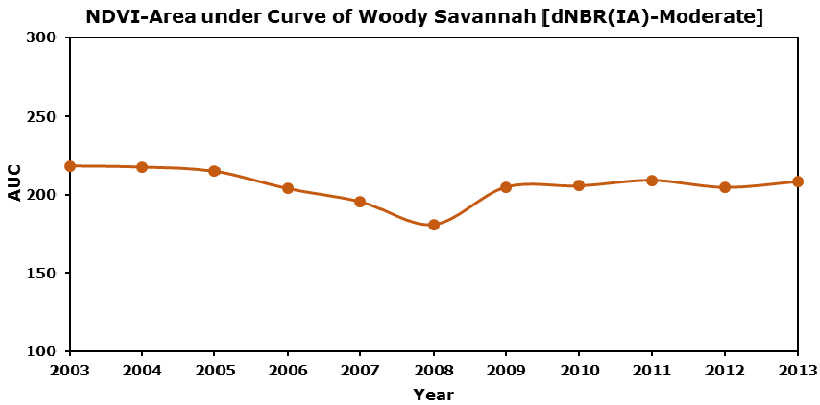


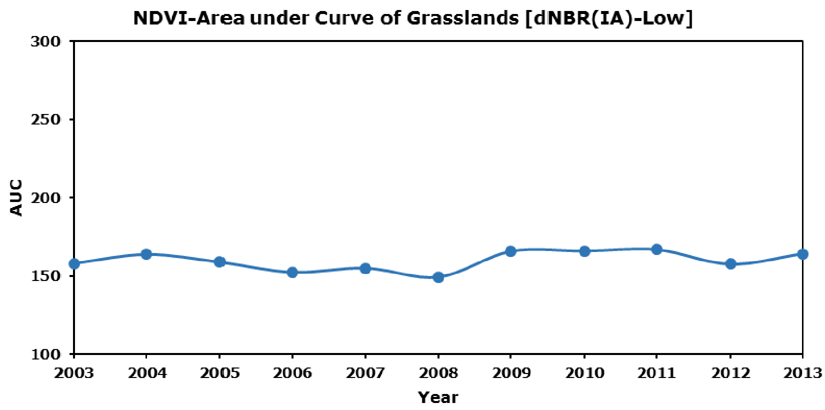


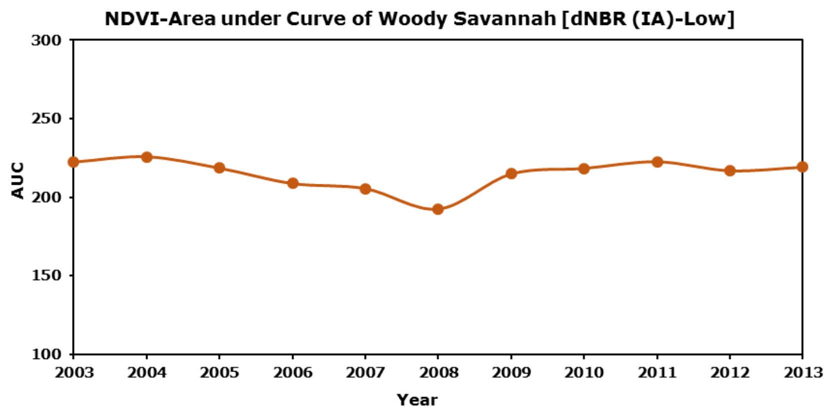


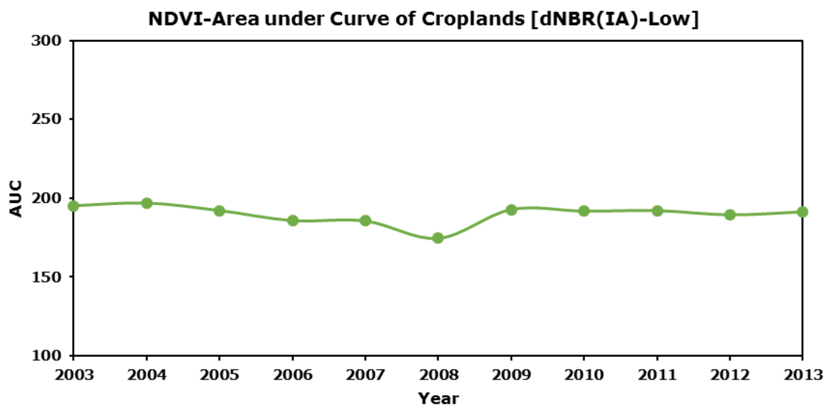

NDVI-Area under Curve of Grasslands [dNBR(IA)-Moderate)]
300
250
200
150
100
AUC
2003
2005
2007
2009
2011
2013
Year

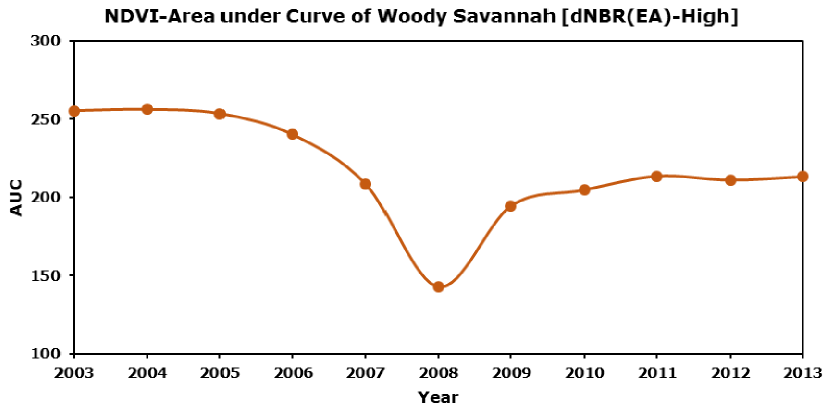

NDVI-Area under Curve of Croplands [dNBR(IA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [dNBR(IA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Grasslands [dNBR(IA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [dNBR (IA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Croplands [dNBR(IA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [dNBR(EA)-High]
300
250
200
150
100
AUC
2003
2004
2005
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2007
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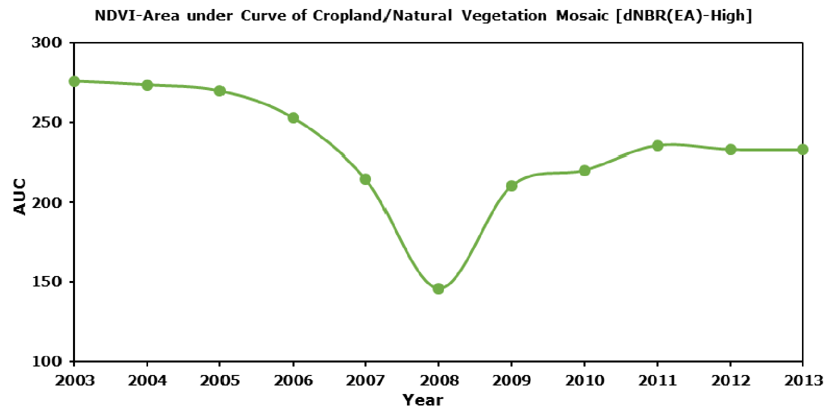
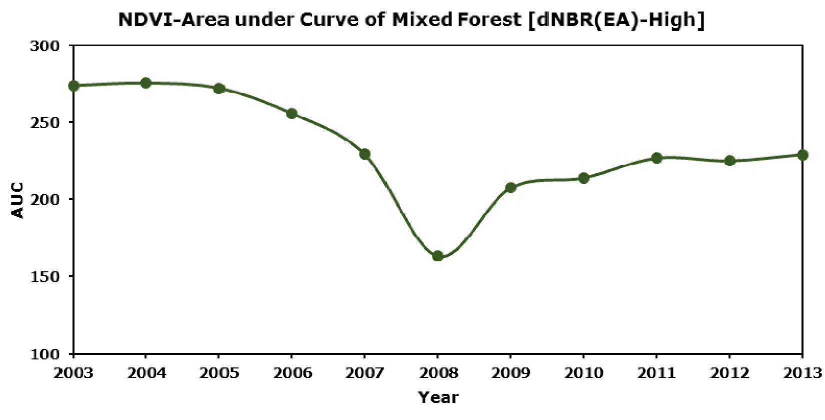
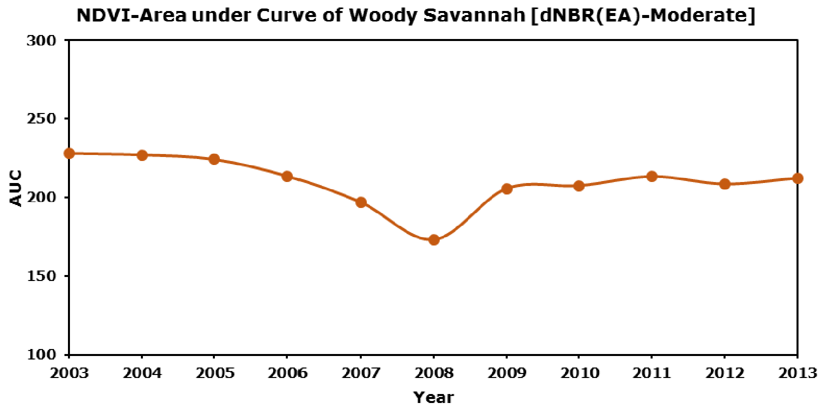
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Cropland/Natural Vegetation Mosaic [dNBR(EA)-High]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Mixed Forest [dNBR(EA)-High]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [dNBR(EA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
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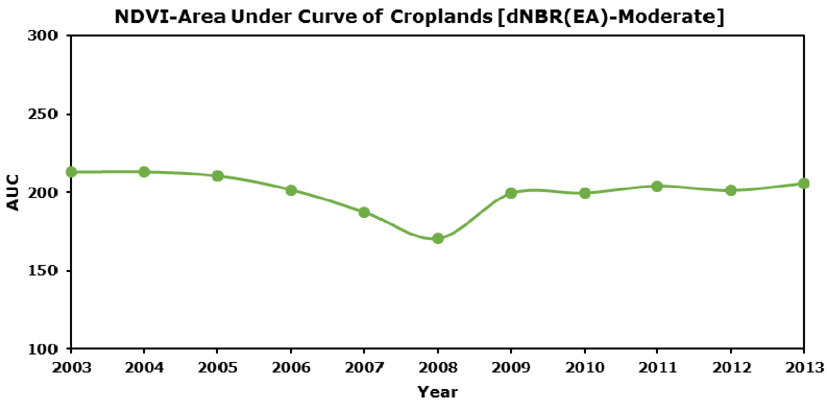
2010
2011
2012
2013
Year


NDVI-Area Under Curve of Croplands [dNBR(EA)-Moderate]
300
250
200
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AUC
2003
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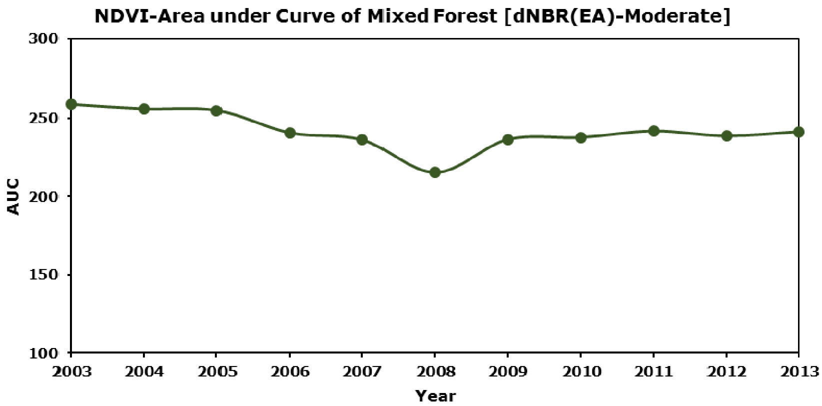
2011
2012
2013
Year


NDVI-Area under Curve of Mixed Forest [dNBR(EA)-Moderate]
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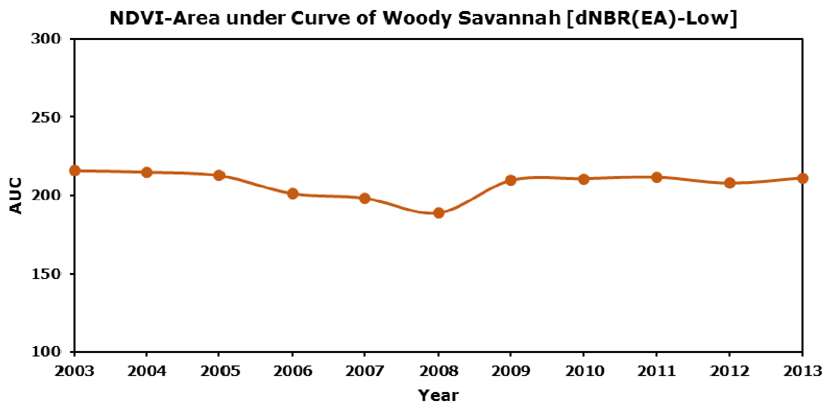
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [dNBR(EA)-Low]
300
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AUC
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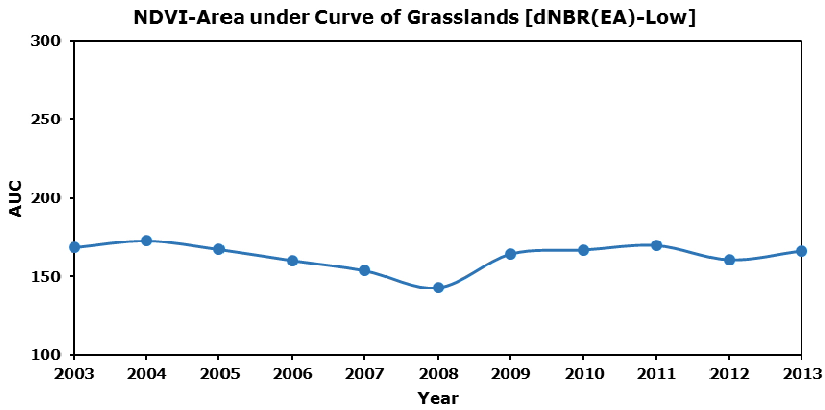
2013
Year


NDVI-Area under Curve of Grasslands [dNBR(EA)-Low]
300
250
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AUC
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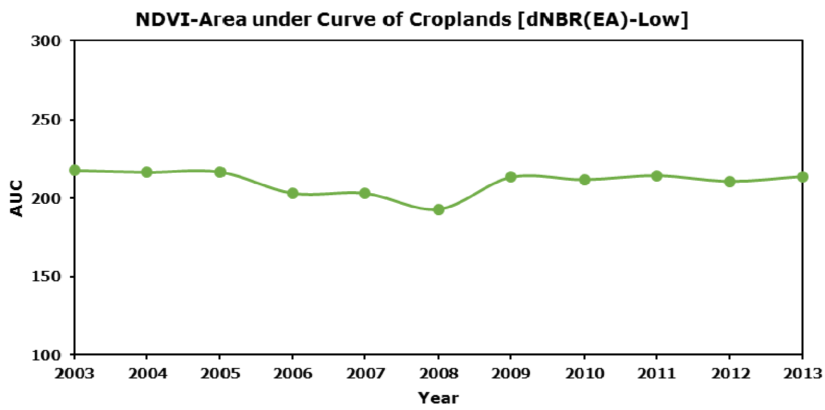
2013
Year


NDVI-Area under Curve of Croplands [dNBR(EA)-Low]
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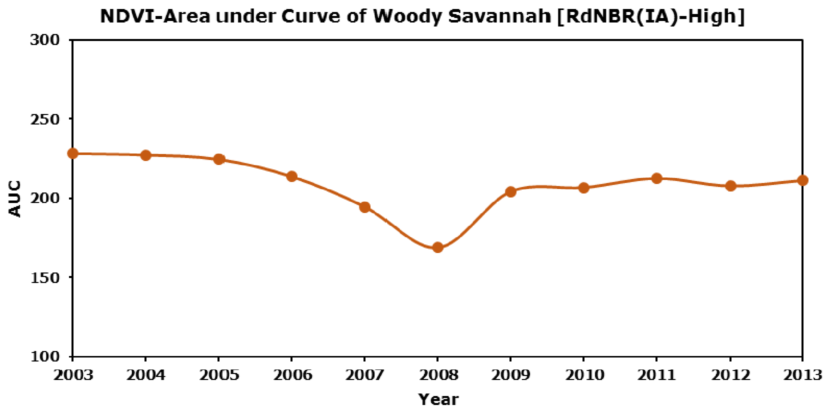
Year


NDVI-Area under Curve of Woody Savannah [RdNBR(IA)-High]
300
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AUC
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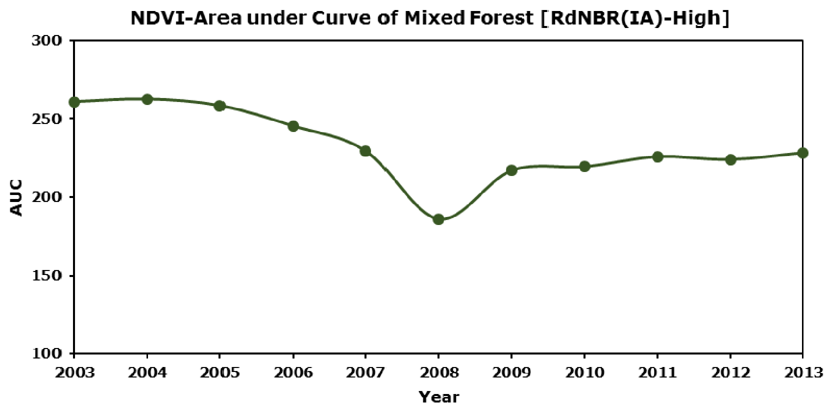
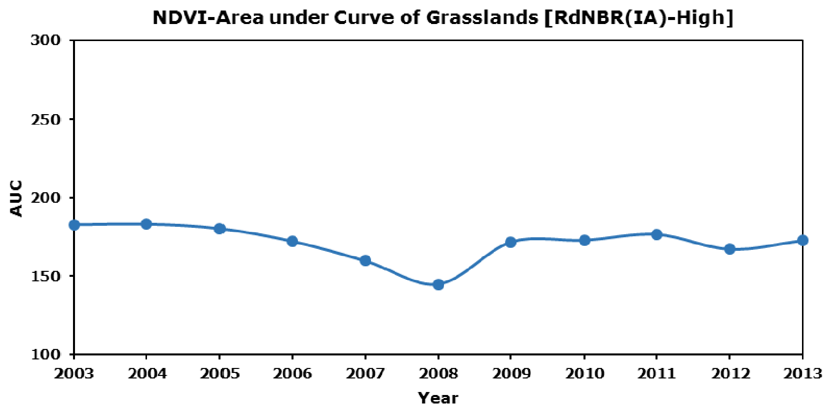
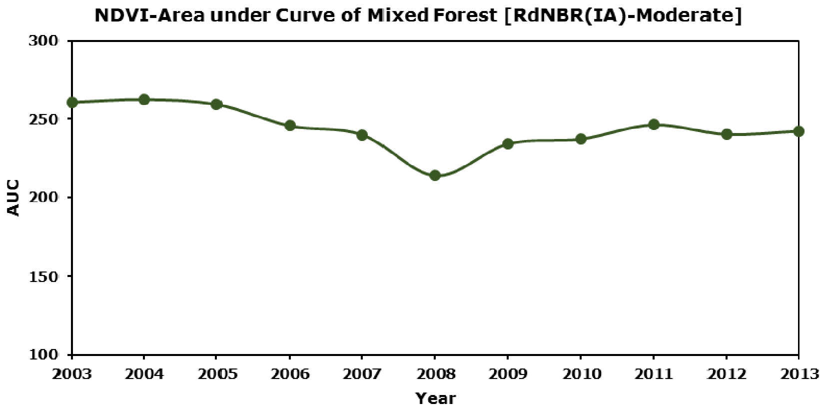
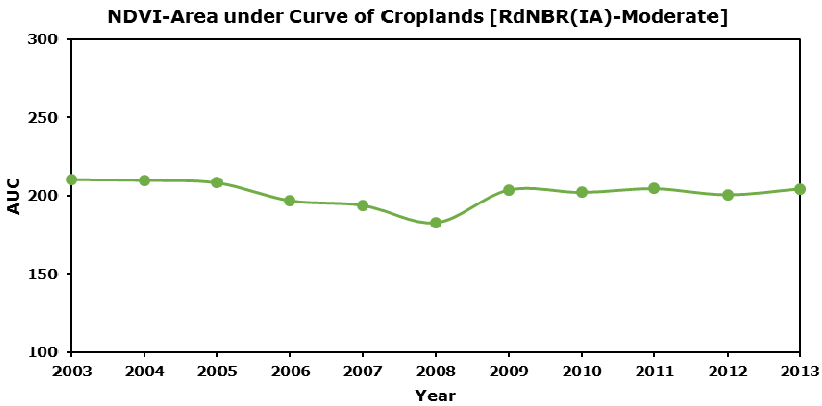
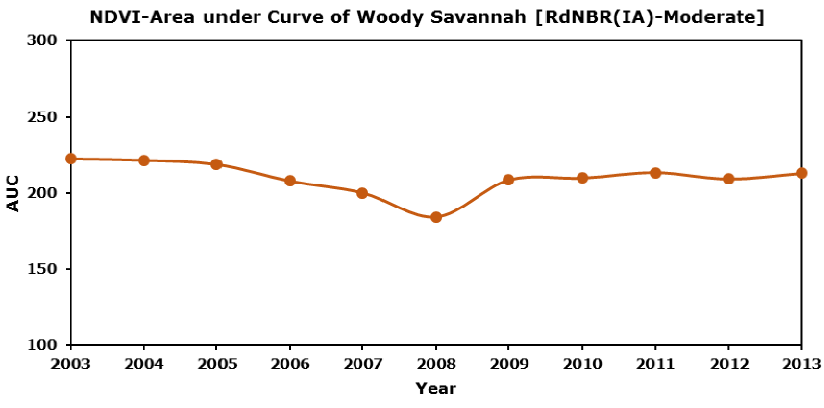
2013
Year

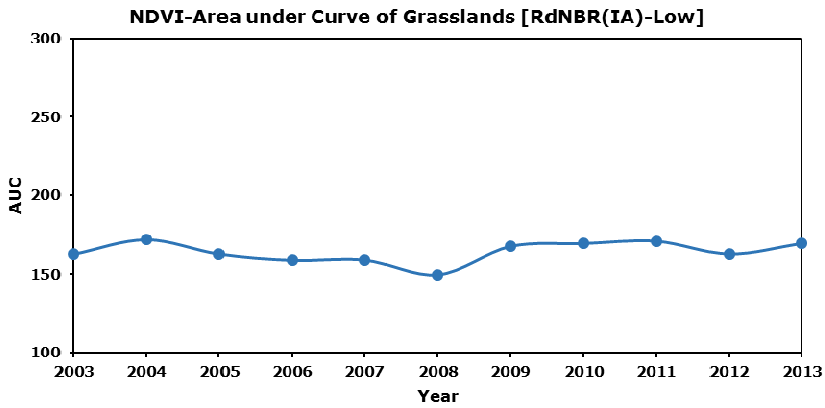

NDVI-Area under Curve of Mixed Forest [RdNBR(IA)-High]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

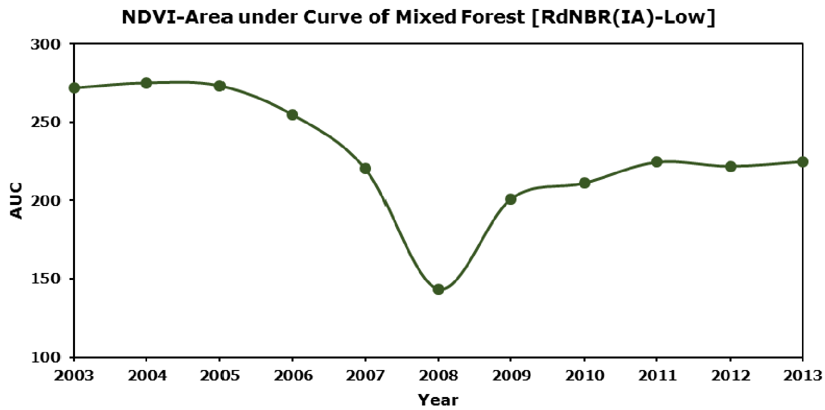

NDVI-Area under Curve of Grasslands [RdNBR(IA)-High]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

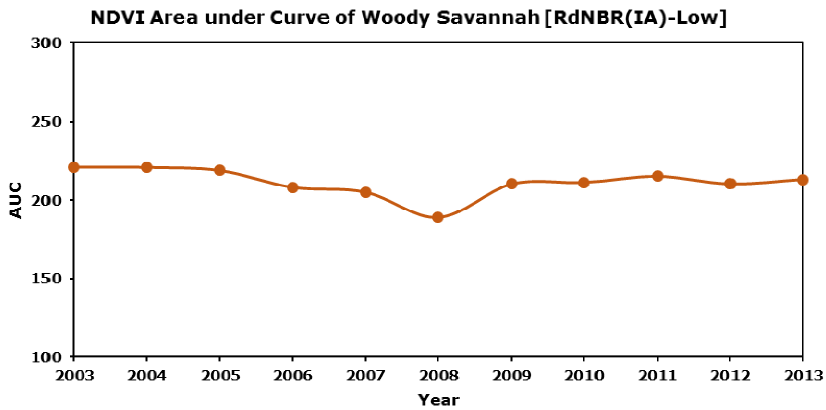

NDVI-Area under Curve of Mixed Forest [RdNBR(IA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

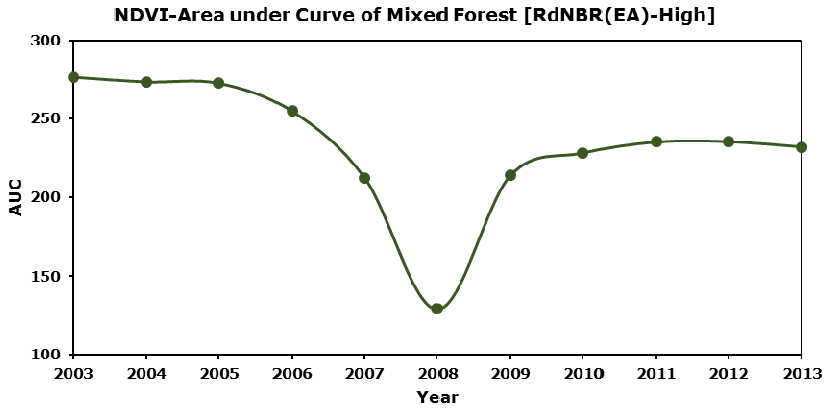

NDVI-Area under Curve of Croplands [RdNBR(IA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

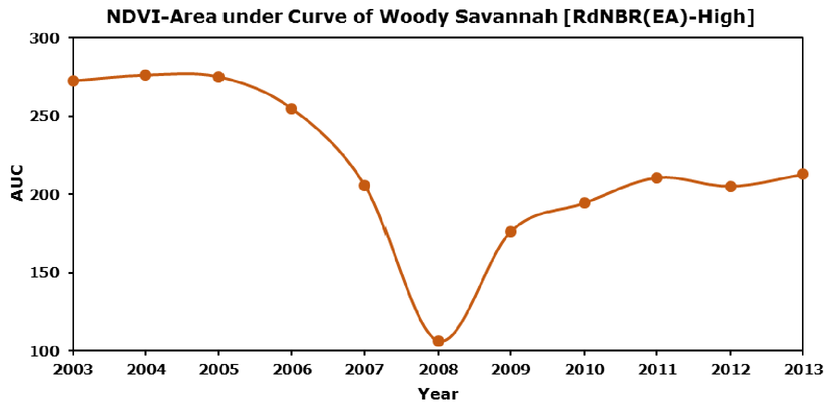

NDVI-Area under Curve of Woody Savannah [RdNBR(IA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

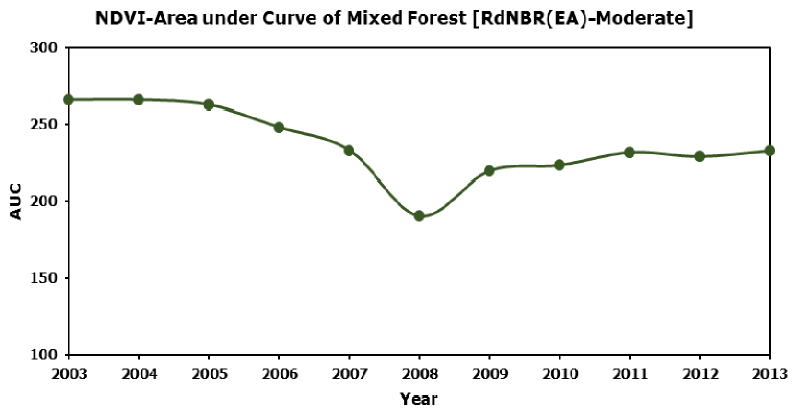

NDVI-Area under Curve of Grasslands [RdNBR(IA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

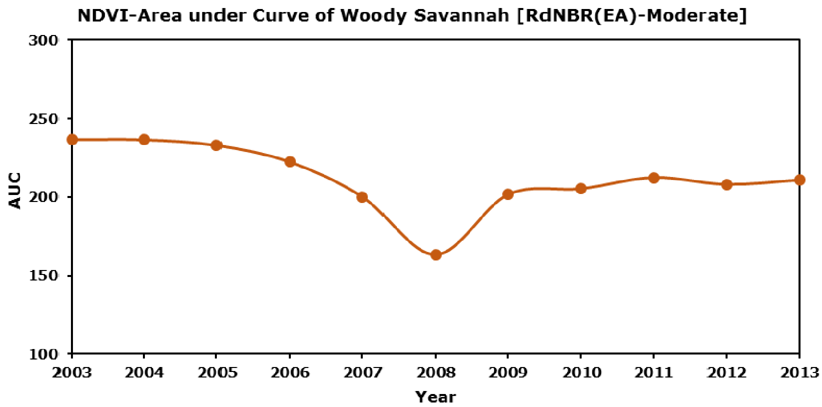

NDVI-Area under Curve of Mixed Forest [RdNBR(IA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

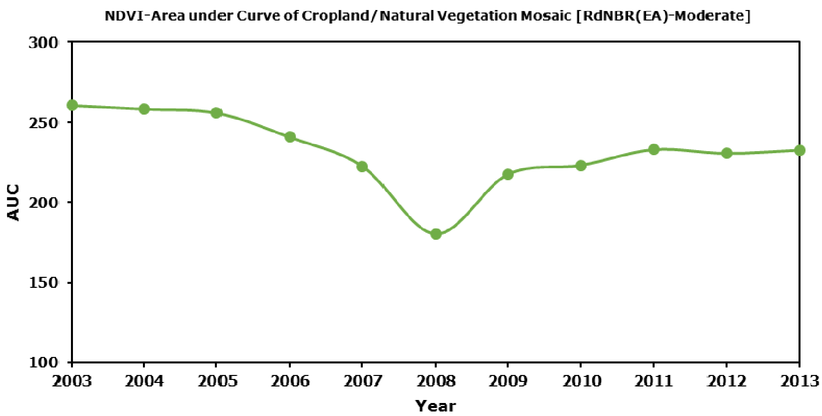

NDVI Area under Curve of Woody Savannah [RdNBR(IA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

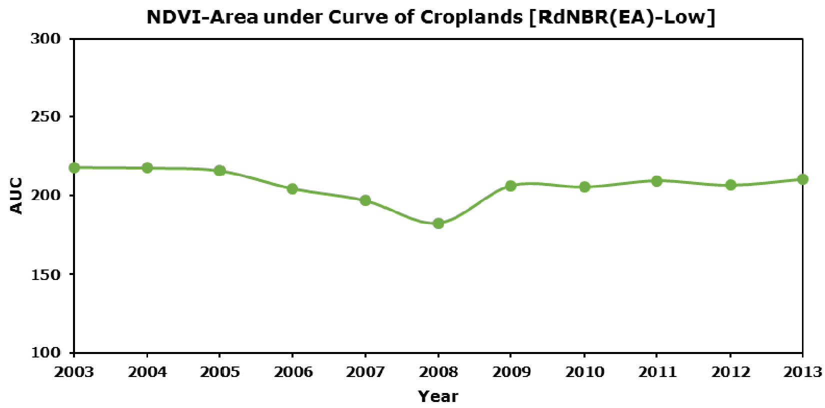

NDVI-Area under Curve of Mixed Forest [RdNBR(EA)-High]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [RdNBR(EA)-High]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

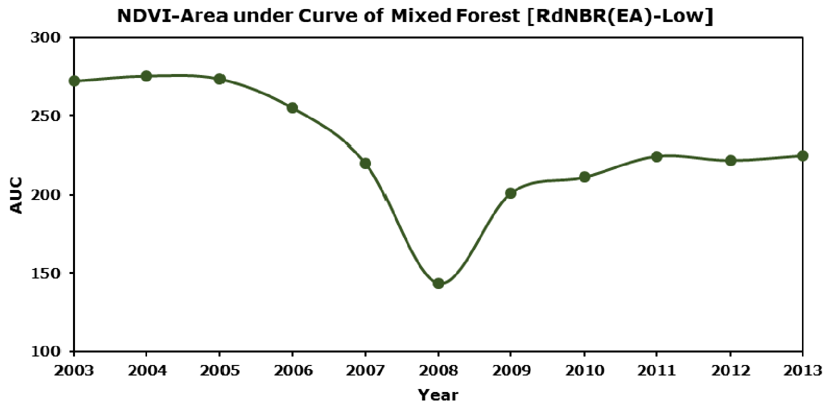

NDVI-Area under Curve of Mixed Forest [RdNBR(EA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year


NDVI-Area under Curve of Woody Savannah [RdNBR(EA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

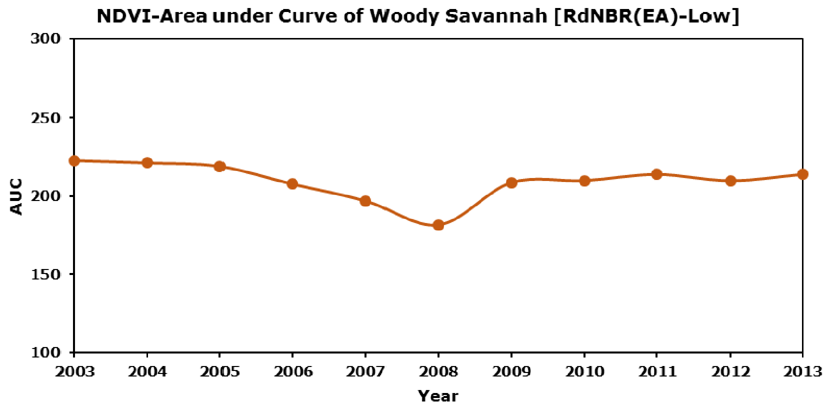

NDVI-Area under Curve of Cropland/Natural Vegetation Mosaic [RdNBR(EA)-Moderate]
300
250
200
150
100
AUC
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year



NDVI-Area under Curve of Croplands [RdNBR(EA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year



NDVI-Area under Curve of Mixed Forest [RdNBR(EA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

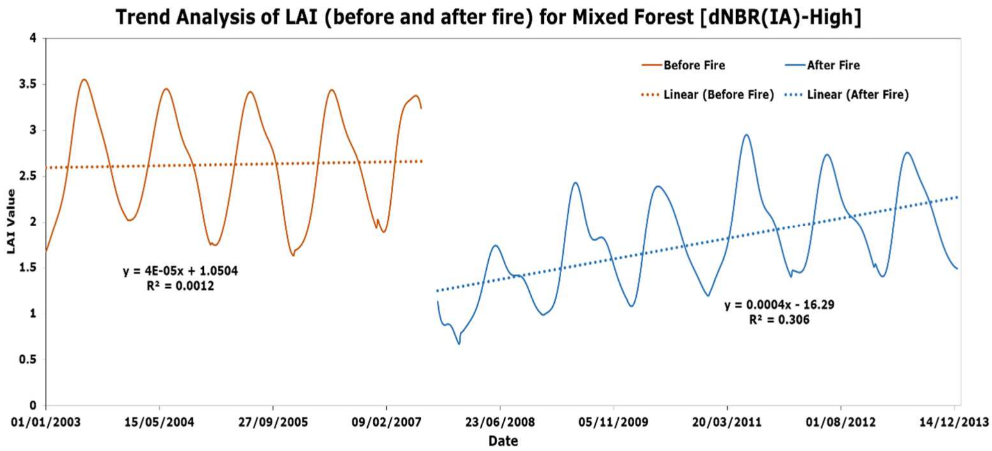


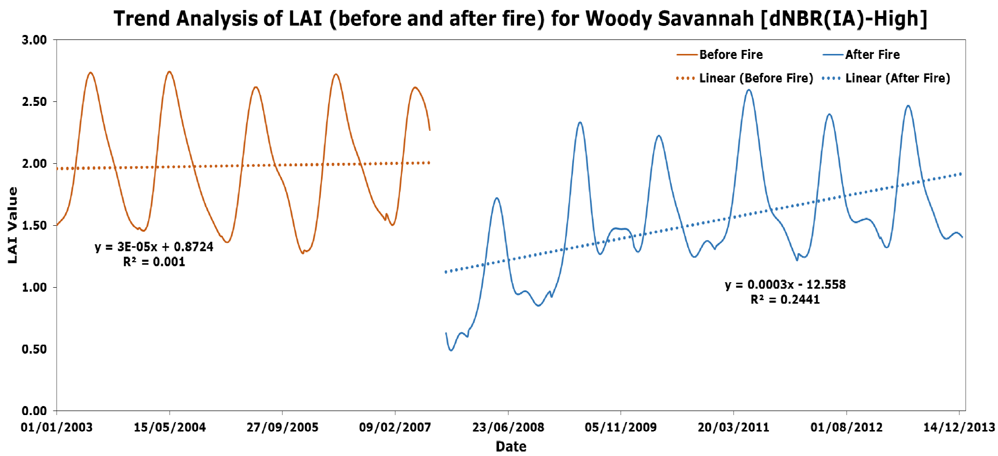
NDVI-Area under Curve of Woody Savannah [RdNBR(EA)-Low]
AUC
300
250
200
150
100
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Year

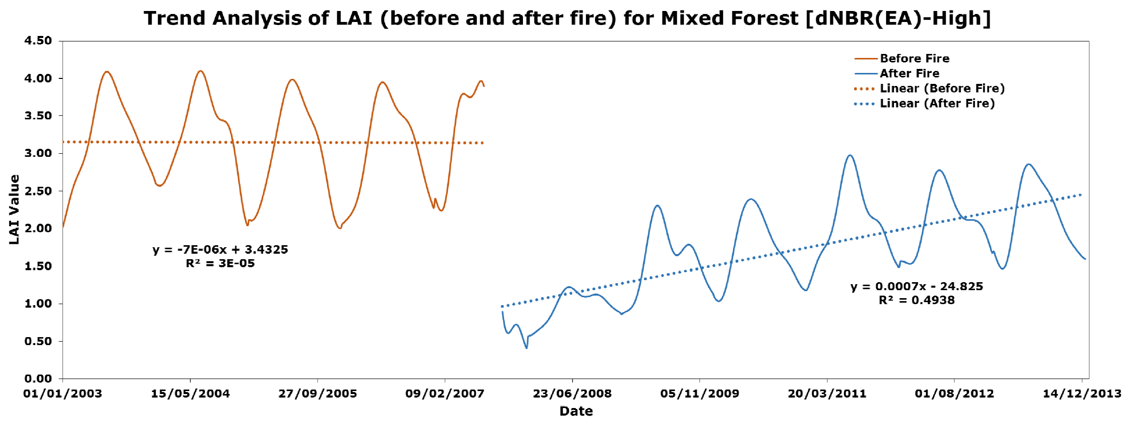
Appendix-E: Trend Analysis of LAI (High Severity)

Graphics show in this appendix, sequentially are:

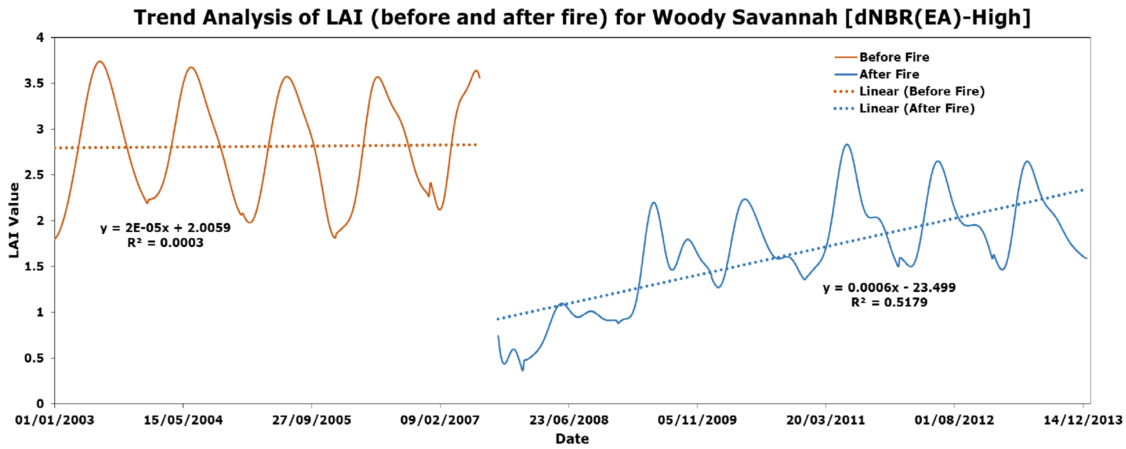
- Trend Analysis of LAI before and after fire in high severity for Mixed Forest and Woody Savannah in dNBR-IA and EA
- Trend Analysis of LAI before and after fire in high severity for Mixed Forest and Woody Savannah in RdNBR-IA and EA



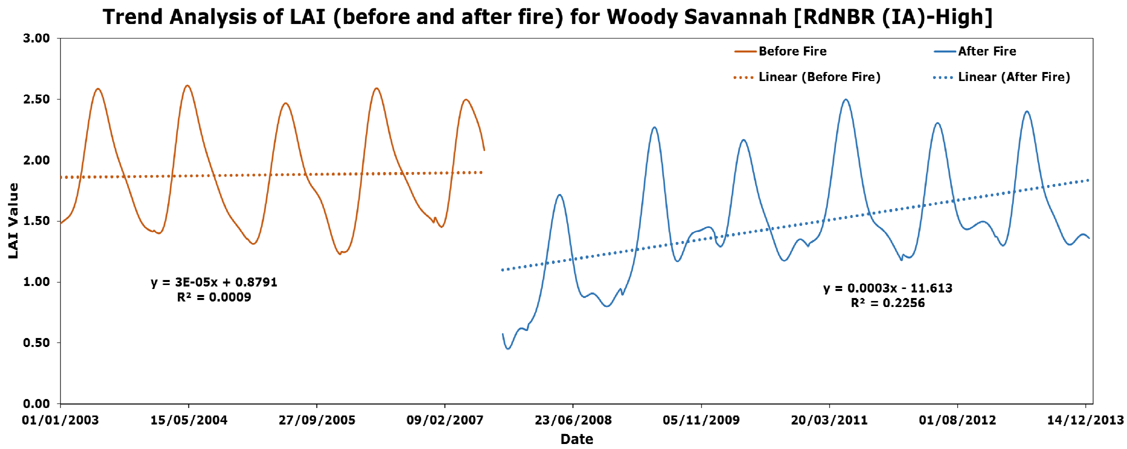




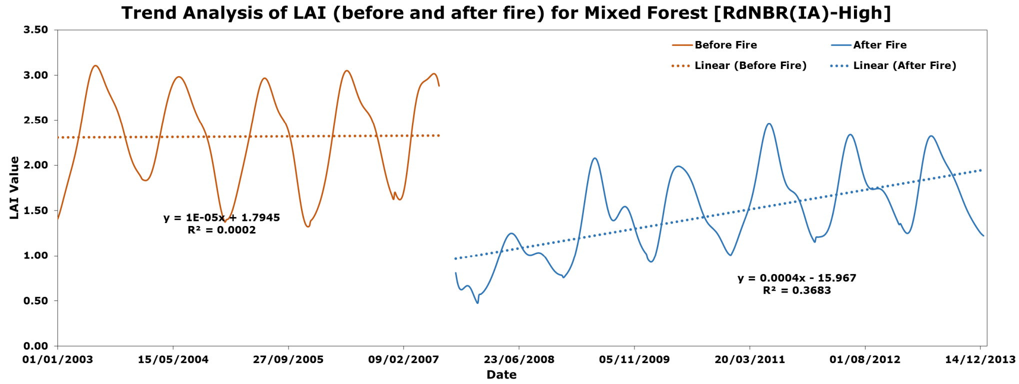
Trend Analysis of LAI (before and after fire) for Mixed Forest [dNBR(EA)-High]
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
LAI Value
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
y = -7E-06x + 3.4325
R² = 3E-05
y = 0.0007x - 24.825
R² = 0.4938
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date

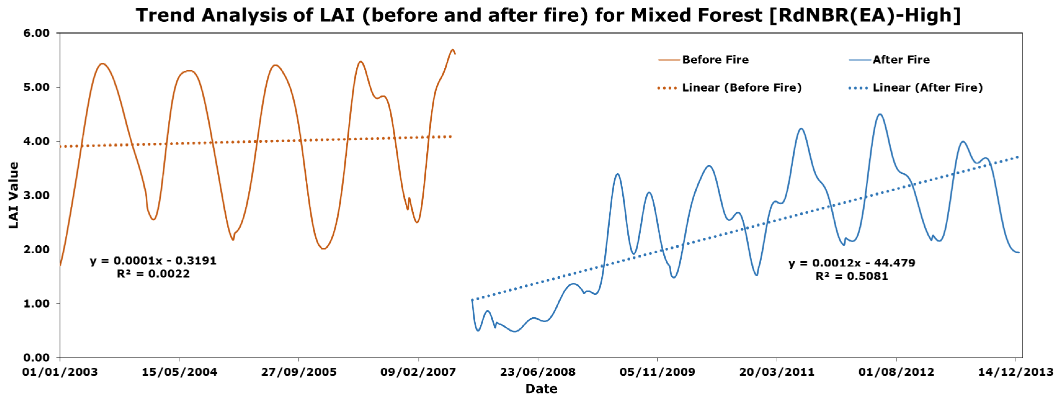


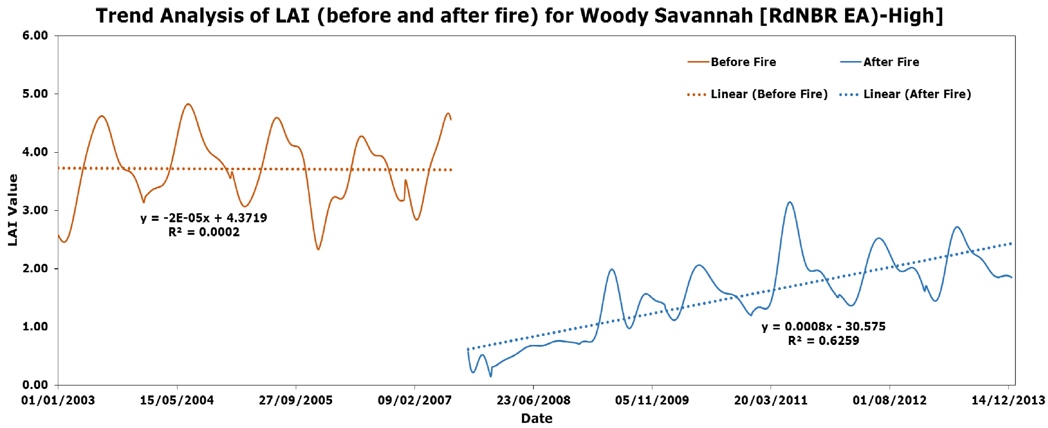
Trend Analysis of LAI (before and after fire) for Woody Savannah [dNBR(EA)-High]
4
3.5
3
2.5
2
1.5
1
0.5
0
LAI Value
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
y = 2E-05x + 2.0059
R² = 0.0003
y = 0.0006x - 23.499
R² = 0.5179
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date



Trend Analysis of LAI (before and after fire) for Woody Savannah [RdNBR (IA)-High]
3.00
2.50
2.00
1.50
1.00
0.50
0.00
LAI Value
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
y = 3E-05x + 0.8791
R² = 0.0009
y = 0.0003x - 11.613
R² = 0.2256
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date


Trend Analysis of LAI (before and after fire) for Mixed Forest [RdNBR(IA)-High]
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
y = 1E-05x + 1.7945
R² = 0.0002
y = 0.0004x - 15.967
R² = 0.3683
LAI Value
Date
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013

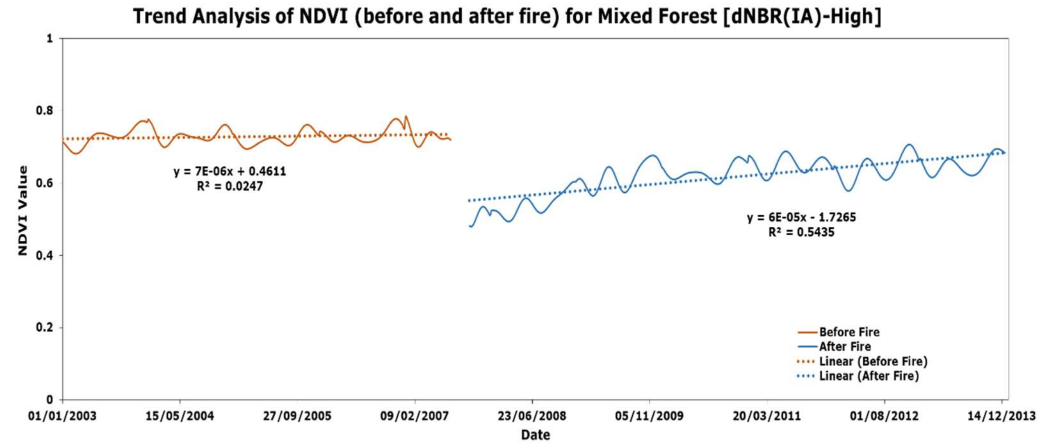

Trend Analysis of LAI (before and after fire) for Mixed Forest [RdNBR(EA)-High]
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
y = 0.0001x - 0.3191
R² = 0.0022
y = 0.0012x - 44.479
R² = 0.5081
LAI Value
Date
6.00
5.00
4.00
3.00
2.00
1.00
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013

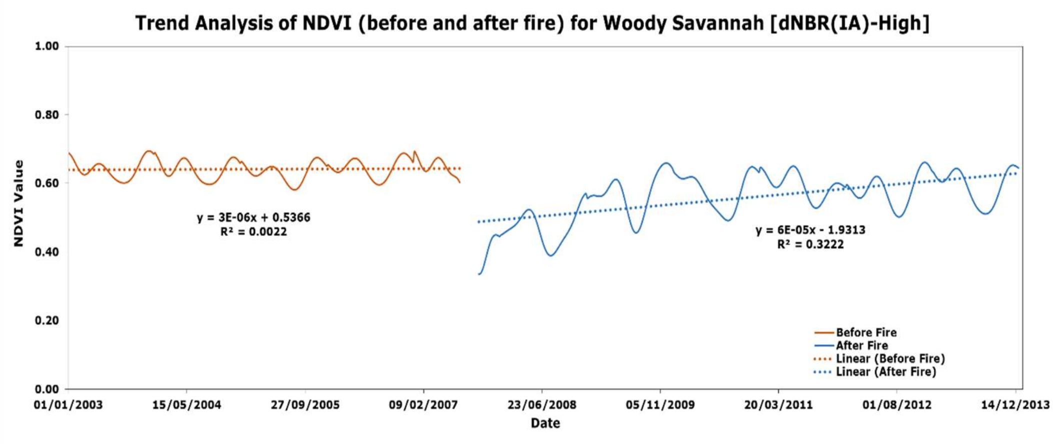

Trend Analysis of LAI (before and after fire) for Woody Savannah [RdNBR EA)-High]
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
y = -2E-05x + 4.3719
R² = 0.0002
y = 0.0008x - 30.575
R² = 0.6259
LAI Value
Date
6.00
5.00
4.00
3.00
2.00
1.00
0.00
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013

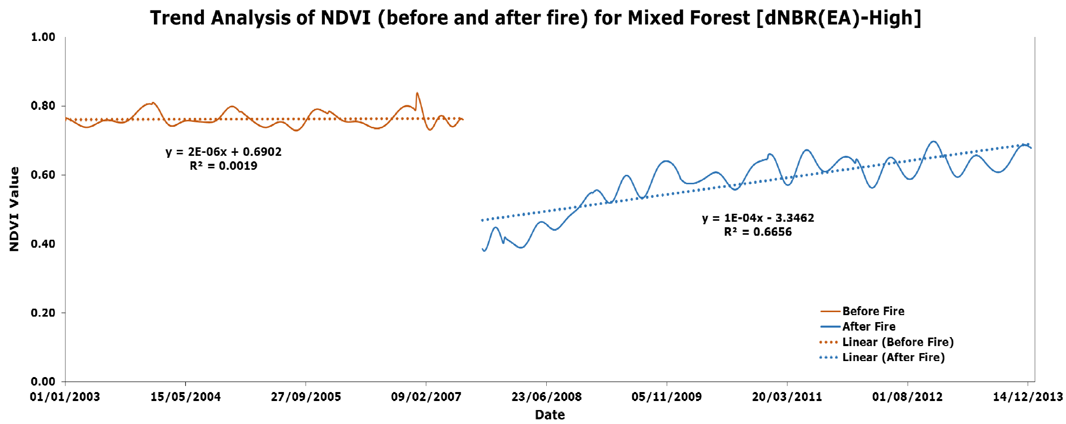
Appendix-F: Trend Analysis of NDVI

Graphics show in this appendix, sequentially are:

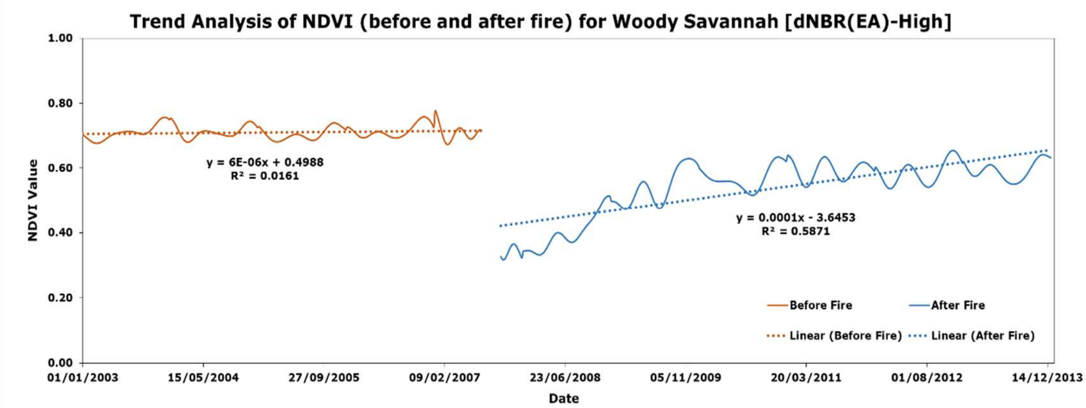
- Trend Analysis of NDVI before and after fire in high severity for Mixed Forest and Woody Savannah in dNBR-IA and EA
- Trend Analysis of NDVI before and after fire in high severity for Mixed Forest and Woody Savannah in RdNBR-IA and EA



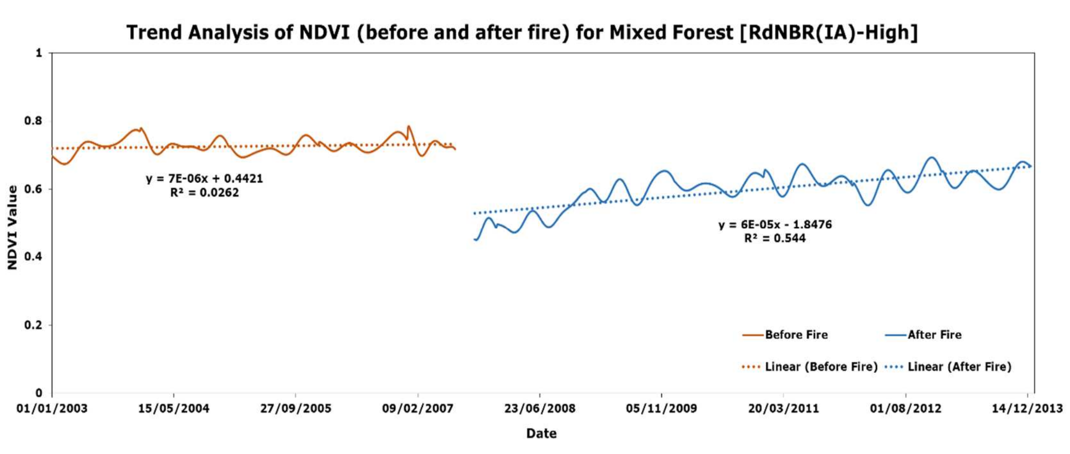




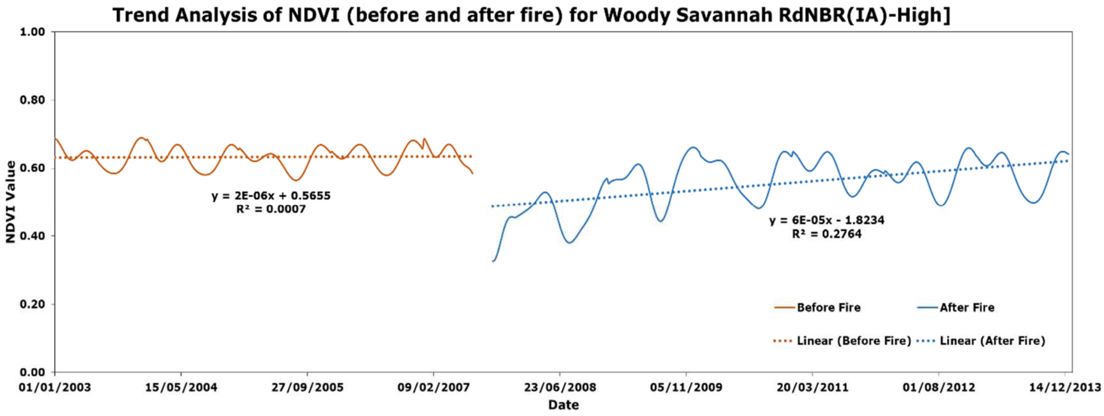
Trend Analysis of NDVI (before and after fire) for Mixed Forest [dNBR(EA)-High]
y = 2E-06x + 0.6902
R² = 0.0019
y = 1E-04x - 3.3462
R² = 0.6656
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
NDVI Value
Date

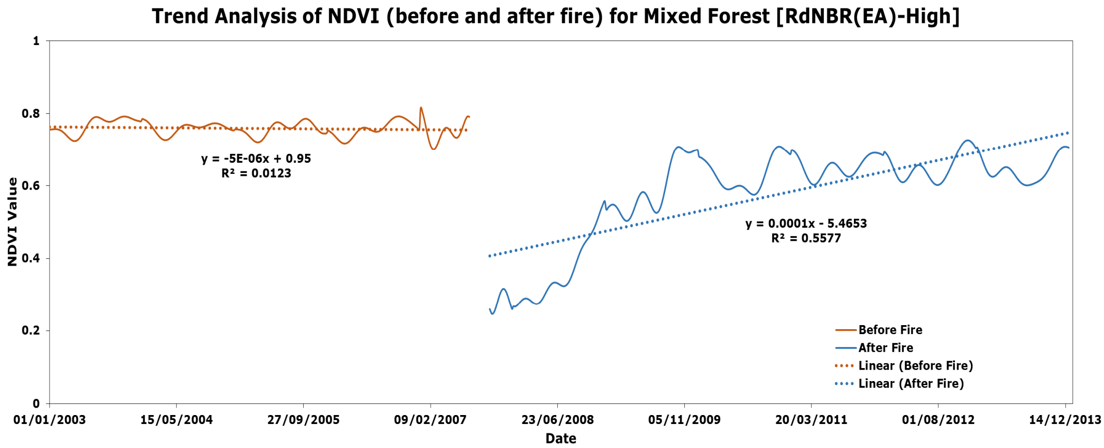


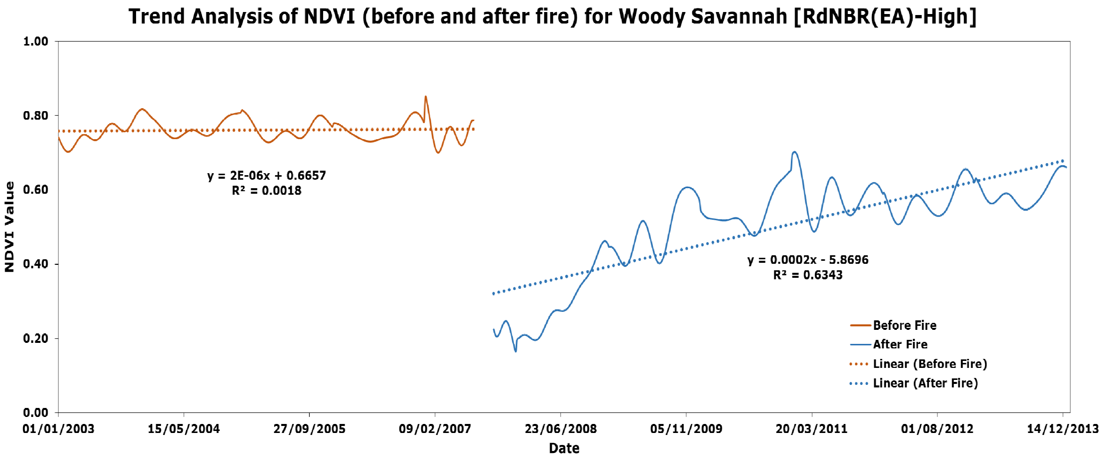
Trend Analysis of NDVI (before and after fire) for Woody Savannah [dNBR(EA)-High]
y = 6E-06x + 0.4988
R² = 0.0161
y = 0.0001x - 3.6453
R² = 0.5871
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
NDVI Value
Date



Trend Analysis of NDVI (before and after fire) for Mixed Forest [RdNBR(IA)-High]
y = 7E-06x + 0.4421
R² = 0.0262
y = 6E-05x - 1.8476
R² = 0.544
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
NDVI Value
Date


Trend Analysis of NDVI (before and after fire) for Woody Savannah RdNBR(IA)-High]
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
y = 2E-06x + 0.5655
R² = 0.0007
y = 6E-05x - 1.8234
R² = 0.2764
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date


Trend Analysis of NDVI (before and after fire) for Mixed Forest [RdNBR(EA)-High]
NDVI Value
1
0.8
0.6
0.4
0.2
0
y = -5E-06x + 0.95
R² = 0.0123
y = 0.0001x - 5.4653
R² = 0.5577
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date


Trend Analysis of NDVI (before and after fire) for Woody Savannah [RdNBR(EA)-High]
NDVI Value
1.00
0.80
0.60
0.40
0.20
0.00
y = 2E-06x + 0.6657
R² = 0.0018
y = 0.0002x - 5.8696
R² = 0.6343
Before Fire
After Fire
Linear (Before Fire)
Linear (After Fire)
01/01/2003
15/05/2004
27/09/2005
09/02/2007
23/06/2008
05/11/2009
20/03/2011
01/08/2012
14/12/2013
Date