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Remote sensing analysis of the vegetation condition of the Białowieza forest

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Summary

W pracy dokonano oceny kondycji roślinności w Puszczy Białowieskiej (PB) na podstawie analizy zobrazowań Landsat TM (4 terminy z 2011 r., od kwietnia do września). W programie ENVI 4.8 obliczano teledetekcyjne wskaźniki: NDVI, NDWI, MSI i wskaźnik ogólny jako iloczyn wymienionych wcześniej wskaźników. Odnotowano wyraźne różnice między obrazami poddanymi i niepoddanymi korekcji atmosferycznej (ATCOR 2), stąd korekcja ta jest niezbędna przy obliczaniu wskaźników kondycji. Zaobserwowano różne wzorce zmian kondycji dla lasów iglastych i liściastych w ciągu sezonu wegetacyjnego. Wysokie wartości wskaźników kondycji niekoniecznie odzwierciedlają stopień naturalności. Lasy gospodarcze w PB odznaczają się wyższą kondycją niż tereny rezerwatów przyrody i Białowieskiego Parku Narodowego.

Key words

Teledetekcja, Puszcza Białowieska, kondycja roślin, teledetekcyjne wskaźniki, roślinność, NDVI, zbiorowiska roślinne

Remote sensing, Białowieża Forest, plant condition, remote sensing indices, vegetation, plant communities

Area of study (codes according to Erasmus Subject Area Codes List)

07.2 Environmental Sciences, Ecology

Teledetekcyjna analiza kondycji roślinności Puszczy Białowieskiej

Contents

Abstract xi
List of Acronyms xii
1.Introduction 1
1.1. Background 1
1.2. Research problem 2
1.3. Objectives 3
1.4. Research questions 4
1.5. Hypothesis 4
1.6. Scope 4
2.Literature review 6
2.1. Vegetation stress and damage 6
2.2. Remote sensing for detecting and mapping of vegetation condition 6
2.2.1. Atmospheric correction of remote sensing data 7
2.2.2. Vegetations spectral properties 8
2.2.3. Vegetation indices 9
3.Study area 12
3.1. Location and general description of the study area 12
3.2. Forest zones and management system in Białowieza Forest 13
3.3. The vegetation of the Białowieza forest 15
3.4. Abundance and distribution of trees 16
4.Chapter Four Materials and Method 18
4.1. Research design 18
4.2. Rationale 18
4.3. Data collection 20
4.3.1. Remote sensing data 20
4.3.2. Field data 21
4.4. Software and tools 22
4.5. Data analysis 22
4.5.1. Pre-processing 23
4.5.2. Calculation of Vegetation Indices 24
4.5.3. Analysis of the effects of pre-processing 24
4.5.4. Temporal analysis of NDVI, NDWI and MSI of major tree species 25
4.5.5. Comparative analysis of the vegetation condition among forest zones. 25
4.6. Validation 27
5.Chapter five: Results 28
5.1. The effects of pre-processing 28
5.2. Temporal analysis of vegetation indices of major tree species 32
5.2.1. The Normalized Difference Vegetation Index (NDVI) 33
5.2.2. The Normalized Difference Water Index (NDWI) 36
5.2.3. The Moisture stress Index (MSI) 39
5.3. Analysis of the vegetation condition among forest zones 42
5.4. Validation 47
6.Discussions 49
6.1. The effects of pre-processing 49
6.2. NDVI, NDWI and MSI of major tree types 49
6.3. Vegetation condition among forest zones 50
7.Conclusions and remarks 52

7.1. Conclusions 52
7.2. Remarks 53
7.2.1. Limitations 53
7.2.2. Further research 54
Bibliography 55
Annexes 59
Annex 1 field measured sample points 59
Annex 2 field measurements 59
Annex 3 raw satellite data 63

Table of Figures

Figure 1: standard vegetation reflectance 9

Figure 2: study area:Białowieza forest 12

Figure 3 : Map of forest zones of Białowieza Forest 14

Figure 4: Major tree types of Białowieza Forest 16

Figure 5: abundance of major tree types 17

Figure 6: Distribution of major tree type 17

Figure 7: research design 18

Figure 8: analysis schema 23

Figure 9: pre-processing (a) original image (b) pre-processed image 28

Figure 10: Box plot of VIs 29

Figure 11: scatter plot of NDWI ground vs. original and pre-processed data 31

Figure 12 scatter plot of MSI ground vs. original and pre-processed data 32

Figure 13: Spectral profile of major tree species (a) April 2011 and (b) June 2011 .. 33

Figure 14: NDVI in the growing season 34

Figure 15: Box plot of NDVI of major tree types 35

Figure 16: NDWI in growing season (April - September 2011) 37

Figure 17: Box plot of NDWI of major tree types 38

Figuur 18: MSI in growing season (April - September 2011) 40

Figure 19: Box plot of MSI of major tree types

Figure 20: Vegetation condition map of the Białowieza forest 43

Figure 21: vegetation condition of the Białowieza forest 44

Figure 22 vegetation condition of forest zones 44

Figure 23: (a) Box plot of vegetation indices per forest zones; (b) vegetation condition per forest zones 45

List of tables

Table 1: Freely available moderate resolution remote sensing datasets 7

Table 2: Landsat TM properties: source 20

Table 3: Landsat TM bands 21

Table 4: Software and tools 22

Table 5: Equation of vegetation indices 24

Table 6: Reclassification values 26

Table 7: Values of vegetation condition 26

Table 8:Approximate Probabilities for Post Hoc Tests 30

Table 9: Mean ranges of vegetation indices for deciduous and coniferous trees for early September 2011 42

Table 10: Approximate Probabilities for Post Hoc Tests 46

Table 11: Regression Summary for NDVI from ground and pr-processed data........ 47

Table 12 Regression Summary for NDWI from ground and pr-processed data........ 47

Table 13 Regression Summary for MSI from ground and pr-processed data........... 47

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Abstract

Vegetation Condition (VC) has emerged in to fundamental concept in forest studies. This is because it includes the aspects of quality and health in addition to the conventional approaches of forest extent and quantities of wood applied in forest studies. In this study remote sensing based spatio-temporal analysis have been applied to detect and map the vegetation condition of the Białowieza Forest and to compare the condition of the different forest zones namely the oldest and the current Białowieza National Park (BNP), nature reserves, managed forest and open areas. The main objective of the research was to analyze the vegetation condition of the Białowieza Forest using Landsat TM and field measured hyper spectral reflectance data. The study was conducted for the northern hemisphere vegetation growing season (April to end of September) 2011. The analysis was carried out using vegetation indices and statistical methods.

Landsat TM driven NDVI, NDWI and MSI have resulted in fairly strong correlation ($r>0,8$) with field measured NDVI, NDWI and MSI data. This has illustrated that vegetation indices produced from moderate resolution satellite datasets can be used for precise detection and estimation of vegetation condition spatially and temporally.

The result of this study has demonstrated that atmospheric correction and haze removal are essential parts of pre-processing in the analysis of vegetation indices. Indices that are particularly computed along the visible and NIR spectrum are highly affected by atmospheric interaction. In this study, atmospheric correction and haze removal have resulted in significant difference ($p<0,01$). Overlooking the effects of the atmosphere can therefore, create discrepancies in the analysis and significantly affect the application of satellite data.

In general, more than 80% of the vegetation in Białowieza forest had good condition. The managed and open zone had significant differences ($p<0,01$) from the strictly protected Old BNP, BNP and actively protected nature reserves. The managed zone had the highest condition and the open zone had the lowest. The results have also highlighted the role of vegetation condition as reflection to the type and intensity of management or conservation practices implemented on forests.

List of Acronyms

BF: Białowieza Forest

BNP: Białowieza National Park

FAO: Food and Agriculture Organization of the United Nations

MSI: Moisture Stress Index

NDVI: Normalized Difference Vegetation Index

NDWI: Normalized Difference Water Index

NIR: Near Infra Red

SWIR: Short Wave Infra Red

USGS: United States Geological Survey

VC: Vegetation Condition

VI: Vegetation Index

1. Introduction

1.1. Background

There is growing awareness on forests particularly linked to climate change and livelihoods in recent years. Forests have become global focus of research and policies. The United Nations General Assembly has proclaimed the year 2011 as the "*international year of forests*" with the aim to highlight the ecological and social functions of forests and to promote forest health (FAO 2011). It is apparent that forests are one of the most valuable resources. They provide immense ecological and social services. They have served as life supporting ecosystems and have regulated local and global climates. In fact, it is difficult to list all of the functions of forests at once. Unfortunately, these valuable resources have been subject to centuries of over exploitation and deforestation. These has led to reduction in forest extent, quality, composition and naturalness in different parts of the world (FAO 2010).

Despite its relative exceptional state of preservation, the Białowieza forest has also been experiencing degradations and has undergone significant changes in composition (Bernadzki, Bolibok et al. 1998). Bernadzki, Bolibok et al. (1998) fifty six years observation based research on the compositional dynamics of the forest indicates that the forest has undergone high compositional instability due to absence or presence of different disturbance agents. Falinski (1994) has reported that the forest has lost 45 % of its original size in the last three centuries but increasing anthropogenic impacts have occurred in the last century. This is supported by the research of Żmihorski and Durska (2011) who conducted study on reconstruction of long term succession dynamics of temperate woodland in Białowieza forest. Their findings have also indicated that sever damage of the forest has occurred in these period.

Naturally, forests are renewable resources. Thus, their quality and extent can be recovered if timely measures are set to properly manage and conserve them. This requires fundamental understanding of the forest ecosystem and existing management and conservation practices linked to it. Analysis of the condition or the state of the forest is hence an integral part of this process.

Vegetation Condition (VC) has emerged in to fundamental concept in forest studies. This is because it includes the aspects of quality and health in addition to the conventional approaches of forest extent and quantities of wood applied in forest studies (Mucina 2009). Vegetation condition gives general reflection on the internal and external process taking place in the plant and in its respective environment. VC is mainly impacted by natural and anthropogenic disturbances posed on the vegetation. The natural disturbances include fire, insects, diseases, drastic weather conditions and catastrophic events (Müller, Bußler et al. 2008). The anthropogenic disturbances consists of logging, sanitary cutting, colonization for agricultural or settlement purposes, mining and pollution (Lichtenthaler 1996).

In this study remote sensing based spatio-temporal analysis have been applied to detect and map the vegetation condition of the Białowieza forest and to compare the condition of the different forest zones namely the oldest and the current zones of Białowieza National Park (BNP), nature reserves, managed forest and open areas. The study was conducted for the northern hemisphere vegetation growing season (April to end of September) 2011. The analysis was mostly carried out using vegetation indices. Vegetation Indices (VIs) have promoted the application of remote sensing to forest studies by providing simple and robust technique to analyze remote sensing data and estimate different parameters linked to VC.

The detection and mapping of vegetation condition of the Białowieza Forest has provided information on the state of the forest in general and the status of the different forest zones and major tree species in particular. Based on that, the possible impacts of different management and conservation practices on VC were illustrated. This will contribute to better understanding and management of the forest and add up to existing body of knowledge.

1.2. Research problem

Different degrees of disturbances and damages have been reported in the Białowieza forest particularly in the managed zone (Wesołowski 2005; Bobiec 2012).

The research of Dorota Czeszczewik (2006) indicate that continuation of logging at its current rate will wipe out the entire old growth of pristine character in the managed forest in the coming 10-20 years. Damages have put the forest to risk its pristine characters that took centuries of ecological processes to develop. Furthermore, logging and sanitary clearings are threatening fauna species dependent on dead wood and natural ecosystems (Wesołowski 2007).

Studies done on disturbed forests emphasized the need for further research in vegetation condition. Żmihorski and Durska (2011) has described the urgent need for research on vegetation condition of forests in order to assist the development of intervention mechanisms. Research is particularly indispensable to understand and portray rare forests like Białowieza. Most studies carried out on BF mainly focus on the degree of naturalness, species composition, habitat suitability (Wesołowski 2007), abundance of fauna (Bobiec, van der Burgt et al. 2000) and forest disturbances Hilszczanski, Gibb et al.(2007). Other aspects of the forest such as its vegetation condition and health however have not got sufficient coverage.

Most of the studies have covered wide temporal scales from few years to decades and centuries but the spatial scale were mostly limited to few plots or forest patches. Furthermore, most studies were conducted mainly based on field based data collection methods using ground measurements. It is evident that field based data collection provide more straight forward and accurate data. However, it also pause limitations as it demand the use of sophisticated instruments, high financial resources and longer time. Remote sensing has alleviated these challenge by facilitating accurate and cost effective collection and analysis of data that can be easily integrated with filed measured data Win, Suzuki et al.(2012). Based on this premises this study has set the following main and specific objectives.

1.3. Objectives

The main objective of the research was to analyze the vegetation condition of the Białowieza Forest using Landsat TM and field measured hyper spectral reflectance data.

Specific objectives

- Analyze the vegetation indices (NDVI,NDWI,MSI) of the forest
- Analyze the effects of pre-processing on the analysis of vegetation indices
- Analyze the temporal variations in vegetation indices between major tree species in the growing season (April to end of September)
- Compare the condition of the different forest zones
- Map the vegetation condition of the forest

1.4. Research questions

- What are the effects of pre-processing on the analysis of vegetation indices (NDVI, NDWI and MSI)?
- Are there temporal variations in vegetation indices between major tree species in the growing season (April to end of September)?
- What is the vegetation condition of the Białowieza forest?
- Are there differences in vegetation condition among the different forest zones?

1.5. Hypothesis

- H0: there is no significant difference between pre-processed and original remote sensing data.
- H0: there is no significant difference in vegetation indices (NDVI, NDWI and MSI) among major tree species in the growing season.
- H0: there is no significant difference in vegetation condition among the major forest zones

1.6. Scope

Despite of its frequent usage there is no standard definition for vegetation condition rather a contextual use of the term is widely applied (Gibbons, Zerger et al. 2006). Zirlewagen, Raben et al. (2007) defined the term as "one *comprising the quality, health, function and viability of forest*". Gibbons, Zerger et al. (2006) provide comparative terminology by defining it as " *a degree to which current state of vegetation deviate from bench mark vegetations of its type or to semi-natural vegetations*." Mucina (2009) has defined vegetation condition from biodiversity perspective as “the *ability of the existing vegetation to provide habitat and resources for native plants and animals*”. (Jones 2011) has linked vegetation condition to factors such as productivity, leaf area, biomass, wood structure and biochemical constituent of the vegetation.

For the purpose of this research vegetation condition is defined as the state or health of the vegetation as estimated from its spectral indices. Three vegetation spectral indices have been used as indicators to vegetation condition. These are NDVI, NDWI and MSI. The spatial scope of the research was confined to the Polish part of the Białowieza forest that has an area of 580 km^2. The Belarusian part of the forest could not be included due to the lack of field measured data from that part of the forest. Hence, Białowieza Forest in this study represents only the Polish part of the forest. The time frame of the study was from April to end of September 2011.

2. Literature review

2.1. Vegetation stress and damage

The condition of vegetation is highly dependent on the degree of stress and damage it is exposed to. Lichtenthaler (1996) has defined vegetation stress as "*any unfavorable condition or substance that affects or blocks plants metabolism, growth or development.''* Stress can have either positive or negative impact depending on its intensity, duration and on the plant's physiology and morphology. Positive stress can stimulate the metabolism of a plant and help the vegetation develop resilience. Negative stress can lead to plant strain or total damage. vegetation damage is defined by Godbold (1998) as " *the result of too high stress that can no longer be compensated for."* Persistence damage can lead to extinction or sever decline of fragile species or the entire ecosystem.

2.2. Remote sensing for detecting and mapping of vegetation condition

Remote sensing and Geo-information science have become powerful tool to generate Spatio-temporal information of forest vegetation condition (Hamad 2010). Multispectral remote sensing offers a complementary technology for the detection and mapping of vegetation damages (Gibbons and Freudenberger 2006). Besides, it also has some benefits that are difficult to attain from conventional method applied in vegetation condition analysis. It offers the capacity to cover large spatial areas and provides cost effective collection of accurate, consistence and timely data (Toomey and Vierling 2005; Hais and Kučera 2008).

Satellite remote sensing has contributed to elaborated studies on forest ecosystems and played important role in forest health studies (Wang, Sammis et al. 2010). It has wide range of application from single scene forest health studies to multi-temporal analysis of forest dynamics (Gleason and Im 2011). Furthermore, it has facilitated comprehensive monitoring of forest resources by providing information on the spatial dynamics, bio-chemical and bio-physical properties of forest (Boyd and Danson 2005).

Ranges of remotely sensed datasets have been applied to map vegetation condition. The list can go from the medium resolution MODIS, ASTER and Landsat to the high resolution Worldview, GeoEye_1 and IKONOS. Generally, high resolution datasets allow detection of plant stress and damage at individual crown level that will result in high accuracies (Coops, Johnson et al. 2006). However, most high resolution datasets are costly. Medium resolution datasets nevertheless provide cost effective estimation of vegetation condition with accuracies ranging from 70- 85% (Wulder, White et al. 2006). The following datasets described in table 1 are widely used in forest vegetation condition analysis.

Table 1: freely available moderate resolution remote sensing datasets; Source: J. Wang et al., 2010

Sensor type	Spatial resolution (m)	Temporal resolution (days)	Number of bands	Scene size	Launch Date
Landsat TM	30-120	16	7	185 x185	March 1984
Landsat ETM+	15- 60	16	8	183 x 170	April 1999
Aster	15 - 90	16	15	60 x 60	December 1999
AVHRR	1000	1	4-5	2400x 6400	June 11, 1978
MODIS	250 - 1000	1-2	36	2300x2300	December 1999

2.2.1. Atmospheric correction of remote sensing data

Reflected radiation from earth features such as forests goes under significant interaction with the atmosphere before it reaches the sensor (Liang, Fang et al. 2002). Some of the atmospheric constituents are ozone, water vapor and aerosols.

Errors generated by atmospheric interaction affect the quality of the data such as vegetation indices retrieved from remote measurements (Courault et al.,2003).

Several models exist to compensate for the values of the atmosphere and to produce true reflectance value of the feature. Song, et al (2001) have presented in-depth discussion on the various existing atmospheric correction methods. Their conclusion indicates that all of the correction methods have resulted improvement in the accuracy of the output. The choice for certain atmospheric correction method should base on the scene quality and the application of the remotely sensed data (Mahiny and Turner 2007).

2.2.2. Vegetations spectral properties

Vegetation has distinctive spectral properties like other earth features. The spectral properties of vegetation are influenced by various internal and external factors. Internal factors include species type, canopy architecture, structure of the leaves, contents of pigments, water and chemical elements such as carbon and nitrogen. The most prevalent external factors are temperature, soil moisture and mineral content. Vegetations in the northern hemisphere have growing season from April to October. However, some studies have shown earlier onset of greening and prolonged growing period due to changes in temperature (Schwartz and Reiter 2000; Jeong, Ho et al. 2011).

The spectral properties of healthy and stressed or damaged vegetation can also significantly vary. This is because, vegetation under stress or damage displays characteristics spectral properties associated to change in contents of pigments, water and other chemicals than healthy vegetation of its type.

In optical remote sensing spectral reflectance is usually measured in the visible and infrared region. The visible range is sensitive to contents of leaf pigments. The decrease or increase in contents of pigment such as chlorophyll affects the reflectance in the green and red region. The near infra red region is sensitive to canopy development and cell structure. Reflectance in the SWIR is mainly determined by amount of free water in the leaf tissue as presented in figure 2 below. As the leaves go drier the reflectance in this range increases. Reflectance in the optical and infrared regions can therefore be used to investigate vegetation type and health (ITC 2010).

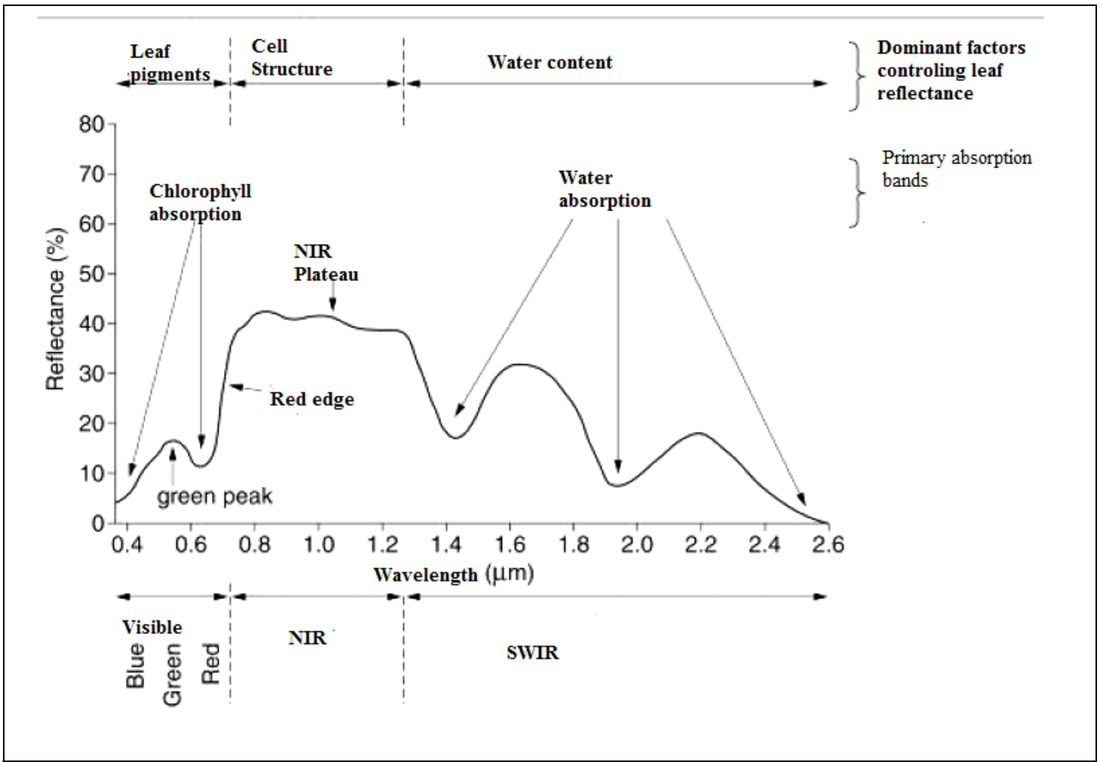


Figure 1: standard vegetation reflectance: source (ITC 2010)

2.2.3. Vegetation indices

The use of vegetation indices have developed in to firm method in the analysis of forest condition. Vegetation Indices (VIs) are " *robust satellite data products that are formed as function of two or more bands*" (Wang, Sammis et al. 2010). They ensure continuous monitoring of ecosystem processes since they can be easily calibrated across different sensor systems (Glenn et al., 2008). VIs have been applied for assessing vegetation condition, cover, phenology, and monitoring processes such as evapo-transpiration and drought. Varieties of VIs have been developed for vegetation studies. The Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDMI), the Moisture Stress Index (MSI) are among the widely applied indices in forest condition analysis (Wang, Sammis et al. 2010; Win, Suzuki et al. 2012).

2.2.3.1 Normalized Difference Vegetation Index (NDVI)

NDVI is by far the most utilized index. It is a ratio based index derived from the NIR and red band (Rouse 1974). It is formulated as;

$$NDVI = (\rho NIR - \rho RED) / (\rho RED + \rho NIR)$$

The red radiance show inverse relationship with green biomass and near infrared shows direct relationship (Tucker 1979). This is caused as a result of strong absorption of the red light by chlorophylls. The values of NDVI range from +1.0 to -1.0. The common range for vegetation is from 0.2 – 0.8. Sparse vegetation such as shrubs or senescing crops may have moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as temperate and tropical forests (Glenn, Huete et al. 2008). In general, high NDVI values are attributed to healthy vegetation and low values are linked to poor condition or senescence. This is because; higher values indicate greater light use efficiency and productivity. NDVI has been widely applied to monitor forest health, productivity, phenology, occurrence of drought and fire (Tucker 1979; Glenn, Huete et al. 2008).

2.2.3.2 The Normalized Difference Water Index (NDWI)

The normalized difference water index (NDWI) is a more recent satellite-derived index. It is formulated as the ratio of the NIR and the SWIR bands that reflects changes in water content (absorption of SWIR radiation) and spongy mesophyll in vegetation canopies (Gao 1996; Ceccato, Flasse et al. 2002). It was formulated as

$$NDWI = (\rho NIR - \rho SWIR) / (\rho NIR + \rho SWIR)$$

SWIR region was critical to estimating vegetation water content and the NIR channel was needed to account for leaf internal structure and dry matter content. Therefore, NDWI is sensitive to changes in liquid water content of vegetation canopies (Gao 1996). The values of NDWI range from -1.0 to 1.0. Generally, vegetation can have NDWI ranges from -0.1 to 0.4. Healthy vegetation result in positive values due to the weak liquid water absorption in the near 1.4μm (Gao 1996). Like NDVI, higher values of NDWI are attributed to healthy vegetation as they indicate greater level of productivity and reduced probability of occurrence of fire. NDWI has been applied in vegetation water content evaluation, canopy stress analysis, fire susceptibility mapping, plant productivity modeling and wetland mapping (Jackson, Chen et al. 2004).

2.2.3.3 The Moisture Stress Index (MSI)

Moisture stress is a result of lack of water in the leaves that hampers transpiration (Godbold 1998). MSI is sensitive to increasing leaf water content (Rock 1985). MSI is formulated as

$$MSI = \rho SWIR / \rho NIR$$

The SWIR channel detects free water in vegetation canopy and the NIR channel accounts for leaf structure. The values of MSI range from 0 to > 4. The common ranges of values for vegetation is from 0.4 – 2 (Rock 1985). Low MSI values are related to less canopy water stress therefore are taken as indicator for healthy vegetation. The application of MSI includes vegetation physiology, drought and stress assessment and fire risk analysis (Vidal and Devauxros 1995; Gao, Gao et al. 2011).

3. Study area

3.1. Location and general description of the study area

The Białowieza forest is located at 52^0 $43^/$ N & $23^0 50^/$ E in the heart of the European plains bordering Poland and Belarus (Tomiałojć and Wesołowski 2004). The total forest covers an area of 1250 km^2 from which 670km^2 belongs to Belarus and the rest 580 km^2 is inside the Polish territory (Bernadzki, Bolibok et al. 1998). The Poland part of the forest is shown in the figure 3 below.

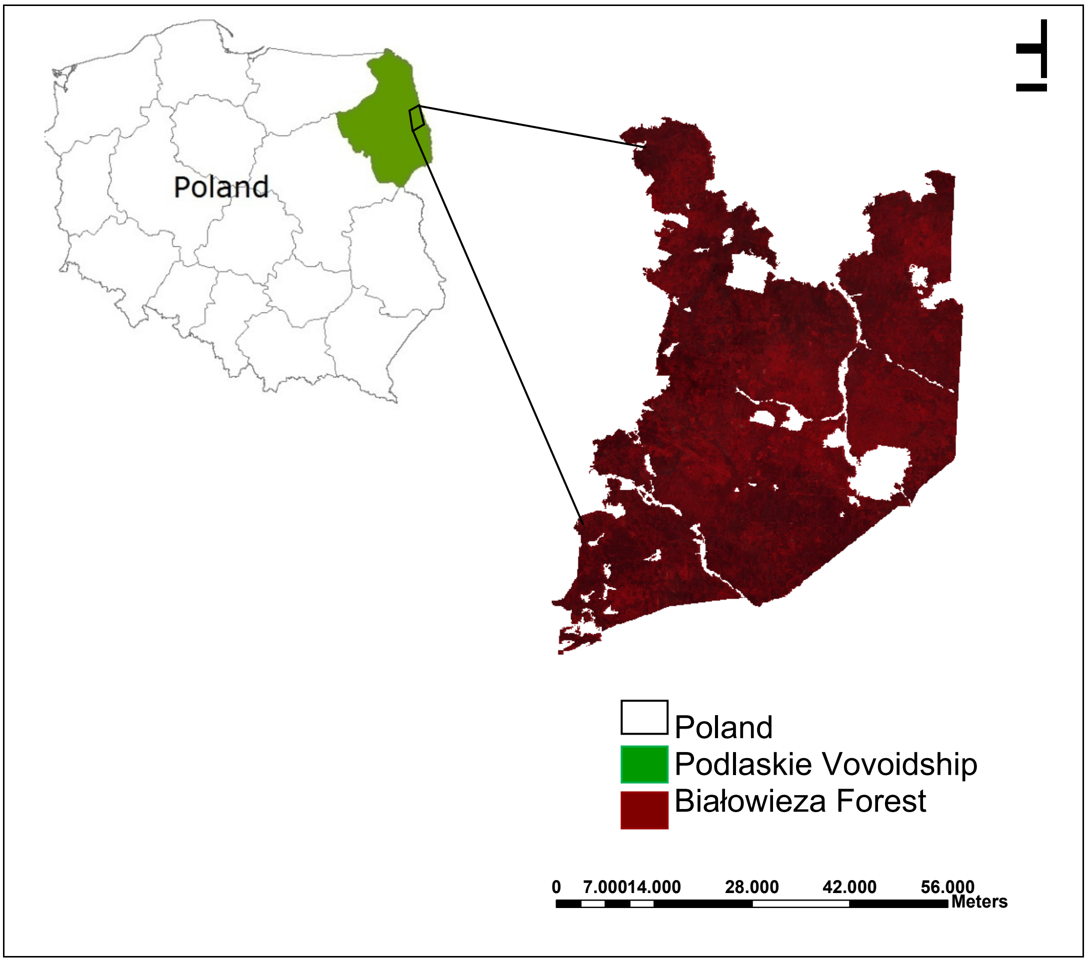


Figure 2: study area:Białowieza forest

The forest has mean temperature of 6.8 ^{0}C, mean precipitation of 641 mm and mean snow cover of 92 days (Falinski 1994). Rainfall accounts for 85% of the precipitation (Bobiec 2012). The forest has flat terrain. Local difference in height hardly exceeds 10m (Faliniski 1986). Moreover, the forest is located under the continental watershed.

North and central parts of the forest are fed by Narew River. Narew is the largest river crossing the forest; however the hydrological axis of the forest is Narewka. It is tributary to the Narew river (Falinski 1994).

3.2. Forest zones and management system in Białowieza Forest

The forest is divided in to a strictly protected area called Białowieza National Park (BNP), fragments of nature reserves, managed forest and open areas including grassland, river valleys and meadows as displayed in Figure 4. BNP is the most important site in the forest in terms of biodiversity and degree of naturalness. Part of the BNP is under strict protection since 1921. This part of the park is called the Old BNP. It has 4700ha and it got enlarged to its current extent of 10500 ha in 1996 (Bernadzki, Bolibok et al. 1998). The nature reserves are used for the conservation of old forest patches that are not large enough to be designated as national park. The managed zone is mainly used for timber extraction. Management practices such as sanitary cutting, collection of dead wood and plantation is carried out in this part of the forest. Open areas are accessible for public use and tourism activates. They include meadows, built up areas and small villages inside the forest.

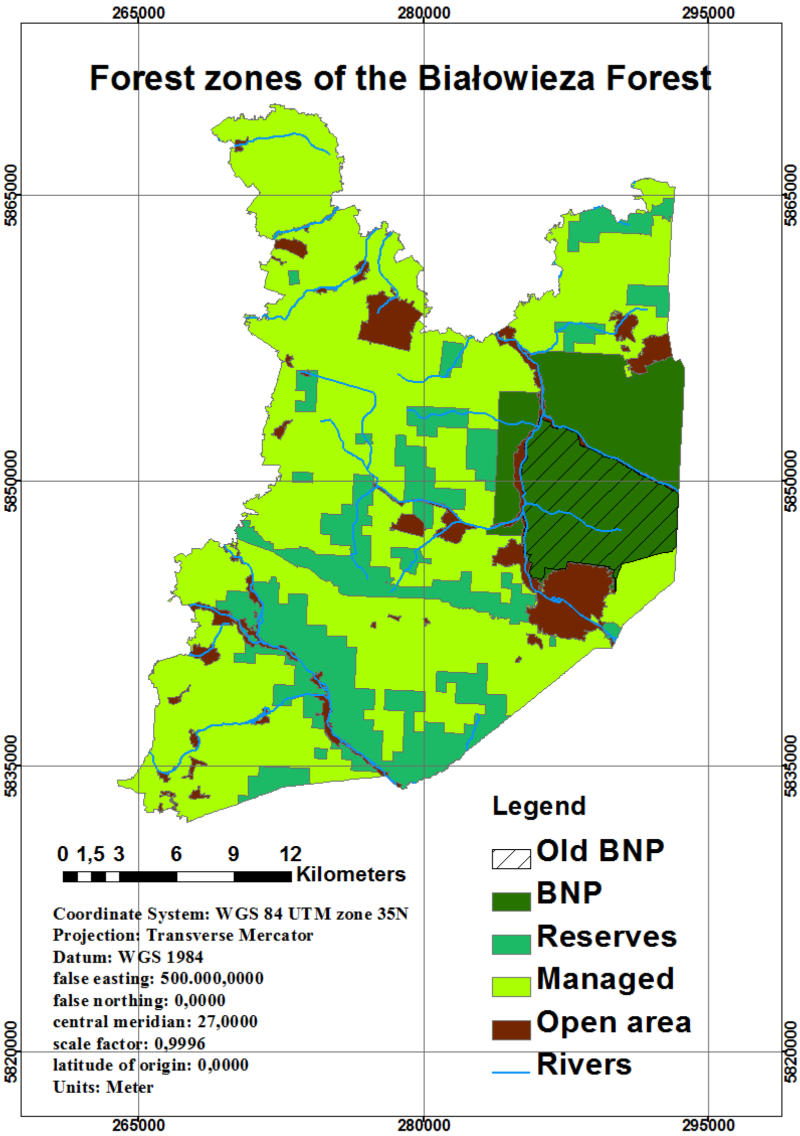


Figure 3 : Map of forest zones of Białowieza Forest

According to the Polish nature conservation policy, BNP fell under strict protection. This implies full protection of the forest from clearing, sanitary cutting or any other forms of human disturbance. This gives the forest opportunity to go through uninterrupted ecological process. The BNP part of the forest therefore serves as a showcase for forests in undisturbed state. Nature reserves stand lower in the hierarchy. In reserves, natural ecosystems such as forests, peat bogs and alpine communities are under strict protection while anthropogenic ecosystems such as grass developed by human and meadows are under active protection. Active protection allows mowing, sanitary clearings or promotion of selected species and removal of invasive species (Roge-Wisniewska 2010). Managed forests are open for commercial timber extraction and plantation. Open areas have no official form of protection or management.

3.3. The vegetation of the Białowieza forest

There is ongoing scientific debate on the degree of naturalness of the BF. The claim that the Białowieza as a primeval or virgin forest is supported in the works of Falinski (1994) and Wesołowski (2005). Some researchers such as Bobiec (2012) however, counterview this claim and suggest that the forest is a remnant of culturally modified ecosystem that has experienced human interference for long period of time.

Regardless of the degree of naturalness, Białowieza has a great wealth of flora that designate it as internationally recognized biodiversity hot-spot (Wesołowski 2007). It contains the most extensive stands of old growth temperate woodland in Europe. It harbors all kind of forest communities possible in its geographical location (Faliniski 1986). It has around 990 vascular and more than 2000 non vascular plant species (Falinski 1994). Furthermore, many tree species grow up to their maximum lifespan. The oldest trees in the forest have the ages between 250-400 years. The Oak is the oldest tree species with about 400 years, followed by the pines 375 and spruce 300 years (Wesołowski 2005).

The vegetation composition of the BF has distinct transitional characteristics. Absences of beech species differentiate it from the western European forests and abundance of oak and hornbeam distinguish it from the forests in the East (Faliniski, 1996). The forest is dominantly covered by deciduous and mixed forest types as can be seen in as indicated in Figure 5. Deciduous are 34.9%, mixed forests are 39.3%, wet alder & ash are 12.6%, coniferous are 6.2% and open habitats are 7% (Kowalczyk, Taberlet et al. 2011). They grow on different habitats zones. The deciduous forests are usually multilayer with high seasonal dynamics and they occupy the nutrient rich fresh habitat. The coniferous forests display lower seasonal variations and they are mostly weakly layered. They inhibit the poor acidic grounds. Mixed forest of Linden, Maple and Hornbeam inhibited the moist and fertile habitat. The Willow grows on the sandy alluvial ground in the large river valleys (Faliniski 1986).

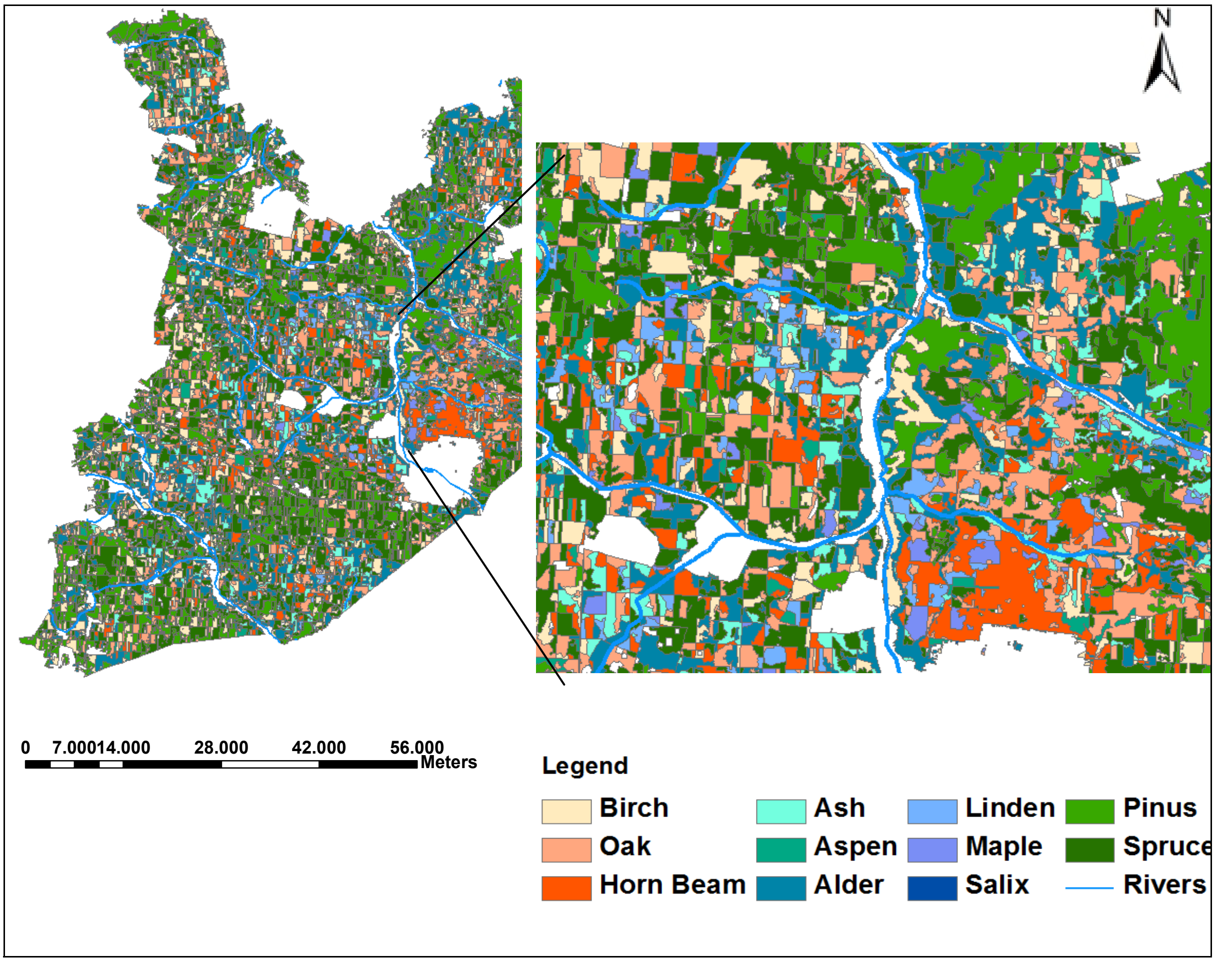


Figure 4: Major tree types of Białowieza Forest source: Institute of Mammal Biology

3.4. Abundance and distribution of trees

The majority of trees in the forest are deciduous. However, per individual tree type the coniferous trees Spruce and Pinus take the leading position in abundance followed by the deciduous trees Alder and Oak.

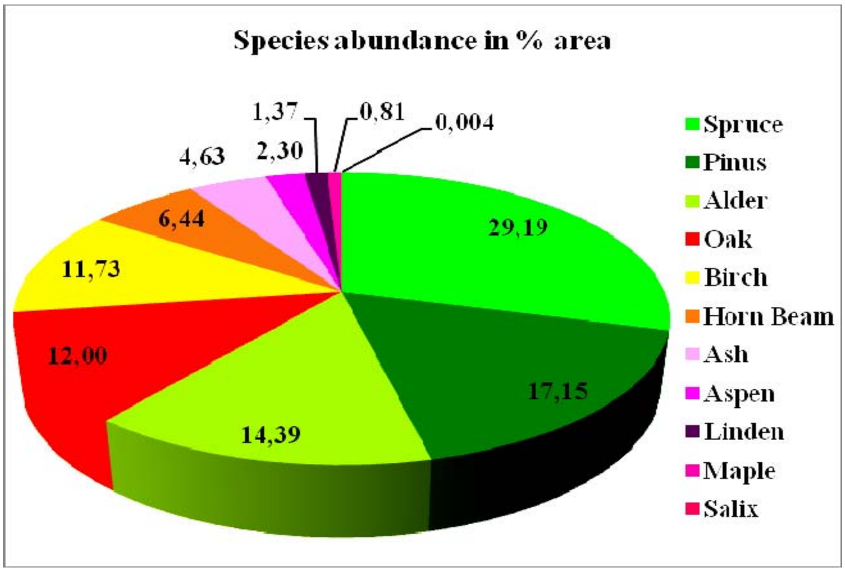


Figure 5: abundance of major tree types source: Institute of Mammal Biology

The two species have fairly even distribution in the different forest zones. Oak is dominant in the oldest section of BNP and it's the third dominant species in the current extents of BNP following Pinus and Spruce. According to Falinski (1994) Oak was more common in the other parts of the forest as well, however, the enormous size and commercial demand of hard wood had let to its decline from the managed part. Spruce and Pinus are the dominant species in the managed zone and nature reserves. Salix, Maple and Linden are rare and they are only found in small parts of the forest.

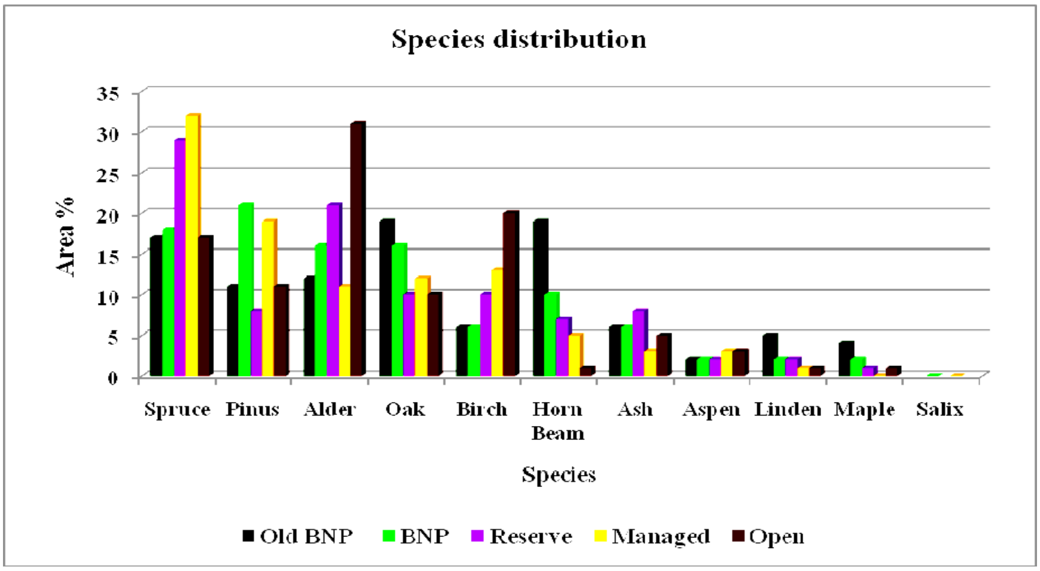


Figure 6: Distribution of major tree type; source: Institute of Mammal Biology

4. Chapter Four Materials and Method

4.1. Research design

The different phases of the research are illustrated in the figure 8 below.

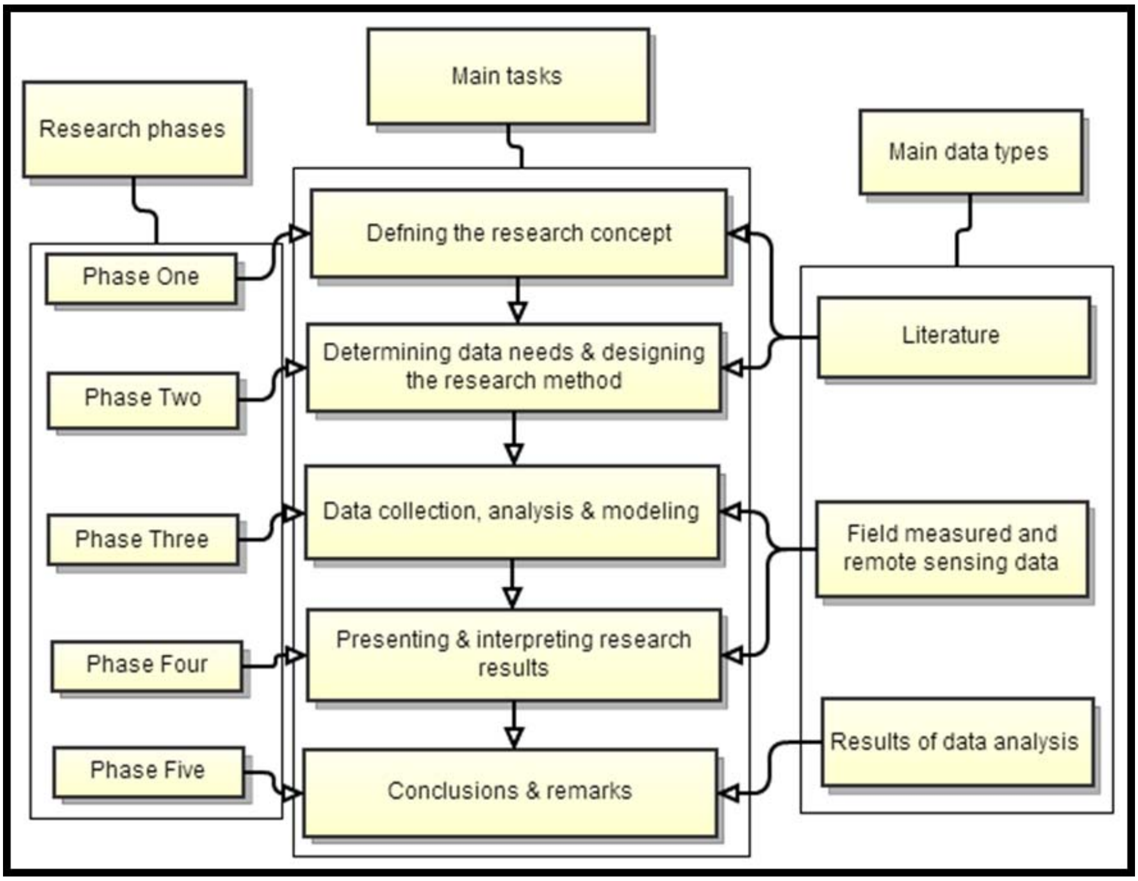


Figure 7: research design

4.2. Rationale

Much of the works carried out on the Białowieza Forest have been based on analysis of transect data collected over small spatial scales. But the Białowieza Forest ecosystem is large. Therefore, cost-effective methods for comprehensively characterizing the vegetation condition were essential. Although field measurements are proven to provide accurate data, the high cost of filed data collection methods have made them unsuitable to cover large area and time frame involved in this study.

Therefore, the study has employed remote sensing data and GIS tools to execute its objectives. Remote sensing has widely proven to be efficient in mapping VC over larger spatial extent (Baret, Houles et al. 2007). Besides, remote sensing and geospatial processing technologies provide non-destructive means of data collection (Jones 2011).

Variety of sensors has been producing remote sensing datasets. Each sensor has its own benefits and drawbacks in resolution, costs and time of acquisition. The choice of the type of sensor or imagery and the complexity of the parameters that can be estimated from the data are therefore, largely dependent on the scope and the focus of the investigation (Wulder 1998). This study has chosen Landsat TM among the ranges of remote sensing datasets that provide high quality and freely available data. This is because Landsat TM has established higher potential for mapping vegetation condition at local scale than the other medium resolution datasets. The 30m spatial resolution makes it favorable to facilitate ground data collection with the imagery, thus assuring homogeneity of vegetation conditions within pixels (USGS 2012). Furthermore, Landsat TM has demonstrated higher accuracy to detect stressed vegetation and stronger correlations with field measurements of moisture content compared to the other medium resolution datasets (De Rose et al, 2011). Although MODIS has higher temporal resolution and more number of bands its spatial scale has reduced its suitability for mapping at local scales (Toomey and Vierling 2005; Meigs, Kennedy et al. 2011). Landsat TM also provides better quality image for the study area than its successor Landsat ETM+ because of the striping effect caused by malfunctioning of the Scan Line Corrector of ETM+.

The study was investigated for the time span of April to end of September 2011. This time duration was chosen because it represented the standard growing season for most of the vegetation in the northern hemisphere. The choice of single year analysis over multiple years was determined based on the scope and the focus of the research. The year 2011 was selected to make use of available field data collected for this year. The investigation of this research was started on October 2012 and it was not possible to collect data for the growing period prior to October 2012 due to practical reasons. Therefore, taking the advantage of available field data for validation process was efficient way to conduct the study. Besides, forests undergo gradual processes unless major disturbances such as fire, insect infestation, and large area clearings took place. None of these situations were reported in the Białowieza forest between 2011 and 2012. Thus, 2011 was considered recent enough to represent the condition of the forest at the time of the study.

Analysis of vegetation condition from remotely sensed data have mainly employed either the use of spectral signature or vegetation indices (Wang, Sammis et al. 2010). This study has used vegetation indices for the analysis of the satellite and field measured data. Vegetation indices provide accurate method to estimate productivity, contents of water and pigments that are essential to characterize VC (Ceccato, Flasse et al. 2002; Glenn, Huete et al. 2008). Further analysis of the data was carried out using statistical methods since the data were quantitative in nature. It is apparent that statistics is suitable for describing, inferring and testing hypothesis of quantitative data.

4.3. Data collection

4.3.1. Remote sensing data

The remote sensing data were acquired from the official USGS Earth Explorer site. The data were obtained few days after official request to the site in TIFF format. Total of twelve scenes were available for the time period of April to end of September 2011. However, only four scenes could be utilized in the study due to large percentage of cloud cover on the rest of the imageries. The four imageries were distributed along the growing season.

Table 2: Landsat TM properties: source: USGS 2011

Sensor Landsat TM; path 186 row 23 Map projection UTM; Datum: WGS 84 UTM ZONE 35		
Scene	**Cloud cover**	**Image quality**
14-04-2011	8%	9

01-06-2011	11%	9
05-09-2011	0%	9
29-09-2011	0%	9

The Landsat is the oldest satellite used in remote sensing of the earth surface. Since 1972 seven satellites have been launched successively with mission to observe the earth. Thematic Mapper (TM) sensor is mounted on Landsat 5 at an altitude of 705.3 km. Landsat 5 has set a record for longest running earth observation satellite. Landsat TM is constructed to attain better spectral differentiation and higher image and radiometric resolutions than the Multi Spectral Scanner System (MSS) sensor (USGS 2012). The detailed spectral and spatial resolution are presented in table 3 below.

Table 3: Landsat TM bands (source USGS, 2012)

Bands	Wave length in µm	Resolution in m
1 (blue)	0.45-0.52	30
2 (Green)	0.52-0.60	30
3 (Red)	0.63-0.69	30
4 (Near Infrared)	0.76-0.90	30
5 (Mid Infrared)	1.55-1.75	30
6(Thermal Infrared)	10.4-12.5	120m
7 (Mid Infrared)	2.08-2.35	30

4.3.2. Field data

Two types of field data were used in this study. The first one was hyper spectral data of sample vegetation from Białowieza Forest. These data were collected by the faculty of Regional Geography, department of Remote Sensing and Geo-Informatics of the University of Warsaw in cooperation with the Institute of Mammal Biology. The data were collected using Field spec 3 plant propping instrument from 26 to 28 August 2011. The department has collected ninety one samples and from these thirty six had registered coordinates with GPS. For each sample feature, twenty five measurements were taken to get representative reflectance value. The data were acquired in table format. The second one was data on major tree types of the Białowieza Forest. These data were acquired from the survey of the Institute of Mammal Biology in vector format. The data were collected and organized per forest compartments. Each compartment or polygon in the vector dataset represented single tree type.

4.4. Software and tools

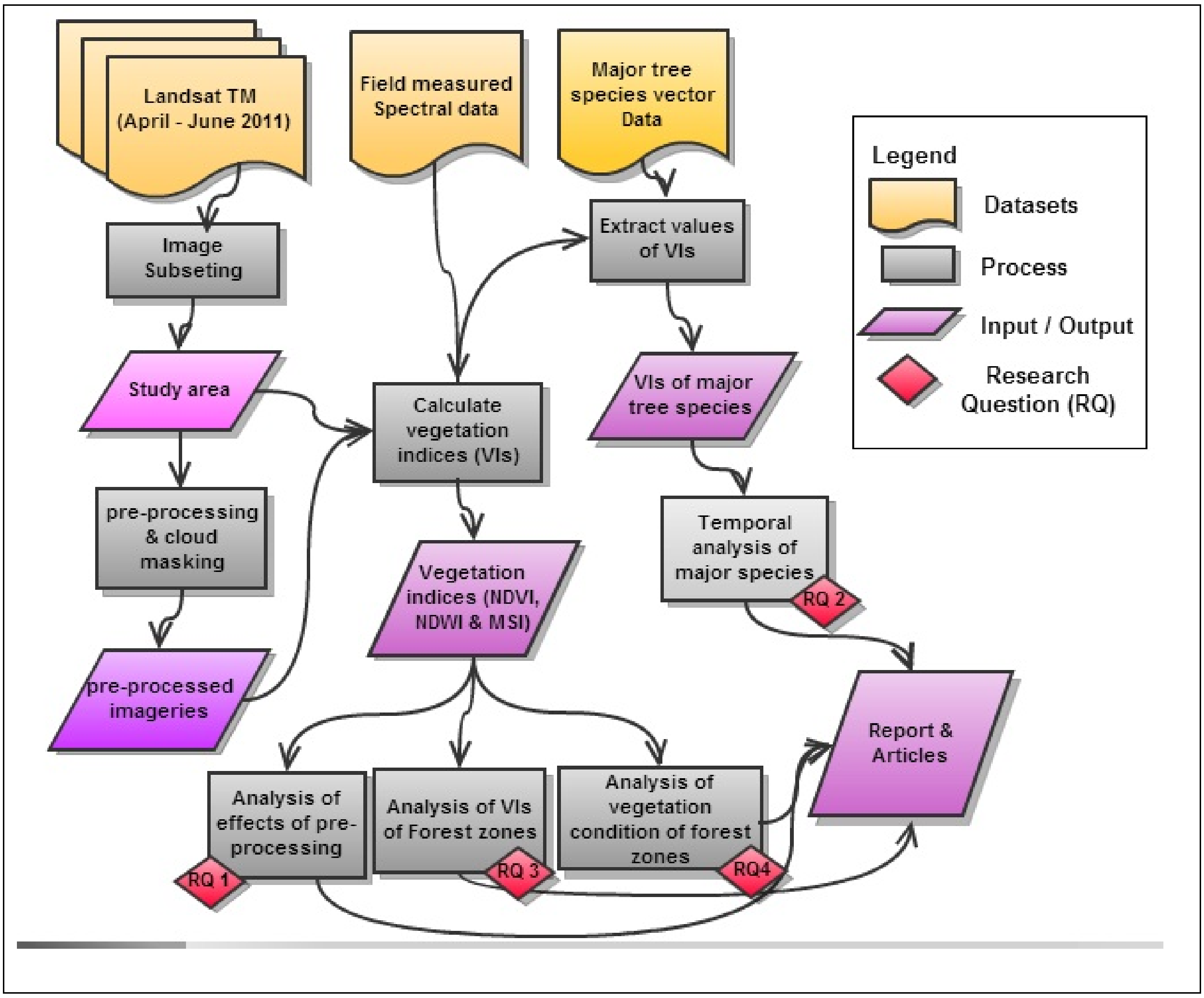
The following tools and software presented in Table 4 were used in the analysis of the remotely sensed and filed measured data.

Table 4: software and tools

Name of software	Purpose of usage
ATCOR 2 flat terrain	Pre-processing
ENVI 4.8	Image processing
Arc GIS 2010	GIS analysis
Statistical	Statistical analysis

4.5. Data analysis

This section describes the steps in the analysis of the data. The general layout of the data analysis is presented in Figure 9 below.



Figuur 8: analysis schema

4.5.1. Pre-processing

The study area was selected from the satellite imageries by using image subseting tool in ENVI 4.8. Subsequently, atmospheric correction and haze removal were performed. The images were pre-processed in "*ATCOR 2 atmospheric and haze correction module for flat terrain*". The module applies partly customized radiative transfer model to convert top of atmosphere radiation to surface reflectance. It requires input information on the date, sensor type, pixel size, and atmospheric type, viewing angle, visibility and optical thickness of the data. ATCOR uses look up tables calculated with MODTRAN 5 radaitve transfer code. This processing system has been reported to produce high accuracy atmospheric correction and haze removal (Dorigo, Richter et al. 2009; Guanter, Richter et al. 2009). In addition, clouds were masked from both original and atmospherically corrected imageries.

4.5.2. Calculation of Vegetation Indices

In this study, three indices namely, NDVI, NDWI and MSI were retrieved using Landsat TM 3, 4 and 5 bands. As described in the second chapter of this report NDVI is sensitive for canopy chlorophyll content, greenness and productivity. NDWI is sensitive to canopy water content and MSI detects canopy moisture stress. Together the three indices were used to estimate vegetation condition (VC). The vegetation indices were calculated on the original, the pre-processed and field measured spectral data. The vegetation indices from satellite data were computed using the "*Band Math*" tool in ENVI 4.8 environment as presented in Table 5. The output files were in ENVI format that could also be analyzed in Arc Map 10.0.

Table 5: Equation of vegetation indices

Indices	Equation	Band Math (b=band)	Sources
NDVI	(ρNIR-ρRED)/ (ρNIR+ρRED)	(float (b4) – b3)/(float(b4)+b3)	(Rouse 1974)
NDWI	(ρNIR-ρMIR) /(ρNIR+ρMIR)	(float (b3) – b5)/(float(b3)+b5)	(Gao 1996)
MSI	ρMIR / ρNIR	(float (b5))/(float(b4))	(Rock 1985)
VC	NDVI*NDWI*MSI	(float (b1)*(b2)*(b3))	

For the field collected spectral data, VIs were calculated on MS Excel. As described above there were hyper spectral reflectance data for thirty six sample points. Each sample had 25 measurements. As a result the average values of the 25 measurements were taken. The spectral band ranges were set according to the seven Landsat TM band ranges in order to facilitate comparison with satellite driven VIs.

4.5.3. Analysis of the effects of pre-processing

This analysis was carried to investigate the effects of atmospheric correction and haze removal on vegetation indices and to determine whether pre-processing of satellite data is necessary for vegetation condition analysis or not. The effects of atmospheric correction and haze removal on the vegetation indices have been analyzed using multiple regression and statistical significant tests of ANOVA and Tuckey HSD Post Hoc. The VIs from the original and pre-processed dataset were extracted for the 36 field sample points using "*extract to point tool*" in Arc Map 10.0. Then, multiple regression, ANOVA and Post Hoc tests were carried out to investigate the relationship and the differences among the VIs produced from the three datasets.

4.5.4. Temporal analysis of NDVI, NDWI and MSI of major tree species

Temporal analysis of NDVI, NDWI and MSI of major tree species were carried out to analyze the effects of temporal variation on vegetation indices. The temporal dimension is taken to investigate the effects of seasonal changes mainly temperature and moisture on productivity and contents of water in different tree types. Fifty sample points were randomly generated for each tree type from the species vector data using "*create random point tool*" in Arc Map 10. In total 550 sample points were generated for the 11 major tree types. These points were used to extract NDVI, NDWI and MSI values from the atmospherically corrected data for April, June, Early and end of September using "*extract to point tool*" in Arc Map 10.0. The VIs were then compared using statistical analysis of ANOVA and Tuckey HSD Post Hoc were carried out.

4.5.5. Comparative analysis of the vegetation condition among forest zones

Comparative analysis of the VIs and VC of the different zones were carried out to investigate the state of each zone in comparison to the other. Furthermore, the analysis was set to investigate the impacts of management or conservation practices on the condition of the vegetation. This analysis was carried out on the image acquired for 05 September 2011 because this data was the closest to the field measured data used for validation purpose. VC was formulated as a function of NDVI, NDWI and MSI. Prior to the calculation of VC, the indices were reclassified using the "*reclassify tool*" as described in Table 6 below to aid their combinations.

Table 6: reclassification values

NDVI	Reclassify	NDWI	Reclassify	MSI	Reclassify
<0,2	1	<0,2	1	<0,5	5
0,2-0,4	2	0,2-0,4	2	0,5 - 1	4
0,4 -0,6	3	0,4 -0,6	3	1 -1,5	3
0,6-0,8	4	0,6 – 0,8	4	1,5- 2	2
> 0,8	5	> 0,8	5	>2	1

In general, lower values to f 1 and 2 represented low or poor condition 3 moderate condition and 4 and 5 good and very good conditions for each indices. The reclassified images were multiplied using the "*raster calculation tool*" to produce VC. The multiplication of the three indices resulted in single dataset that contained values from 1 to 100. Subsequently, these values were reclassified to 1 to 5 as indicated in Table 7 below. The reclassification was made basing on the combination of the VIs.

Table 7: values of vegetation condition

Values of VC	Reclassify	Condition
>80	5	Very good
79 - 36	4	Good
35 - 9	3	Moderate
8 - 2	2	Poor
< 2	1	No vegetation

Accordingly comparative analysis of VC was carried out among the different forest zones using statistical tests of ANOVA and Tukecy HSD post Hoc tests of significance. For this purpose 50 sample points for each of the forest zones were generated using the "*create random point tool*" in Arc Map 10. Values of VC were extracted for this points using "*extract to point*'' tool described above.

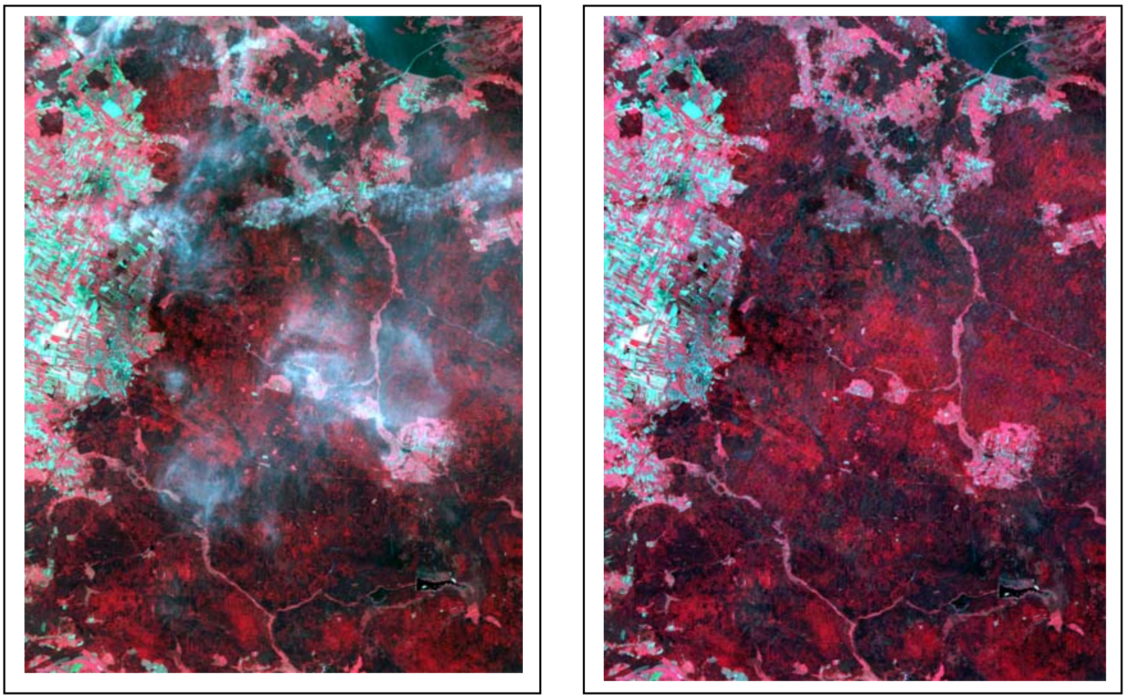
4.6. Validation

The satellite data were validated using the field collected spectral data. Regression analysis was done to investigate the relationship between satellite and field driven vegetation indices. The field measurements were taken from 26 to 28 August 2011. This is a week difference from the early September image acquired for 05 September 2011. Therefore, this imagery has been used for the validation.

5. Chapter five: Results

5.1. The effects of pre-processing

Atmospheric correction and haze removal have resulted in spectral reflectance that resembled to the data measured on the field. It has also eliminated the haze and improved the appearance of the scenes. An example of original and pre-processed images from early September 2011 is presented in figure 10 below. As can be seen from the figures, the pre-processed image appears brighter and clearer than the original image.



(a) (b)

Figure 9: pre-processing (a) original image (b) pre-processed image

The effect of pre-processing was more pronounced in the visible and NIR region than the SWIR. The original dataset had higher reflectance in the visible range and lower reflectance in the NIR range than the pre-processed data. The pre-processed data had sharp increase from red to infrared. However, the SWIR was hardly affected by the pre-processing. As a result, NDVI which computed the reflectance at the red and NIR bands were higher for the pre-processed data than the original data but MSI that computed the reflectance at the SWIR over the NIR was lower for the pre-processed data as presented in Figure 11 below.

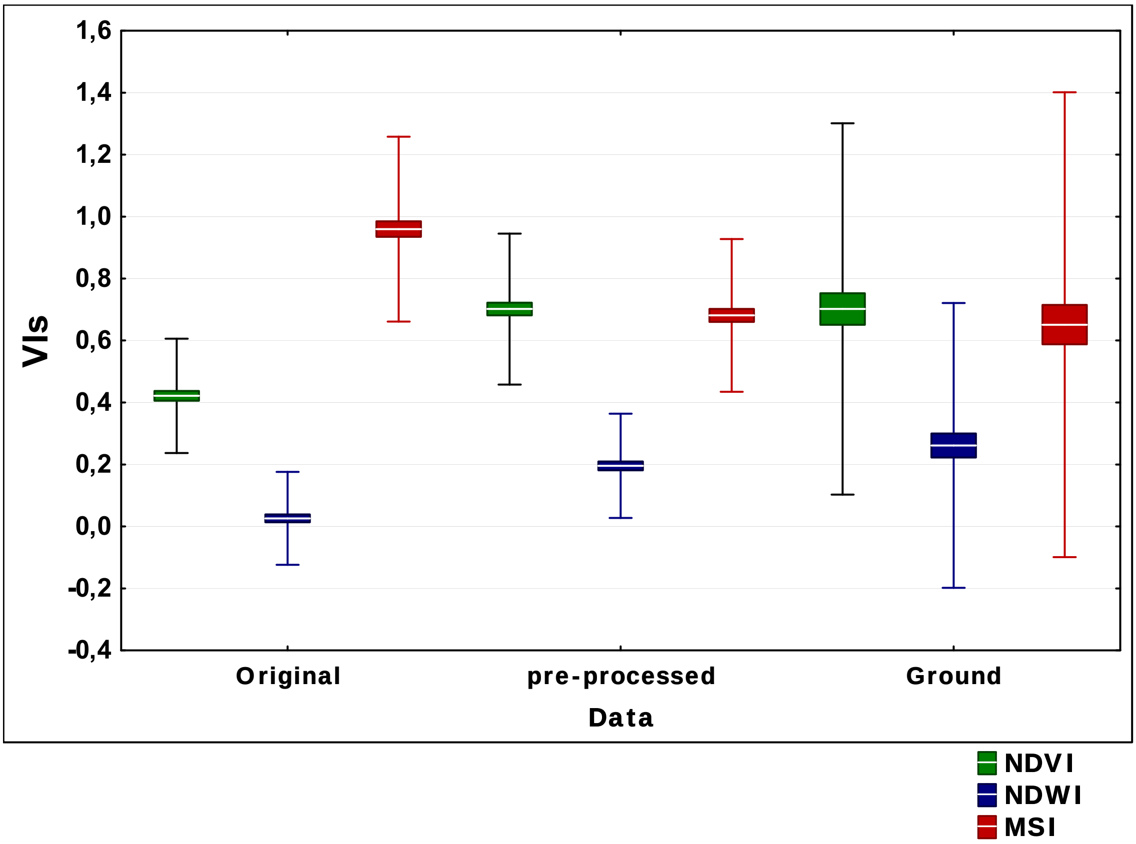


Figure 10: Box plot of VIs; Box: Mean±SE; Whisker: Mean±*2SD

The original data had mean values of NDVI 0,42, NDWI 0,026 and MSI 0,95 while the pre-processed data had mean values of NDVI 0,70, NDWI 0,19 and MSI 0,68. The mean values of NDVI, NDWI and MSI from the field measured data were 0,70, 0,26 and 0,65 respectively. The mean values of VIs from the ground data were closer to the VIs from pre-processed data than to the VIs from original data. The ANOVA and Tuckey HSD post Hoc tests presented in Table 8 resulted in significant differences ($p<0,01$) between VIs of field measured and original data. However, there were no significant difference ($p>0,05$) between the VIs of ground measured and the pre-processed data.

Table 8:Approximate Probabilities for Post Hoc Tests; red signify p<0,05

Data type	NDVI			NDWI			MSI		
	Error: Between MS = 0,03773, df = 102,00			Error: Between MS = 0,02184, df = 102,00			Error: Between MS = 0,05941, df = 102,00		
	Original	Pre-processed	Ground	Original	Pre-processed	Ground	Original	Pre-processed	Ground
Original		0,0001	0,0001		0,0001	0,0001		0,0001	0,0001
Pre-processed	0,0001		0,999	0,0001		0,155	0,0001		0,866
Ground	0,0001	0,999		0,0001	0,155		0,0001	0,866	

Regression analysis also resulted in stronger relationship between VIs from field measured data and pre-processed data than with indices driven from the original dataset. All the three indices produced from the ground measurements were better correlated with the pre-processed than the original datasets.

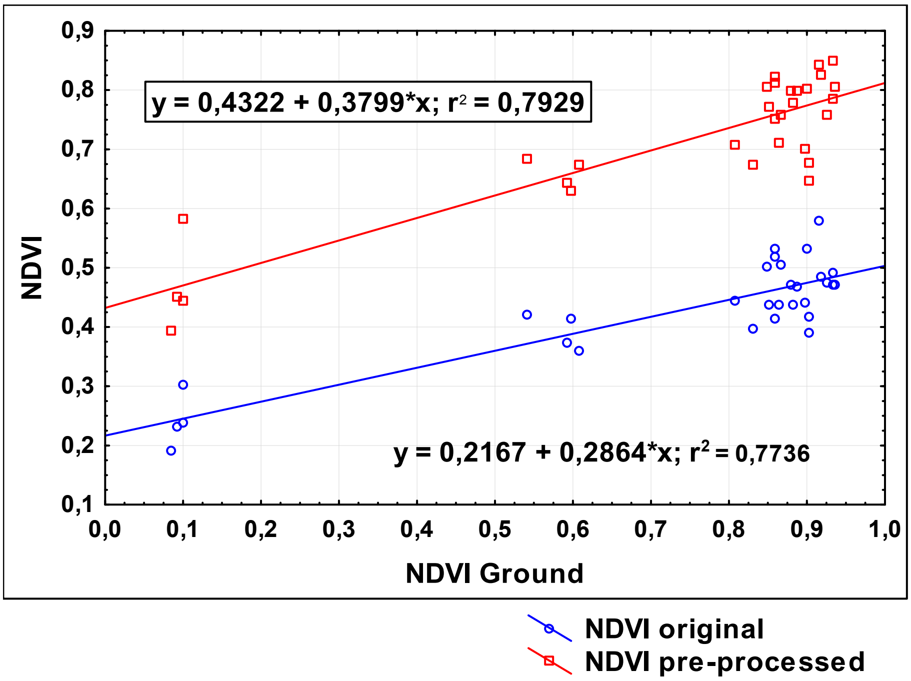


Figure 11 scatter plot of NDVI ground vs. original and pre-processed data

As indicated in figure 12 NDVI of field measured and ground data had stronger relationship (R^2=0,79) than with NDVI from original data (R^2=0,77).

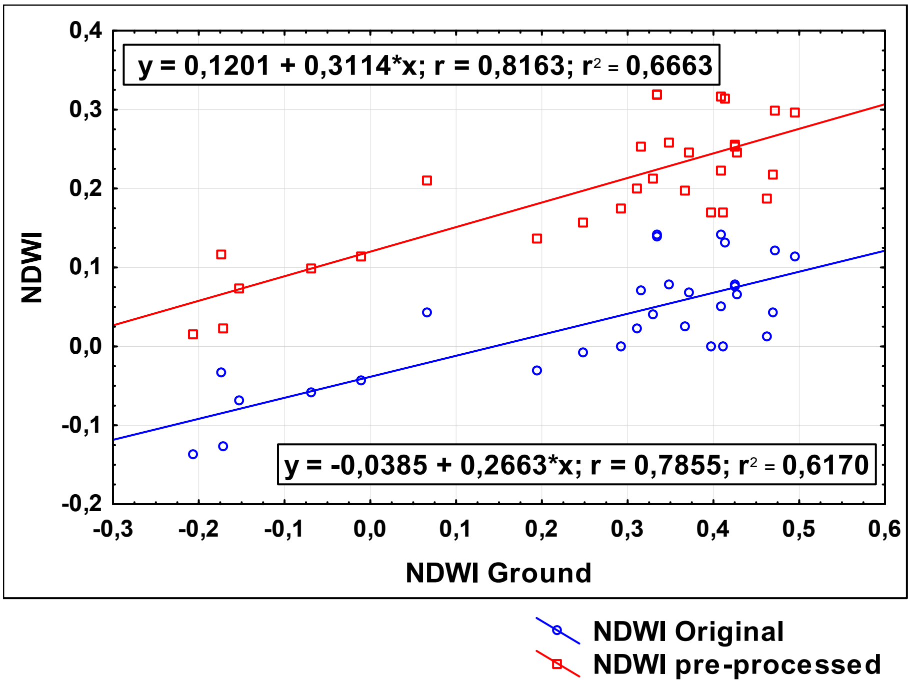


Figure 11: scatter plot of NDWI ground vs. original and pre-processed data

As can be seen in figure 13 above, the NDWI from the ground data was also more correlated to the pre-processed data (R^2=0,66) than the ground data (R^2=0,61).

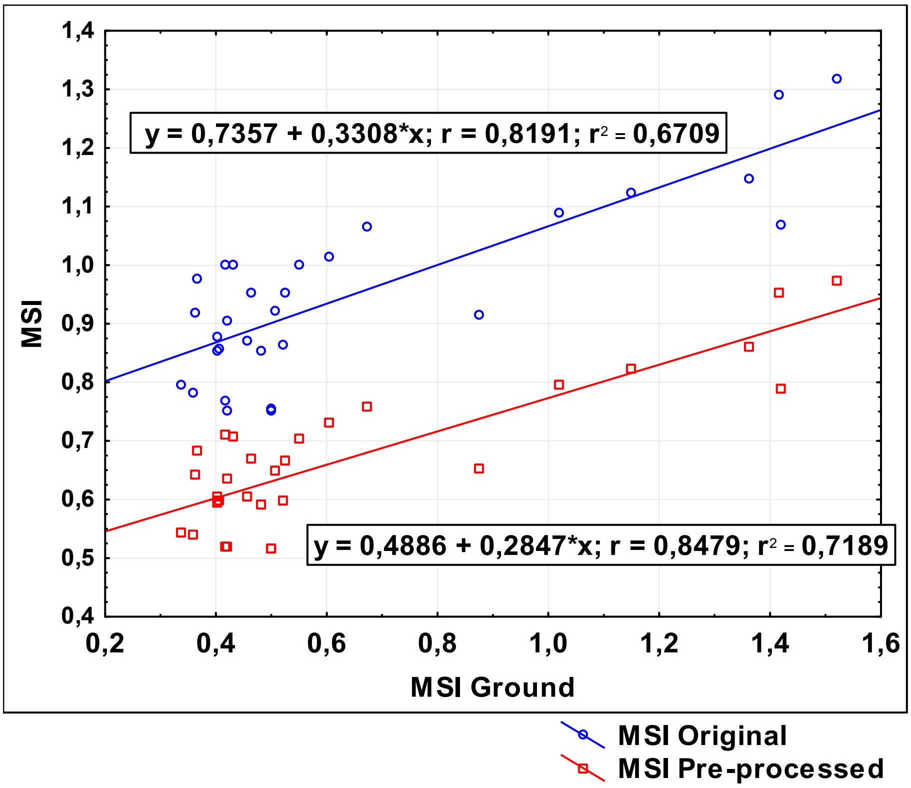
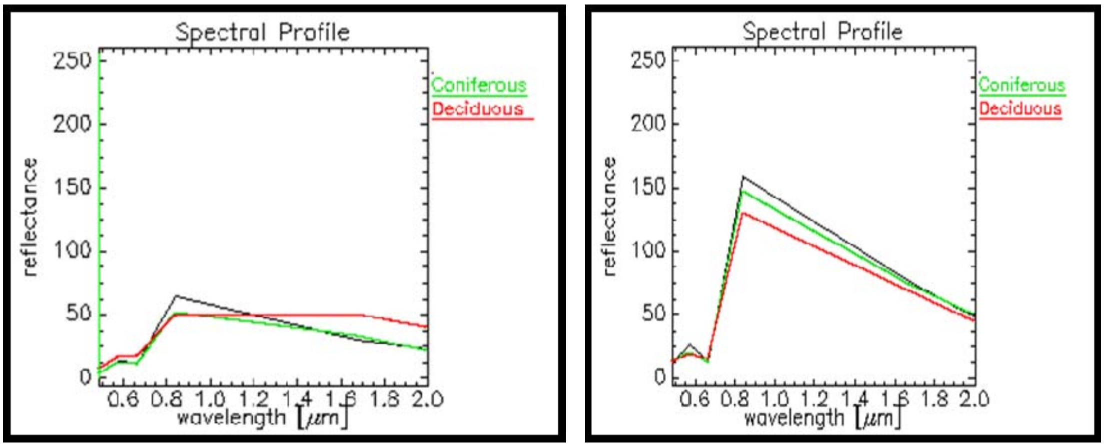


Figure 12 scatter plot of MSI ground vs. original and pre-processed data

Like the other two indices the MSI was more correlated (R^2=0,71) with the pre-processed data than the MSI from the original data (R^2=0,67) as presented in figure 14 above.

5.2. Temporal analysis of vegetation indices of major tree species

The temporal analysis of vegetation indices revealed the effects of seasonal variations on the vegetation greenness, canopy water content and canopy moisture stress. As presented in figure 15 the spectral reflectance of the coniferous and deciduous trees show temporal variations. In April, the spectral reflectance of coniferous trees were similar in the NIR (0,76-0,90µm) but lower in the red (0,63-0,69µm) and in the SWIR (1,55-1,75µm) region. In June, however, the reflectance values of the two species were in reverse order thus causing variations in their NIR to red and SWIR to NIR ratios in the different time periods.



(a) **(b)**

Figure 13: Spectral profile of major tree species (a) April 2011 and (b) June 2011

5.2.1. The Normalized Difference Vegetation Index (NDVI)

As can be seen in Figure 16 below, the vegetation went greener with increasing NDVI values from April to June substituted by gradual decrease from June to late September.

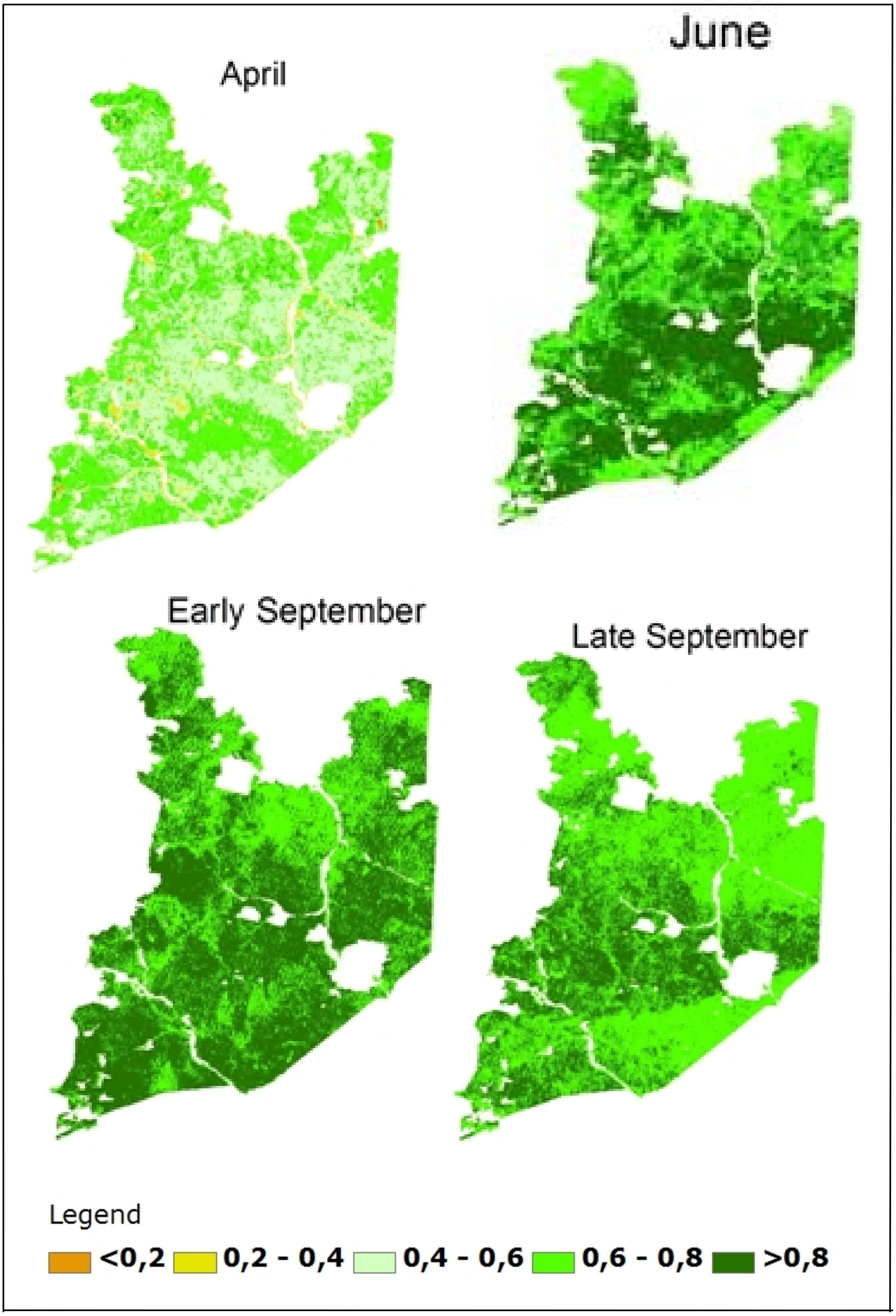


Figure 14: NDVI in the growing season

The mean NDVI ranges were from 0,46 for Salix to 0,68 for Pinus in April; from 0,71 for pinus to 0,87 for Linden in June; from 0,79 for Alder to 0,83 for Maple in early

September and from 0,73 for Salix to 0,79 for Linden in late September as presented in Figure 17 below.

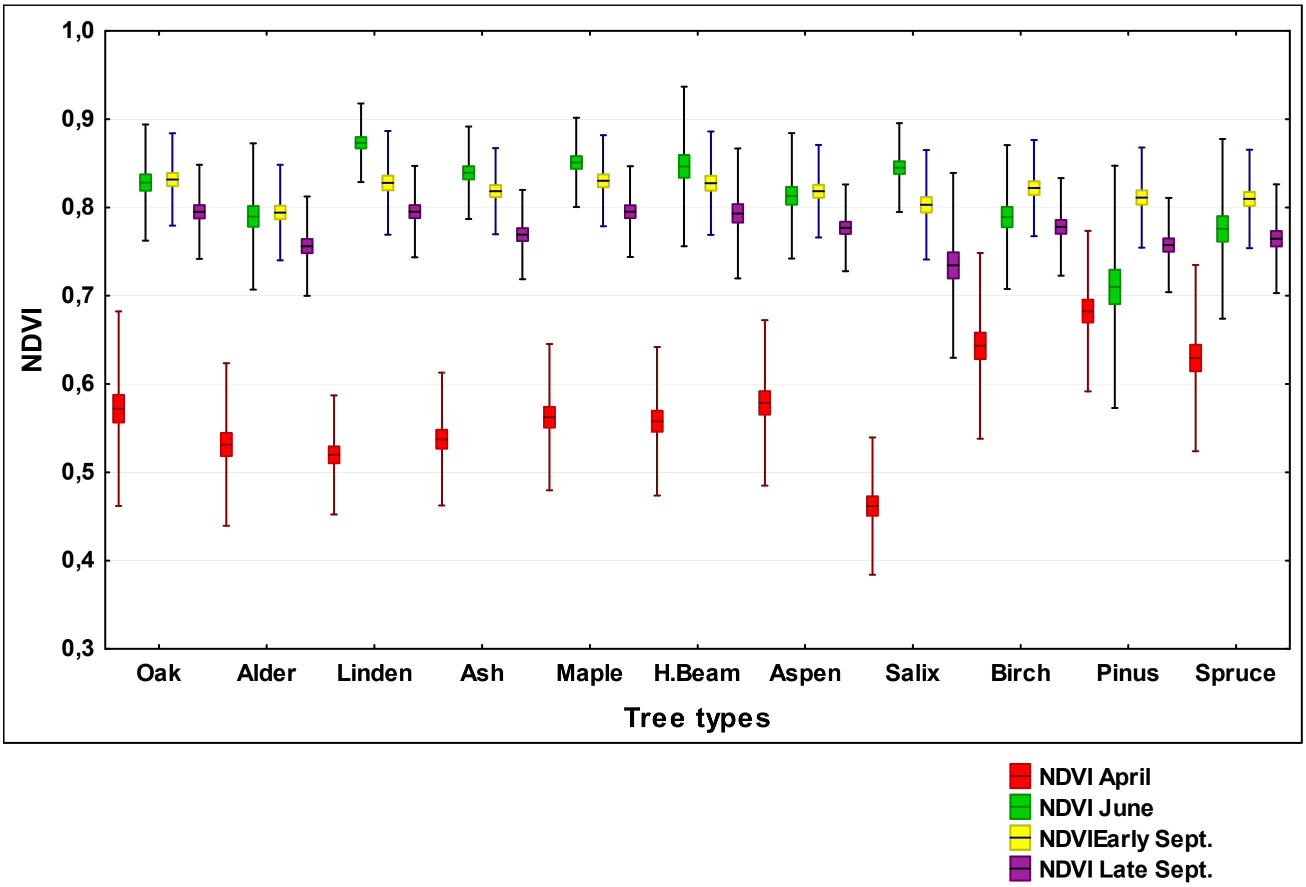


Figure 15: Box plot of NDVI of major tree types; Box: Mean±SE; Whisker: Mean±SD

As presented in the Annex 4 NDVI values of deciduous and coniferous trees were significantly different ($p<0,01$) in April, June and late September. This can be result of high sensitivity of deciduous trees to seasonal variations in temperature and moisture. In April, deciduous trees are in the process of growing new leaves and at the early stage of photosynthetic activity. Thus their chlorophyll content and leaf area were relatively small. Coniferous trees unlike the deciduous trees keep their needle leaves throughout the year. In warmer seasons they are only engaged in substitution of dead needles. Hence, in April they already have higher amount of green needle leaves exposed for sunlight that resulted in higher NDVI values.

In June this pattern was reversed. Deciduous trees had significantly higher ($p<0,01$) NDVI than coniferous trees. This can be result of the characteristics flat leaves, broad canopies and multi layer structure of deciduous trees that accounted for higher level of exposure to sunlight and photosynthetic activity. In early September, there were no significant differences ($p>0,05$) in NDVI between the two species. This denoted that the stable greening period for the Białowieza Forest was in this time period. Subsequently in late September, NDVI values of deciduous trees became significantly lower ($p<0,01$) than the coniferous trees following leaf senescence.

5.2.2. The Normalized Difference Water Index (NDWI)

The NDWI also exhibited differences temporally. Like NDVI, NDWI also had increasing trend from April to June which has indicated increase in canopy water content followed by subsequent decrease towards the end of the growing season as indicated in figure 18 below.

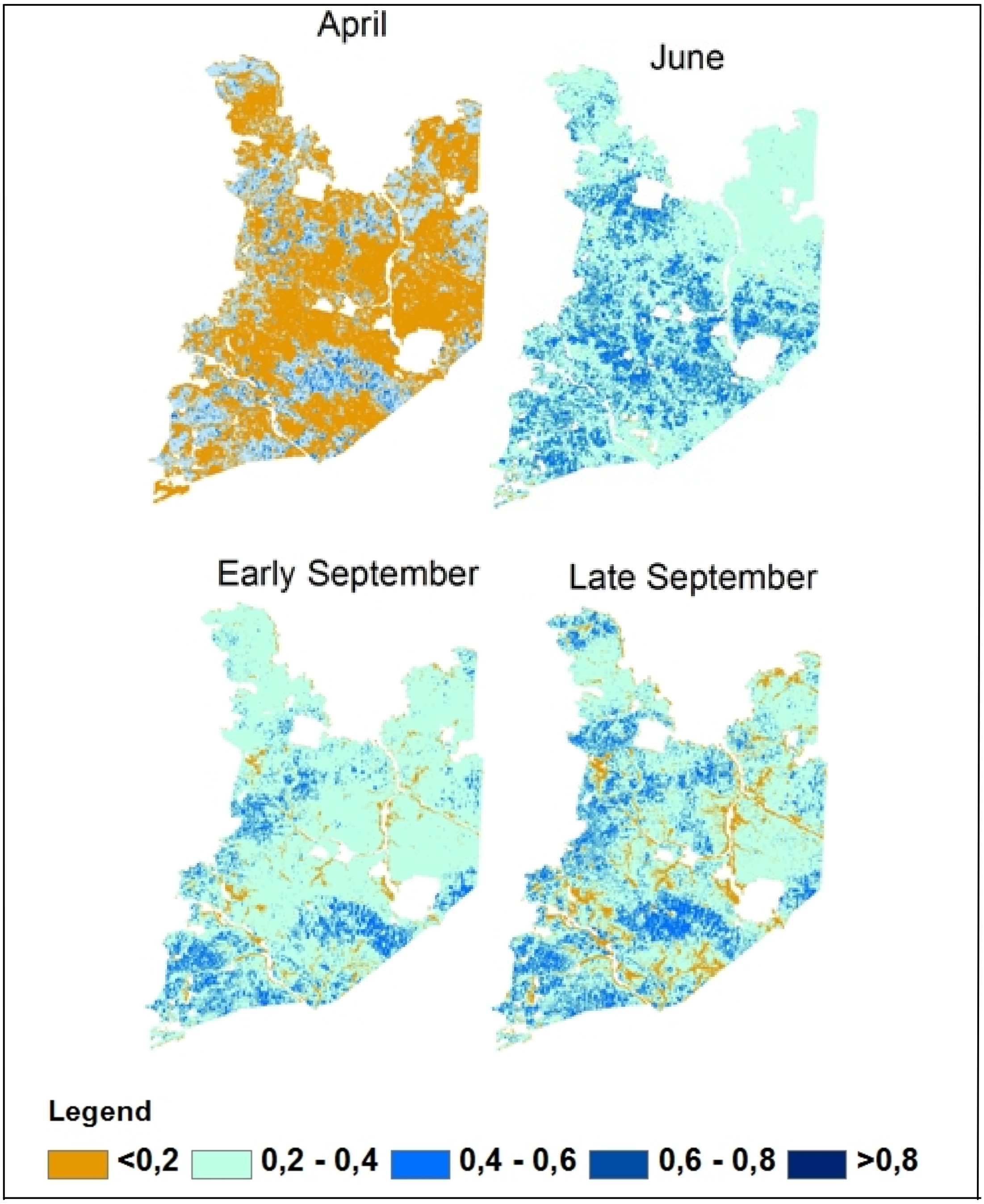


Figure 16: NDWI in growing season (April - September 2011)

As indicated in Figure 19 below, the mean NDWI ranges were from -0,12 for Salix to 0,283 for Pinus April; from 0,337 for Pinus to 0,39 for Linden in June; from 0,26 for Salix to 0,35 for Spruce in early September and from 0,19 for Salix to 0,37 for Pinus in late September.

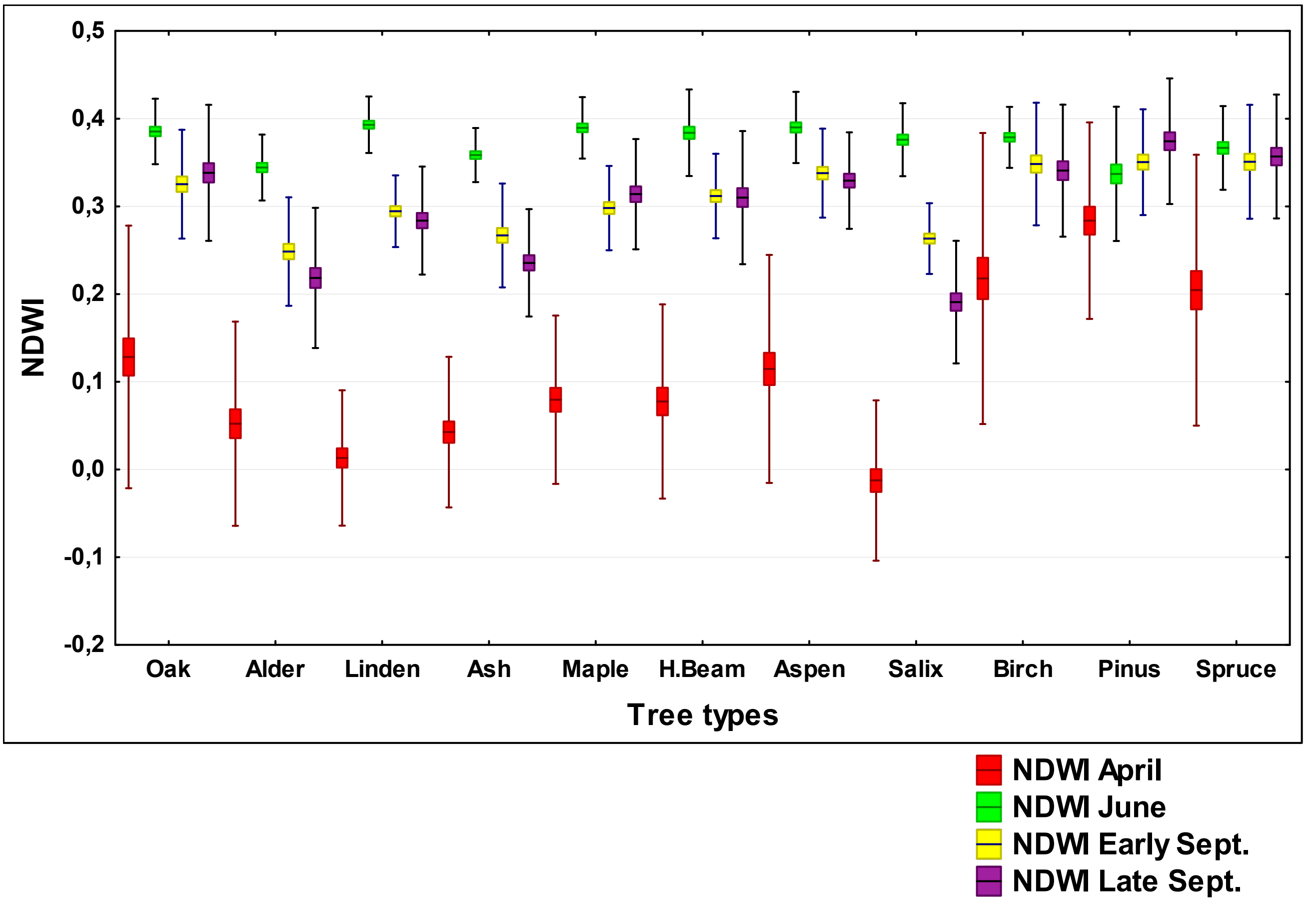
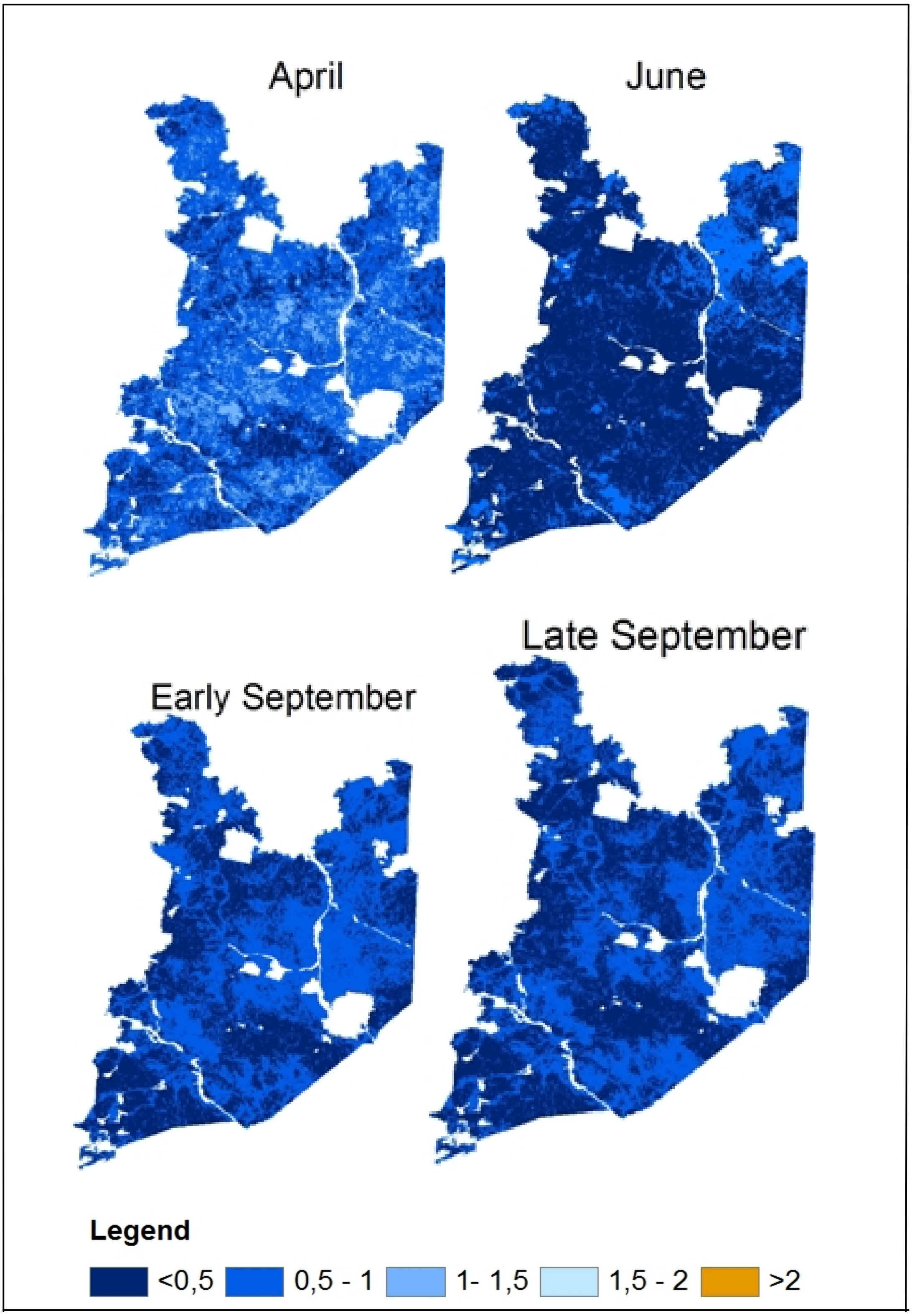


Figure 17: Box plot of NDWI of major tree types; Box: Mean±SE; Whisker: Mean±SD

As presented in the Annex 4 NDWI values of deciduous and coniferous trees were significantly different (p<0,01) in April, June and early September. There were no significant differences (p>0,05) in late September. The NDWI trend from April to June followed similar pattern as that of NDVI. Thus similar explanation of leaf growing dynamic can held valid for the difference in NDWI values of deciduous and coniferous trees in April and June. The broad and flatter leaf of the deciduous trees can held much water in the leaves and canopies in its peak growth than the needle leaved trees. Thus, they generate low NDWI values in April at the start of the growing season and high values in June at the peak of the growing season. However, NDWI showed different trend from June to end of September. Unlike the NDVI, NDWI had significant differences (p<0,01) in early September between deciduous and coniferous trees. This indicates that difference NDVI was preceded by differences in NDWI. This can be an explanation that green canopies or leaves have the probability to be dry. But the effects of reduction in water content were noticed in subsequent reduction of NDVI in late September while NDWI did not show any significant difference ($p>0,05$) in this period.

5.2.3. The Moisture stress Index (MSI)

As can be seen in Figure 20, unlike NDVI and NDWI; MSI, had a reverse trend from April to June and from June to late September. The values of MSI went decreasing from April to June indicating decrease in water stress substituted by gradual increase from June towards the end of September.



Figuur 18: MSI in growing season (April - September 2011)

MSI values ranged from 0,57 for Pinus to 0,98 for Ash in April; from 0,43 for Aspen to 0,5 for Pinus in June, from 0,48 for Pinus to 0,60 for Alder in early September and from 0,67 for Salix to 0,45 to Pinus in end of September.

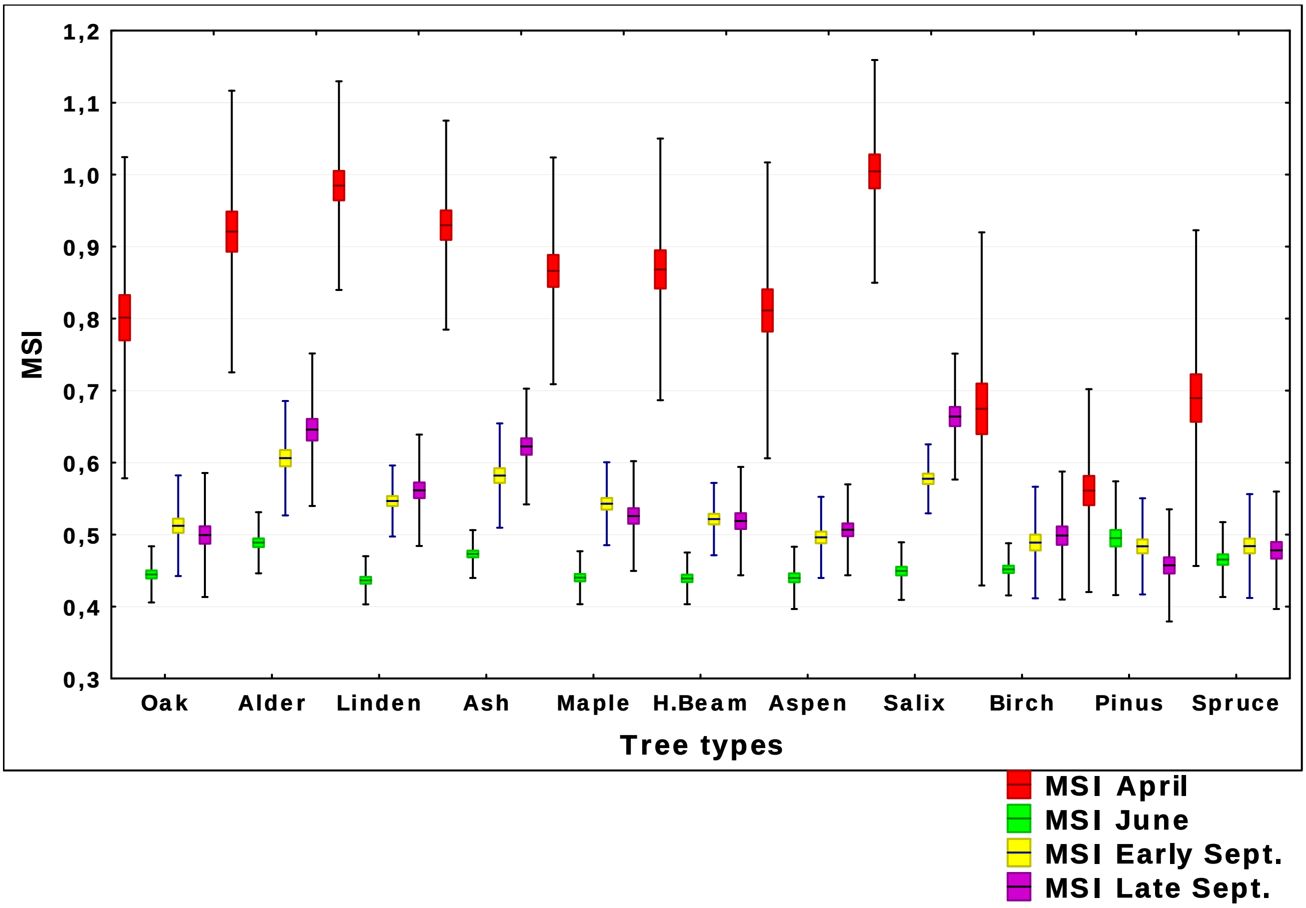


Figure 19: Box plot of MSI of major tree types; Box: Mean±SE; Whisker: Mean±SD

MSI values had reverse trend than NDWI as it measured the SWIR over the NIR to estimate the moisture stress of vegetation. Thus, from the four temporal ranges, values of MSI were significantly different ($p<0,01$) between coniferous and deciduous trees in April, June and early September. In April and early September deciduous trees had higher moisture stress than the coniferous tress. However, in June they had lower moisture stress than the coniferous trees.

In general, both tree species and the different tree types within the species were in healthy range of NDVI, NDWI and MSI as presented in table in table 9 below.

Table 9: mean ranges of vegetation indices for deciduous and coniferous trees for early September 2011

NDVI		**NDWI**		**MSI**	
Deciduous	Coniferous	Deciduous	Coniferous	Deciduous	Coniferous
0,79- 0,83	0,80-0,81	0,24-0,34	0,35-0,35	0,48-0,60	0,48-0,48

5.3. Analysis of the vegetation condition among forest zones

The collective effects of the vegetation indices were analyzed through the vegetation condition which is driven as a multiplication factor of the three indices (NDVI, NDWI and MSI). As discussed in the Method chapter of this report the multiplication of the three indices were preceded by reclassification. Thus the resulting VC values were from 1 to 100. The maxiumum possible VC value was 125 but there was no pixle with this value. Acordingly, the VC were also reclassified to 5 classes to aid mapping of the forest which is presented in figure 22 below.

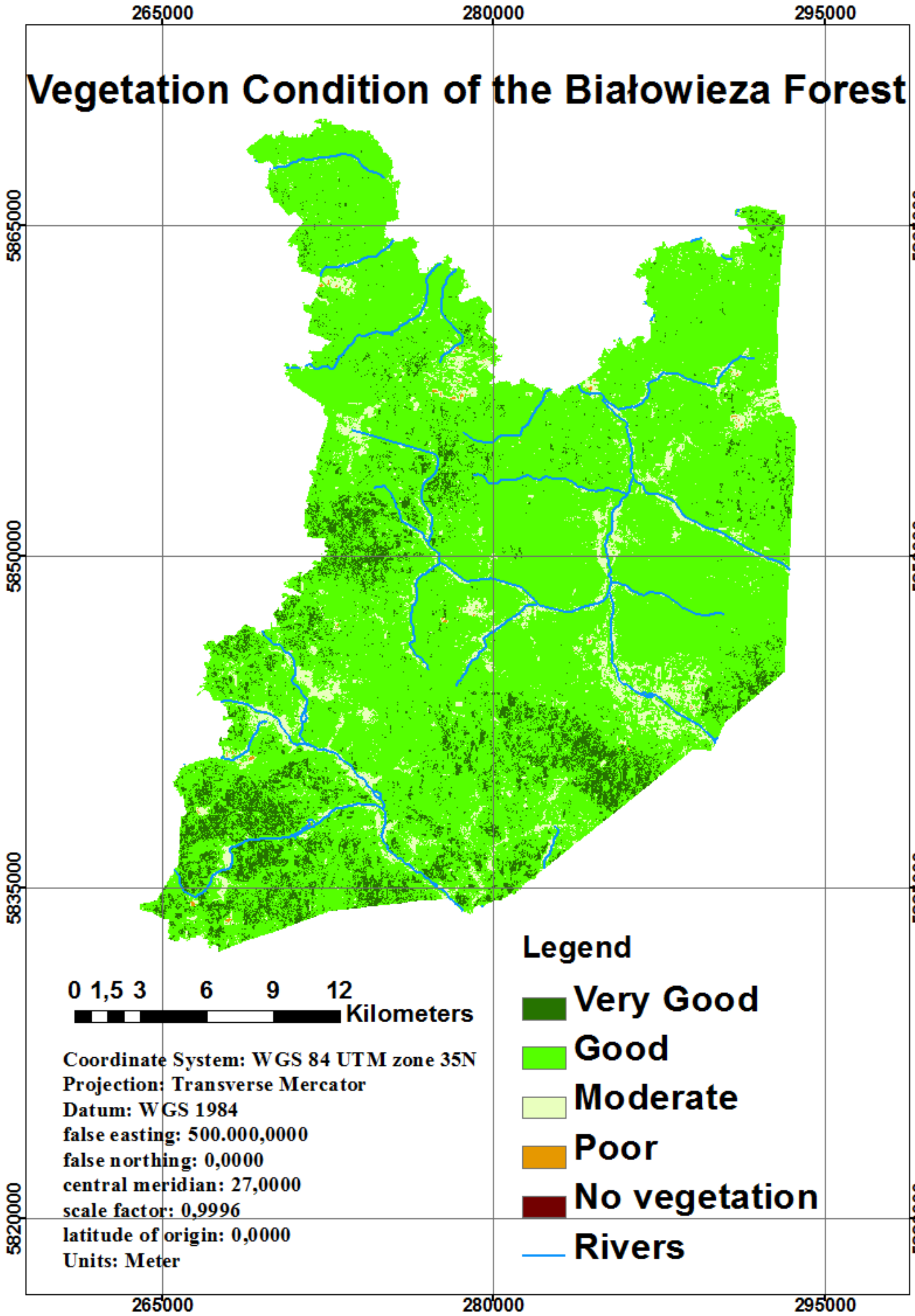


Figure 20: Vegetation condition map of the Białowieza forest

The results of the analysis on vegetation condition of the forest zones showed that more than 80% of the forest was in good condition as presented in Figure 22 below. Only less than 5% of the forest was in poor state.

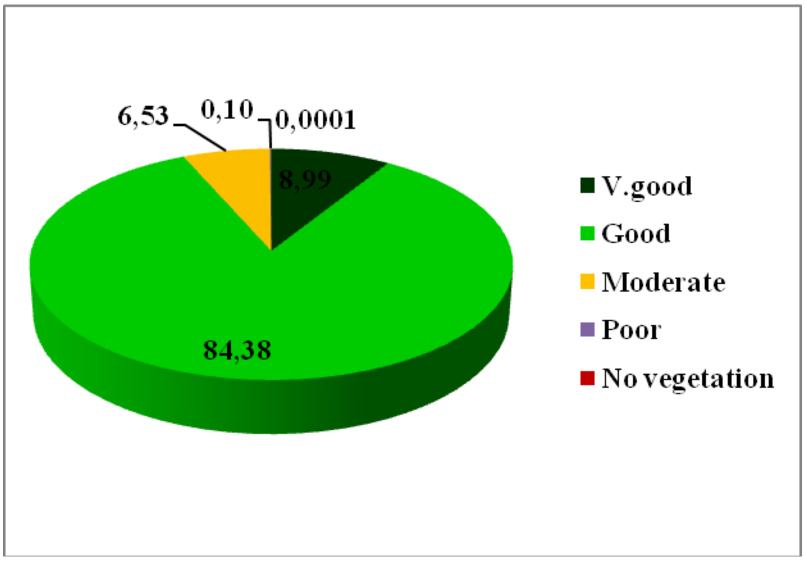


Figure 21: vegetation condition of the Białowieza forest

The condition of the forest zones is presented in the figure 23 below, as can be seen from the figure, the managed forest had the highest condition per area followed by the three protected zones.

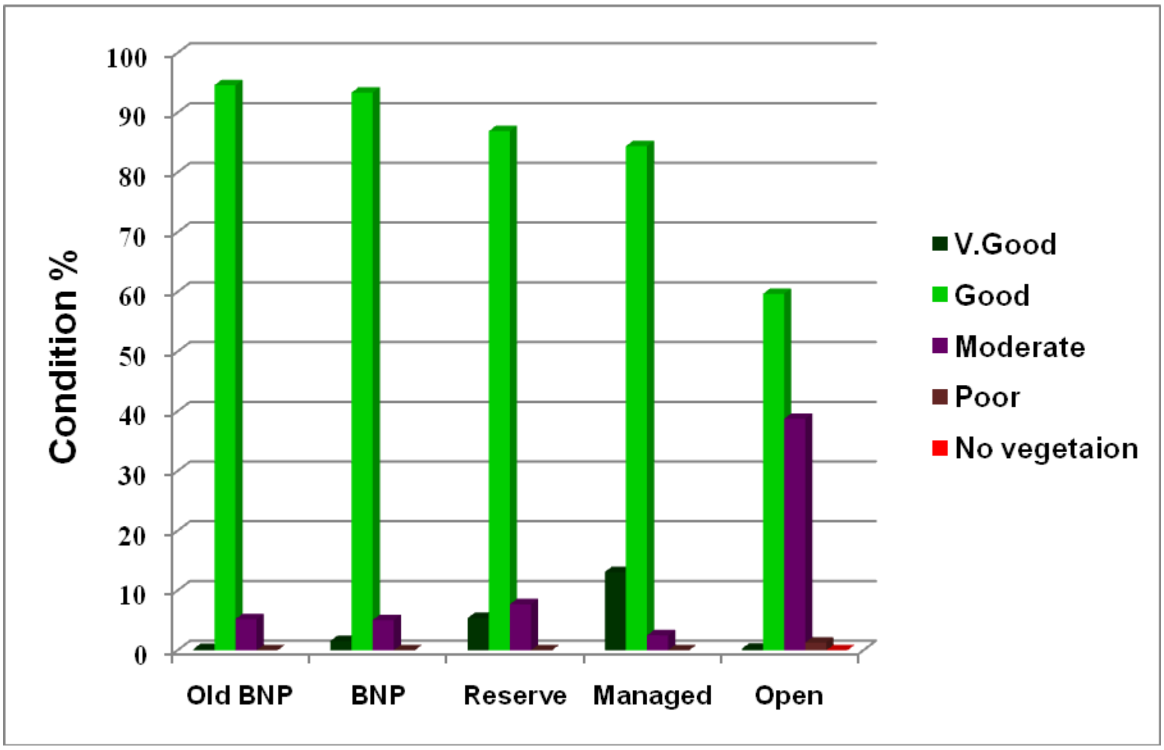
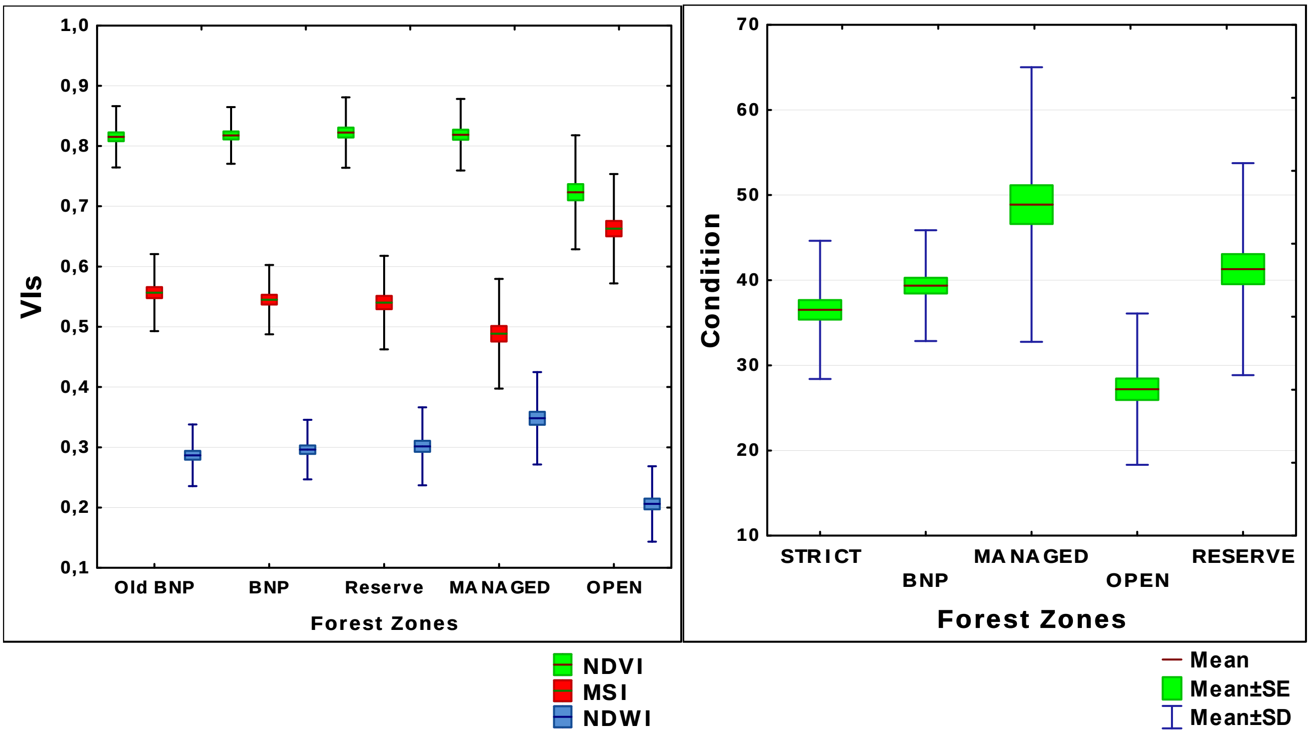


Figure 22 vegetation condition of forest zones

The results of the analysis of the vegetation indices and the vegetation condition of the forest zones is presented in Figure 23 below.



(a) (b)

Figure 23: (a) Box plot of vegetation indices per forest zones; Box: Mean±SE; Whisker: Mean±SD (b) vegetation condition per forest zones

As can be seen in the figures above, the managed part had the highest NDVI (mean= 0,82) and NDWI (mean=0,32) and the lowest MSI (mean=0,49) values. Subsequently, its condition was higher (mean=48,88) than the rest of the forest zones. While the open areas had the lowest NDVI (mean =0,72) and NDWI (mean=0,21) and the highest MSI (mean=0,66) that has resulted in lower VC values (mean=27,20) than the rest of the zones. The protected zones (Old BNP and BNP) had mean values of NDVI, 0,81 and 0,82; NDWI, 0,29 and 0,30 and MSI, 0,56 and 0,54 respectively. The actively protected nature reserves had mean NDVI of 0,82, NDWI of 0,30 and MSI of 0,54 values. The strictly protected zones and the nature reserves had moderate VC values. Mean values of VC for old BNP, BNP and nature reserves were 36,52, 39,36 and 41,30 respectively.

The ANOVA and Post Hoc test result of the vegetation condition indicates no significance difference (p>0,05) among the protected areas (old part of BNP, BNP and the reserves). However, the conditions of the managed zone and open areas show significant differences (p<0,01) from the protected zones as indicated in Table 10 below.

Table 10: Approximate Probabilities for Post Hoc Tests; red=p<0,05

Tukey HSD test;
Error: Between MS = 120,49; df = 245,00

Zone	Old BNP	BNP	Reserve	Managed	Open
Old BNP		0,695180	0,188262	0,000017	0,000224
BNP	0,695180		0,903033	0,000154	0,000017
Reserve	0,188262	0,903033		0,005049	0,000017
Managed	0,000017	0,000154	0,005049		0,000017
Open	0,000224	0,000017	0,000017	0,000017	

The values of vegetation indices as well as the vegetation condition have illustrated the possible relationship among the condition of the forest zones and the management or conservation practices implemented on the zone. The high VC values of the managed zone are possible result of the intensive management practices executed in this part of the forest. Dead wood and dying trees are cleared from this part of the forest and substituted by young trees as part of a management practice. Furthermore, sanitary cutting is employed to control insect infestation and disease. Moderate values of VC in the protected zones of Old BNP and BNP could be resulted as a consequence of absence or limited management interventions. The vegetation in these three zones has undergone uninterrupted natural processes which imply that these zones are exposed to natural disturbances such as insect infestation and disease. Furthermore, mature and dead trees are left untouched in these zones that possibly contribute to lower VC. The very low values of VC in the open zone demonstrated the state of the forest in the absence of management or conservation practice.

5.4. Validation

The satellite data was validated using vegetation indices from the field measured and the atmospherically corrected data. Regression analysis have been carried out between NDVI, NDWI and MSI from the atmospherically corrected data and the ground measured data. The results are presented in tables 11, 12 and 13 below.

Table 11: Regression Summary for NDVI from ground and pr-processed data

R= 0,89043285 R²= ,79287065 Adjusted R²= 0,78547317 F(1,28)=107,18 p<0,00000 Std.Error of estimate:0,05506

N=30	b*	Std.Err. - of b*	b	Std.Err. - of b	t(28)	p-value
Intercept			0,432180	0,028927	14,94044	0,000000
NDVI_G	0,890433	0,086009	0,379863	0,036692	10,35284	0,000000

Table 12 Regression Summary for NDWI from ground and pr-processed data

R= 0,81626532 R²= 0,66628907 Adjusted R²= 0,65437082 F(1,28)=55,905 p<0,00000 Std.Error of estimate: 0,04956

	b*	Std.Err. - of b*	b	Std.Err. - of b	t(28)	p-value
Intercept			0,120053	0,014264	8,416781	0,000000
NDWI_G	0,816265	0,109171	0,311427	0,041652	7,476961	0,000000

Table 13 Regression Summary for MSI from ground and pr-processed data

R= ,84786558 R²=0 ,71887603 Adjusted R²= 0,70883589 F(1,28)=71,600

p<0,00000 Std.Error of estimate: ,06628

N=30	b*	Std.Err. - of b*	b	Std.Err. - of b	t(28)	p-value
Intercept			0,488553	0,024777	19,71787	0,000000
MSI_G	0,847866	0,100201	0,284715	0,033648	8,46169	0,000000

Overall there is fairly strong correlation (r>0,8) between vegetation indices from satellite and field measured datasets. The NDVI values of satellite and ground measured data were strongly correlated r=0,89 than the NDWI r= 0,82 and MSI r= 0,85. The correlation between satellite and field measured data can be affected by several factors. First, the reflectance at leaf and canopy level are not identical. Measuring reflectance at canopy level consider additional parameters such as leaf architecture, leaf area index (LAI), clumping, canopy height, density, non-photosynthetic canopy elements and understory vegetation that can reduce the relationship between the two data sources.

6. Discussions

6.1. The effects of pre-processing

The results of pre-processing have indicated that the visible and the NIR ranges were the most affected bands by atmospheric interaction than the SWIR. (Liang, Fang et al. 2002) has also demonstrated that the SWIR is less susceptible for atmospheric components such as haze thus it is less affected by atmospheric and haze correction. Atmospheric correction and haze removal have resulted in enhanced data quality that increased the correlation with field measured spectral data. The findings of different other studies are also aligned with the results of this analysis. For instance, (Hadjimitsis, Papadavid et al. 2010) has found 18% mean difference in NDVI values between atmospherically corrected and uncorrected images derived from Landsat TM and concluded that atmospheric correction is vital part of pre-processing for VIs produced from Landsat TM 1, 2, 3 and 4 bands . (Hilker, Lyapustin et al. 2012) has also achieved up to 10% reduction in noise level by applying atmospheric correction. Furthermore, (Mahiny and Turner 2007) has illustrated that failure to take the effects of the atmosphere in to consideration might result in significant discrepancies in further processing of the data. They have particularly emphasized on the need for atmospheric correction in the analysis of VIs.

6.2. NDVI, NDWI and MSI of major tree types

Temporal analysis of the VIs marked clear distinction between coniferous and deciduous trees in response to seasonal variations in productivity, canopy water content and canopy moisture stress. The seasonal dynamics was more pronounced in the deciduous trees. As also described by (Falinski 1994) deciduous trees showed more seasonal dynamics than coniferous trees in the forest. This is result of the impact of temperature in temperate broad leaved trees as described by (Chuine, 1999). It can be seen from the analysis that although deciduous trees started increasing in both NDVI and NDWI and reduce in MSI from April to June, their NDWI values significantly decreased prior to their NDVI. This phenomenon illustrated that decrease in NDWI did not immediately result decrease in NDVI. This reveals that green trees have probability to have drier canopies. The findings of (Jackson, Chen et al. 2004) have also illustrated that dry vegetation can stay green for some time range. However the extension of the analysis in to the next temporal range has indicated the delayed impacts of NDWI on NDVI. This implies that green vegetation cannot represent good condition since green plants might experience water stress that is not detectable by only applying NDVI. Therefore, in single scene analysis NDVI might not be effective to estimate vegetation condition alone.

At their peak greening period the deciduous trees had higher NDVI and NDWI values than the coniferous trees. This phenomenon has been explained by (Curran, 1982) as caused by the differences in projected leaf areas of the two species temporally. As indicated in their findings, the more flat and exposed leaf structure of the deciduous trees have enabled them to absorb more light and flatter leaves produce higher NIR reflectance that is exhibited in the high NDVI values at their peak greening period. coniferous trees have also showed differences in NDVI, NDWI and MSI across the growing season. Therefore, the results indicated that seasonality has to be encompassed in the analysis of vegetation condition particularly those of deciduous trees since they exhibit high seasonal dynamics.

6.3. Vegetation condition among forest zones

Comparison among the four forest zones have shown differences in condition. The vegetation condition of the managed zone were higher than the rest of the other zones and the condition of the open areas was the lowest. However there were no significance difference ($p>0,05$) among the old part of the BNP, the BNP and the reserves. Old BNP, BNP and nature reserves have been under strict and active conservation for long period of time. This might have triggered for the vegetation in these zones to develop similar condition.

The high condition values of the managed forest can be results of continuous management and intervention mechanisms such as sanitary clearings, cutting and collection of dying and dead wood and plantation carried out in this zone. Sanitary clearings prevent widespread infestation therefore enhances the health of the forest. In addition, collection of dead wood and substitution of dying trees by young trees boost the productivity of the forest in this zone. Young and healthy trees are more productive and generate more chlorophyll than dead, dying or maturing trees (Wang, Sammis et al. 2010). This is because as the findings of (Huete, Liu, Batchily, & van Leeuwen, 1997) indicates NIR is sensitive to photo synthetically active vegetation than dead or photo synthetically passive vegetation. On the contrary, the low VC values in the open areas are possible indication of uncontrolled human intervention and disturbances taking place in this zone.

The vegetation condition of the reserves did not show significant difference from the old and current zones of the BNP. This indicates that the active protection practiced in the strict reserves did not result in wide differences in terms of vegetation condition from the strictly protected BNP. Although the different between the VC values of the three zones were not significance ($p>0,05$) the mean values were apparently different from each other. The oldest and the most natural section of the BNP had the lowest mean values (VC=36,52) and the reserves had the highest (VC=41,30). This further illustrates the possible link between vegetation condition and absence or presence of management intervention. The Old BNP was under strict protection for almost 100 years. Since then it has been excluded from any form of human intervention. However, the BNP contains some parts that are added later as buffer zone. This parts were formerly part of the managed zone thus they have been subjected to intensive management practices prior to their inclusion as part of the strictly protected area. Although the nature reserves are also protected some management practices such as sanitary cutting are performed in this zone that most probably contributed to the higher values of VC than the old and current BNP zones.

Even though the result seem to contradict with previous studies that highly esteemed the BNP in terms of its ecosystem values, the relatively low vegetation condition values might be results of the abundant old growth and dead trees find in these zones as indicated by (Wesołowski 2007) and (Żmihorski and Durska 2011). The relatively low values of VC then could be taken as possible indication to the higher degree of naturalness reported in their studies.

7. Conclusions and remarks

7.1. Conclusions

The results of this research showed the advantages of remote sensing and the use of VIs in the analysis of forest vegetation condition and related management or conservation practices. The following conclusions were drawn from the results of this study.

1. One of the principal limitations of remote sensing is the issue of data quality. The result of this study has demonstrated that atmospheric correction and haze removal are essential parts of pre-processing in the analysis of vegetation indices particularly computed along the visible and NIR spectrum are highly affected by atmospheric interaction. Atmospheric correction and haze removal can therefore result in significant differences ($p<0,01$) as in this study. This can create discrepancies in the analysis of the data. Overlooking the effects of the atmosphere can therefore, significantly affect the application of satellite data.
2. The analysis of vegetation condition currently involves the utilization of spectral Vegetation Indices (VIs). In this research NDVI, NDWI and MSI were used to assess the VC of the Białowieza Forest. They have resulted in fairly strong correlation ($r>0,8$) with field measured NDVI, NDWI and MSI data. This illustrates that VIs can be used for precise detection and estimation of plant vigor, contents of water and other parameters of VC spatially and temporally.
3. The temporal analysis of VIs for the major tree types of the forest showed variations among the different tree types. The NDVI, NDWI and MSI of both tree species and the different tree types within the species have varied temporally. In general both species exhibited healthy VI ranges in the growing season of 2011. Aspen, alder, Ash, Maple, Linden and Salix from the deciduous trees and Pinus from the coniferous trees had more pronounced and extreme values in different time periods. Oak, Birch and horn Beam from the deciduous trees and Spruce from the coniferous trees were relatively moderate. However, in order to conduct more detailed analysis between the

species, other parameters need to be taken in to account in addition to the analysis of VIs. This is because both greenness, photo synthetic activity and canopy water content are highly affected by seasonal changes in light intensity, temperature and moisture content. Consequently, it was not possible to differentiate if the high or low values of VIs were caused as response to seasonality or due to unhealthy condition.

4. The comparative analyses among the different forest zones have revealed significant differences ($p<0,01$) among the vegetation condition of the forest zones. Highly disturbed parts of the forest had low VC while the actively managed zone had high VC and forests in strict and active protection (Old BNP, BNP and reserves) have resulted in relatively lower VC. These results also highlight the role of vegetation condition as reflection to the type and intensity of management or conservation practices implemented on the forest.
5. These results suggest that old or pristine zones of the forest (BNP and reserves) although are reported to have high ecosystem values they do not have exceptionally high condition. From these we can conclude that high vegetation condition values do not necessarily refer to high biodiversity or greater degree of naturalness. Therefore, the results of this study should be viewed in light of previous studies carried out on these subjects to fully characterize the forest.

7.2. Remarks

7.2.1. Limitations

The study had some limitations. The first limitation was data. Although Landsat TM had good spatial resolution the temporal and spectral resolution of the sensor has constrained the study in certain ways. The 16 days temporal resolution do not facilitate for image selection for higher quality data. This has hindered the continuous analysis of the vegetation throughout the growing season as initially planned. Another limitation of Landsat TM is its spectral resolution. It only has seven spectral bands with wide band range. While these bands are favorable to assess overall plant condition they are not suitable to derive other parameters that require narrow bands.

For instance plant stress due to disease and contents of leaf chemicals such as nitrogen and carbon could not be detected Landsat.

There were also limitations on the method applied. Most prominent of this is the fact that vegetation indices are species, site and time dependent. Although these characteristics of VIs have advantages it also make the results of VIs from one study difficult to be applied to other studies. In addition, field measured spectral reflectance samples were representing vegetation in the measurement range of the instrument however, the Białowieza is complex forest ecosystem with tall trees. Achieving higher correlation with satellite data was therefore a challenge.

7.2.2. Further research

The results of this study as well as the challenges and limitations met through the course of the research present opportunity to further research in this area. another remote sensing datasets can be utilized in addition to the Landsat TM to compensate for its course temporal and spectral resolution. In addition, the effects of natural and anthropogenic disturbances such as clearings, cuttings or insect infestation can be included in the further analysis of the forest in addition to complement the limitation of vegetation indices.

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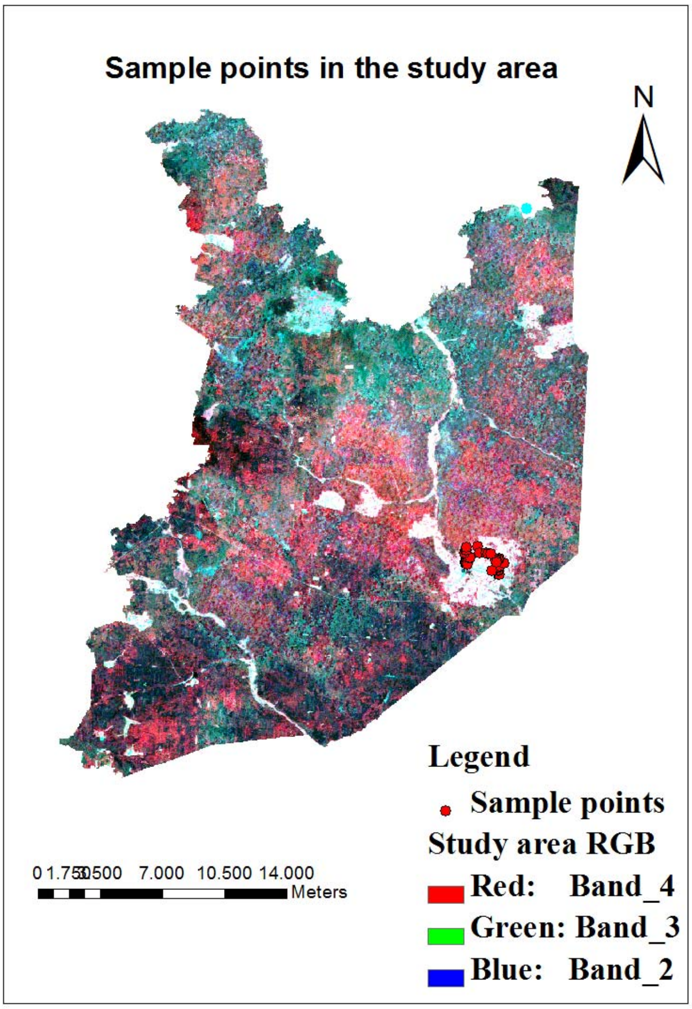
Annexes

Annex 1 field measured sample points



Annex 2 field measurements

Date	Sample number	Name	Type	Class	X_UTM	Y_UTM
26-08-2011	1	road asphalt	man-made	roads	5842800,79	694089,29
26-08-2011	2	grass	vegetation	grasses	5842831,02	694144,94

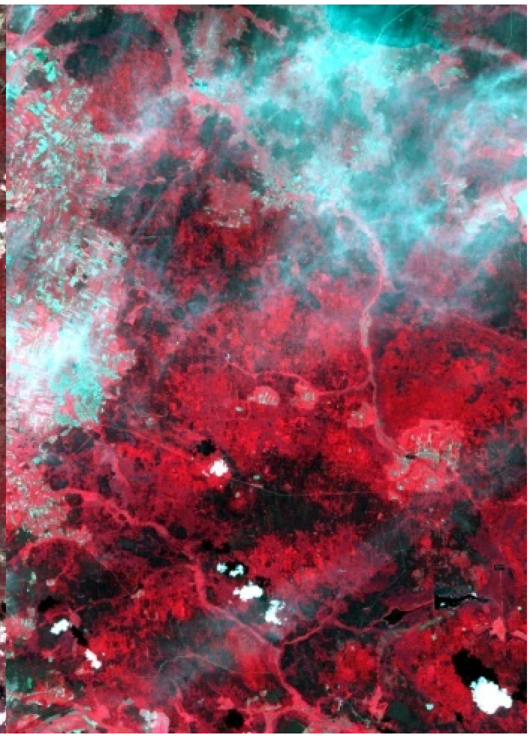
26-08-2011	3	grass	vegetation	grasses	5843019,18	694078,06
26-08-2011	4	grass	vegetation	grasses	5843034,92	694081,3
26-08-2011	5	asphalt square	man-made	squares	5843078,28	694086,85
26-08-2011	6	asphalt square	man-made	squares	5843083,42	694072,22
26-08-2011	7	football pitch	vegetation	grasses	5843187,18	694012,72
26-08-2011	8	football pitch	vegetation	grasses	5843201,1	693985,16
26-08-2011	9	football pitch	vegetation	grasses	5843195,44	693965,27
26-08-2011	10	grass dry	vegetation	grasses	5843261,74	694016,29
26-08-2011	11	grass tall	vegetation	grasses	5843347,11	694055,31
26-08-2011	12	grass	vegetation	grasses	5843450,41	694351,66
26-08-2011	13	grass with picea saplings	vegetation	grasses	5843737,23	694049,01
26-08-2011	14	grass	vegetation	grasses	5843652,55	694015,92
26-08-	15	grass short	vegetation	grasses	5843635,19	693882,95

2011						
26-08-2011	16	grass with trifolium	vegetation	grasses	5843571,96	693873,81
26-08-2011	17	bare soil	soils		5843507,93	693900,12
26-08-2011	18	bare soil	soils		5863501,05	693950,58
26-08-2011	19	grass	vegetation	grasses	5843470,62	693944,53
27-08-2011	20	quercus robur	vegetation	trees	5843278	692294
27-08-2011	21	pinus sylvestris	vegetation	trees	5843370,38	692270,47
27-08-2011	22	quercus rubra	vegetation	trees	5843358,34	692205,05
27-08-2011	23	tilia cordata	vegetation	trees	5843344,44	692160,34
27-08-2011	24	tilia cordata	vegetation	trees	5843312,79	69176,5
27-08-2011	25	arrhenatherion	vegetation	grasses	5843312,81	692189,18
27-08-2011	26	arrhenatherion	vegetation	grasses	5843317,94	692212,91
27-08-2011	27	road unpaved	man-made	roads	5843245,67	692317,29

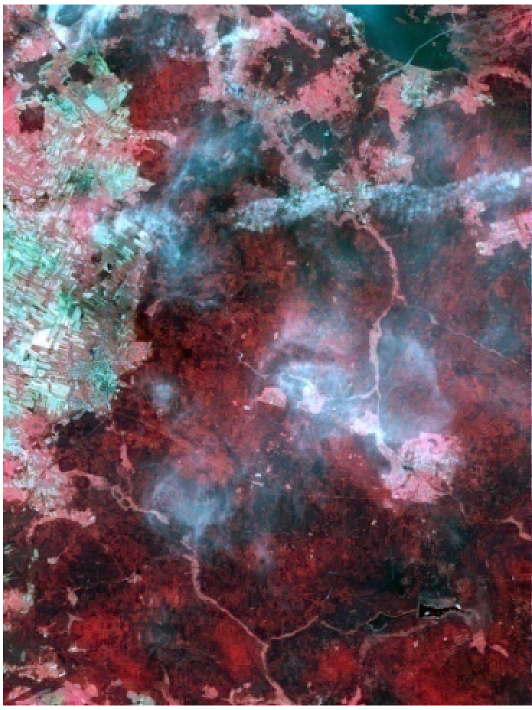
27-08-2011	28	acer platanoides	vegetation	trees	5843689	692315
27-08-2011	29	corylus avellana	vegetation	trees	5843680,98	692310,71
27-08-2011	30	salix aurita	vegetation	trees	5844022,02	692136,66
27-08-2011	31	populus tremula	vegetation	trees	5844034	692192
27-08-2011	32	solidago canadensis	vegetation	herbaceous	5844211,26	692156,86
27-08-2011	33	carpinus betulus	vegetation	trees	5844314	692814
27-08-2011	34	arrhenatherion	vegetation	grasses	5843929,62	692938,17
27-08-2011	35	bare soil	soils		5843956,08	693315,16
27-08-2011	36	brick street	man-made	roads	5843006,45	693704,11

Annex 3 raw satellite data

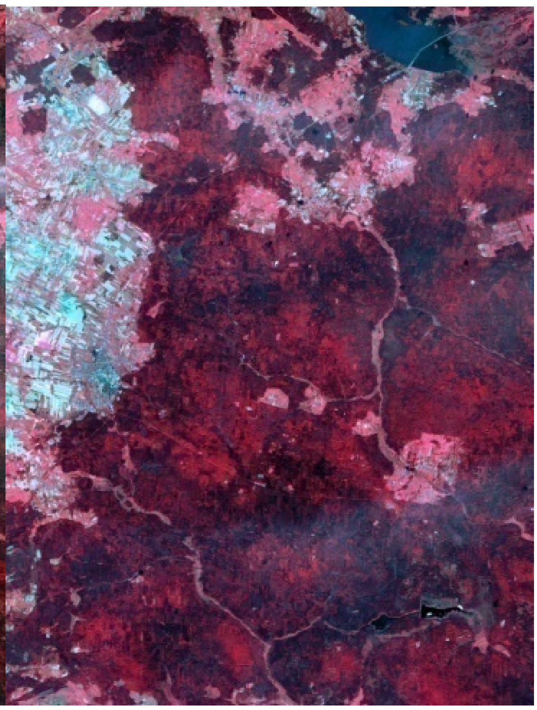
14-04-2011



01-06-2011



05-09-2011



29-09-2011

Annex 4

Tukey HSD test; variable MSI-14-04-2011
Approximate Probabilities for Post Hoc Tests
Error: Between MS = ,03778, df = 539,00

Cell No.	SPECIES	{1} ,66113	{2} ,92161	{3} ,80126	{4} ,57118	{5} ,68958	{6} ,98479	{7} ,92984	{8} ,86627	{9} ,87425	{10} ,81782	{11} 1,0430
1	Birch		0,000	0,014	0,424	1,000	0,000	0,000	0,000	0,000	0,003	0,000
2	Alder	0,000		0,072	0,000	0,000	0,872	1,000	0,943	0,981	0,214	0,067
3	Oak	0,014	0,072		0,000	0,132	0,000	0,038	0,850	0,732	1,000	0,000
4	Pinus	0,424	0,000	0,000		0,083	0,000	0,000	0,000	0,000	0,000	0,000
5	Spruce	1,000	0,000	0,132	0,083		0,000	0,000	0,000	0,000	0,039	0,000
6	Linden	0,000	0,872	0,000	0,000	0,000		0,945	0,082	0,142	0,001	0,921
7	Ash	0,000	1,000	0,038	0,000	0,000	0,945		0,867	0,941	0,129	0,119
8	Maple	0,000	0,943	0,850	0,000	0,000	0,082	0,867		1,000	0,977	0,000
9	orn Beam	0,000	0,981	0,732	0,000	0,000	0,142	0,941	1,000		0,935	0,001
10	Aspen	0,003	0,214	1,000	0,000	0,039	0,001	0,129	0,977	0,935		0,000
11	Salix	0,000	0,067	0,000	0,000	0,000	0,921	0,119	0,000	0,001	0,000	

Tukey HSD test; variable MSI-01-06-2011
Approximate Probabilities for Post Hoc Tests
Error: Between MS = ,00351, df = 539,00

Cell No.	SPECIES	{1} ,45151	{2} ,47891	{3} ,44465	{4} ,50086	{5} ,46523	{6} ,43644	{7} ,47298	{8} ,44021	{9} ,43795	{10} ,43106	{11} ,45471
1	Birch		0,424	1,000	0,002	0,987	0,973	0,773	0,997	0,988	0,822	1,000
2	Alder	0,424		0,125	0,748	0,987	0,015	1,000	0,043	0,023	0,003	0,618
3	Oak	1,000	0,125		0,000	0,816	1,000	0,371	1,000	1,000	0,988	0,999
4	Pinus	0,002	0,748	0,000		0,092	0,000	0,397	0,000	0,000	0,000	0,005
5	Spruce	0,987	0,987	0,816	0,092		0,346	1,000	0,568	0,431	0,128	0,998
6	Linden	0,973	0,015	1,000	0,000	0,346		0,074	1,000	1,000	1,000	0,905
7	Ash	0,773	1,000	0,371	0,397	1,000	0,074		0,171	0,106	0,018	0,905
8	Maple	0,997	0,043	1,000	0,000	0,568	1,000	0,171		1,000	1,000	0,980
9	Horn Beam	0,988	0,023	1,000	0,000	0,431	1,000	0,106	1,000		1,000	0,945
10	Aspen	0,822	0,003	0,988	0,000	0,128	1,000	0,018	1,000	1,000		0,651
11	Salix	1,000	0,618	0,999	0,005	0,998	0,905	0,905	0,980	0,945	0,651	

Tukey HSD test; variable MSI-05-09-2011
Approximate Probabilities for Post Hoc Tests
Error: Between MS = ,00422, df = 539,00

Cell No.	SPECIES	{1} ,48725	{2} ,60572	{3} ,51229	{4} ,48382	{5} ,48404	{6} ,54659	{7} ,58199	{8} ,54281	{9} ,52662	{10} ,49694	{11} ,58475
1	Birch		0,000	0,700	1,000	1,000	0,000	0,000	0,001	0,087	1,000	0,000
2	Alder	0,000		0,000	0,000	0,000	0,000	0,765	0,000	0,000	0,000	0,877
3	Oak	0,700	0,000		0,512	0,524	0,229	0,000	0,401	0,991	0,985	0,000
4	Pinus	1,000	0,000	0,512		1,000	0,000	0,000	0,000	0,040	0,995	0,000
5	Spruce	1,000	0,000	0,524	1,000		0,000	0,000	0,000	0,042	0,996	0,000
6	Linden	0,000	0,000	0,229	0,000	0,000		0,189	1,000	0,908	0,006	0,112
7	Ash	0,000	0,765	0,000	0,000	0,000	0,189		0,090	0,001	0,000	1,000
8	Maple	0,001	0,000	0,401	0,000	0,000	1,000	0,090		0,977	0,018	0,049
9	Horn Beam	0,087	0,000	0,991	0,040	0,042	0,908	0,001	0,977		0,445	0,000
10	Aspen	1,000	0,000	0,985	0,995	0,996	0,006	0,000	0,018	0,445		0,000
11	Salix	0,000	0,877	0,000	0,000	0,000	0,112	1,000	0,049	0,000	0,000	

Cell No.	Tukey HSD test; variable MSI-29-09-2011 Approximate Probabilities for Post Hoc Tests Error: Between MS = ,06153, df = 539,00 SPECIES	{1} ,49661	{2} ,64657	{3} ,49934	{4} ,45925	{5} ,47821	{6} ,56148	{7} ,62234	{8} ,52577	{9} ,63846	{10} ,50703	{11} ,67547
1	Birch		0,088	1,000	1,000	1,000	0,968	0,284	1,000	0,136	1,000	0,014
2	Alder	0,088		0,103	0,007	0,029	0,828	1,000	0,344	1,000	0,153	1,000
3	Oak	1,000	0,103		0,999	1,000	0,976	0,317	1,000	0,156	1,000	0,017
4	Pinus	1,000	0,007	0,999		1,000	0,606	0,040	0,962	0,014	0,997	0,001
5	Spruce	1,000	0,029	1,000	1,000		0,847	0,121	0,997	0,048	1,000	0,003
6	Linden	0,968	0,828	0,976	0,606	0,847		0,980	1,000	0,902	0,991	0,435
7	Ash	0,284	1,000	0,317	0,040	0,121	0,980		0,686	1,000	0,417	0,993
8	Maple	1,000	0,344	1,000	0,962	0,997	1,000	0,686		0,454	1,000	0,090
9	Horn Beam	0,136	1,000	0,156	0,014	0,048	0,902	1,000	0,454		0,224	1,000
10	Aspen	1,000	0,153	1,000	0,997	1,000	0,991	0,417	1,000	0,224		0,029
11	Salix	0,014	1,000	0,017	0,001	0,003	0,435	0,993	0,090	1,000	0,029	

Cell No.	**Tukey HSD test; variable NDVI-14-04-2011 Approximate Probabilities for Post Hoc Tests Error: Between MS = ,00894, df = 539,00** **SPECIES**	{1} ,63131	{2} ,53157	{3} ,57217	{4} ,68265	{5} ,62945	{6} ,51981	{7} ,53762	{8} ,56252	{9} ,55784	{10} ,57869	{11} ,46181
1	**Birch**		**0,000**	**0,065**	**0,193**	**1,000**	**0,000**	**0,000**	**0,012**	**0,005**	**0,164**	**0,000**
2	**Alder**	**0,000**		**0,543**	**0,000**	**0,000**	**1,000**	**1,000**	**0,867**	**0,951**	**0,309**	**0,010**
3	**Oak**	**0,065**	**0,543**		**0,000**	**0,087**	**0,170**	**0,764**	**1,000**	**1,000**	**1,000**	**0,000**
4	**Pinus**	**0,193**	**0,000**	**0,000**		**0,153**	**0,000**	**0,000**	**0,000**	**0,000**	**0,000**	**0,000**
5	**Spruce**	**1,000**	**0,000**	**0,087**	**0,153**		**0,000**	**0,000**	**0,017**	**0,007**	**0,207**	**0,000**
6	**Linden**	**0,000**	**1,000**	**0,170**	**0,000**	**0,000**		**0,997**	**0,463**	**0,641**	**0,068**	**0,078**
7	**Ash**	**0,000**	**1,000**	**0,764**	**0,000**	**0,000**	**0,997**		**0,966**	**0,993**	**0,524**	**0,003**
8	**Maple**	**0,012**	**0,867**	**1,000**	**0,000**	**0,017**	**0,463**	**0,966**		**1,000**	**0,999**	**0,000**
9	**orn Beam**	**0,005**	**0,951**	**1,000**	**0,000**	**0,007**	**0,641**	**0,993**	**1,000**		**0,991**	**0,000**
10	**Aspen**	**0,164**	**0,309**	**1,000**	**0,000**	**0,207**	**0,068**	**0,524**	**0,999**	**0,991**		**0,000**
11	**Salix**	**0,000**	**0,010**	**0,000**	**0,000**	**0,000**	**0,078**	**0,003**	**0,000**	**0,000**	**0,000**	

Cell No.	Tukey HSD test; variable NDVI-01-06-2011 Approximate Probabilities for Post Hoc Tests Error: Between MS = ,01001, df = 539,00 SPECIES	{1} ,78916	{2} ,77444	{3} ,82825	{4} ,71011	{5} ,77576	{6} ,87333	{7} ,83932	{8} ,85111	{9} ,83055	{10} ,79744	{11} ,84521
1	Birch		1,000	0,681	0,004	1,000	0,001	0,300	0,072	0,600	1,000	0,157
2	Alder	1,000		0,204	0,051	1,000	0,000	0,046	0,006	0,156	0,987	0,018
3	Oak	0,681	0,204		0,000	0,237	0,467	1,000	0,988	1,000	0,906	0,999
4	Pinus	0,004	0,051	0,000		0,041	0,000	0,000	0,000	0,000	0,001	0,000
5	Spruce	1,000	1,000	0,237	0,041		0,000	0,057	0,008	0,183	0,992	0,022
6	Linden	0,001	0,000	0,467	0,000	0,000		0,836	0,990	0,550	0,007	0,948
7	Ash	0,300	0,046	1,000	0,000	0,057	0,836		1,000	1,000	0,582	1,000
8	Maple	0,072	0,006	0,988	0,000	0,008	0,990	1,000		0,995	0,208	1,000
9	Horn Beam	0,600	0,156	1,000	0,000	0,183	0,550	1,000	0,995		0,858	1,000
10	Aspen	1,000	0,987	0,906	0,001	0,992	0,007	0,582	0,208	0,858		0,375
11	Salix	0,157	0,018	0,999	0,000	0,022	0,948	1,000	1,000	1,000	0,375	

Cell No.	Tukey HSD test; variable NDVI-05-09-2011 Approximate Probabilities for Post Hoc Tests Error: Between MS = ,00304, df = 539,00 SPECIES	{1} ,82204	{2} ,79432	{3} ,83171	{4} ,81126	{5} ,80972	{6} ,82786	{7} ,81857	{8} ,83033	{9} ,82755	{10} ,81844	{11} ,80311
1	Birch		0,297	0,999	0,997	0,990	1,000	1,000	1,000	1,000	1,000	0,828
2	Alder	0,297		0,029	0,908	0,950	0,084	0,506	0,043	0,091	0,514	0,999
3	Oak	0,999	0,029		0,747	0,653	1,000	0,984	1,000	1,000	0,982	0,252
4	Pinus	0,997	0,908	0,747		1,000	0,918	1,000	0,821	0,927	1,000	1,000
5	Spruce	0,990	0,950	0,653	1,000		0,863	0,999	0,738	0,876	0,999	1,000
6	Linden	1,000	0,084	1,000	0,918	0,863		0,999	1,000	1,000	0,999	0,473
7	Ash	1,000	0,506	0,984	1,000	0,999	0,999		0,993	0,999	1,000	0,948
8	Maple	1,000	0,043	1,000	0,821	0,738	1,000	0,993		1,000	0,992	0,323
9	Horn Beam	1,000	0,091	1,000	0,927	0,876	1,000	0,999	1,000		0,999	0,493
10	Aspen	1,000	0,514	0,982	1,000	0,999	0,999	1,000	0,992	0,999		0,951
11	Salix	0,828	0,999	0,252	1,000	1,000	0,473	0,948	0,323	0,493	0,951	

Cell No.	Tukey HSD test; variable NDVI-29-09-2011 Approximate Probabilities for Post Hoc Tests Error: Between MS = ,00385, df = 539,00 SPECIES	{1} ,77804	{2} ,75624	{3} ,79516	{4} ,75745	{5} ,76470	{6} ,79535	{7} ,76940	{8} ,79534	{9} ,79337	{10} ,77692	{11} ,73447
1	Birch		0,806	0,954	0,856	0,993	0,950	1,000	0,950	0,979	1,000	0,019
2	Alder	0,806		0,064	1,000	1,000	0,061	0,993	0,061	0,096	0,853	0,807
3	Oak	0,954	0,064		0,085	0,332	1,000	0,595	1,000	1,000	0,930	0,000
4	Pinus	0,856	1,000	0,085		1,000	0,081	0,997	0,081	0,125	0,896	0,749
5	Spruce	0,993	1,000	0,332	1,000		0,323	1,000	0,324	0,427	0,996	0,344
6	Linden	0,950	0,061	1,000	0,081	0,323		0,584	1,000	1,000	0,925	0,000
7	Ash	1,000	0,993	0,595	0,997	1,000	0,584		0,585	0,697	1,000	0,153
8	Maple	0,950	0,061	1,000	0,081	0,324	1,000	0,585		1,000	0,926	0,000
9	Horn Beam	0,979	0,096	1,000	0,125	0,427	1,000	0,697	1,000		0,965	0,000
10	Aspen	1,000	0,853	0,930	0,896	0,996	0,925	1,000	0,926	0,965		0,026
11	Salix	0,019	0,807	0,000	0,749	0,344	0,000	0,153	0,000	0,000	0,026	

Cell No.	**Tukey HSD test; variable NDWI-14-04-2011** **Approximate Probabilities for Post Hoc Tests** **Error: Between MS = ,01463, df = 539,00** SPECIES	{1} ,21382	{2} ,05221	{3} ,12833	{4} ,28368	{5} ,20447	{6} ,01315	{7} ,04262	{8} ,07954	{9} ,07760	{10} ,11470	{11} -,0125
1	**Birch**		**0,000**	**0,018**	**0,127**	**1,000**	**0,000**	**0,000**	**0,000**	**0,000**	**0,002**	**0,000**
2	**Alder**	**0,000**		**0,062**	**0,000**	**0,000**	**0,877**	**1,000**	**0,989**	**0,994**	**0,257**	**0,211**
3	**Oak**	**0,018**	**0,062**		**0,000**	**0,062**	**0,000**	**0,017**	**0,637**	**0,580**	**1,000**	**0,000**
4	**Pinus**	**0,127**	**0,000**	**0,000**		**0,042**	**0,000**	**0,000**	**0,000**	**0,000**	**0,000**	**0,000**
5	**Spruce**	**1,000**	**0,000**	**0,062**	**0,042**		**0,000**	**0,000**	**0,000**	**0,000**	**0,009**	**0,000**
6	**Linden**	**0,000**	**0,877**	**0,000**	**0,000**	**0,000**		**0,981**	**0,180**	**0,216**	**0,001**	**0,993**
7	**Ash**	**0,000**	**1,000**	**0,017**	**0,000**	**0,000**	**0,981**		**0,911**	**0,937**	**0,100**	**0,449**
8	**Maple**	**0,000**	**0,989**	**0,637**	**0,000**	**0,000**	**0,180**	**0,911**		**1,000**	**0,935**	**0,007**
9	**orn Beam**	**0,000**	**0,994**	**0,580**	**0,000**	**0,000**	**0,216**	**0,937**	**1,000**		**0,909**	**0,009**
10	**Aspen**	**0,002**	**0,257**	**1,000**	**0,000**	**0,009**	**0,001**	**0,100**	**0,935**	**0,909**		**0,000**
11	**Salix**	**0,000**	**0,211**	**0,000**	**0,000**	**0,000**	**0,993**	**0,449**	**0,007**	**0,009**	**0,000**	

Tukey HSD test; variable NDWI-05-09-2011
Approximate Probabilities for Post Hoc Tests
Error: Between MS = ,00313, df = 539,00

Cell No.	SPECIES	{1} ,34833	{2} ,24851	{3} ,32530	{4} ,35048	{5} ,35076	{6} ,29445	{7} ,26688	{8} ,29809	{9} ,31183	{10} ,33792	{11} ,26328
1	**Birch**		0,000	0,607	1,000	1,000	0,000	0,000	0,000	0,044	0,998	0,000
2	**Alder**	0,000		0,000	0,000	0,000	0,002	0,864	0,000	0,000	0,000	0,965
3	**Oak**	0,607	0,000		0,468	0,451	0,174	0,000	0,345	0,982	0,989	0,000
4	**Pinus**	1,000	0,000	0,468		1,000	0,000	0,000	0,000	0,023	0,990	0,000
5	**Spruce**	1,000	0,000	0,451	1,000		0,000	0,000	0,000	0,021	0,988	0,000
6	**Linden**	0,000	0,002	0,174	0,000	0,000		0,326	1,000	0,901	0,005	0,163
7	**Ash**	0,000	0,864	0,000	0,000	0,000	0,326		0,161	0,003	0,000	1,000
8	**Maple**	0,000	0,000	0,345	0,000	0,000	1,000	0,161		0,979	0,016	0,069
9	**Iorn Beam**	0,044	0,000	0,982	0,023	0,021	0,901	0,003	0,979		0,411	0,001
10	**Aspen**	0,998	0,000	0,989	0,990	0,988	0,005	0,000	0,016	0,411		0,000
11	**Salix**	0,000	0,965	0,000	0,000	0,000	0,163	1,000	0,069	0,001	0,000	

Tukey HSD test; variable NDWI-01-06-2011
Approximate Probabilities for Post Hoc Tests
Error: Between MS = ,00269, df = 539,00

Cell No.	SPECIES	{1} ,37872	{2} ,33764	{3} ,38541	{4} ,33703	{5} ,36663	{6} ,39307	{7} ,35848	{8} ,38956	{9} ,37652	{10} ,38242	{11} ,37608
1	Birch		0,004	1,000	0,003	0,986	0,952	0,682	0,994	1,000	1,000	1,000
2	Alder	0,004		0,000	1,000	0,159	0,000	0,642	0,000	0,008	0,001	0,010
3	Oak	1,000	0,000		0,000	0,774	1,000	0,250	1,000	0,999	1,000	0,998
4	Pinus	0,003	1,000	0,000		0,138	0,000	0,600	0,000	0,007	0,001	0,008
5	Spruce	0,986	0,159	0,774	0,138		0,275	0,999	0,496	0,997	0,912	0,998
6	Linden	0,952	0,000	1,000	0,000	0,275		0,035	1,000	0,884	0,995	0,866
7	Ash	0,682	0,642	0,250	0,600	0,999	0,035		0,095	0,815	0,427	0,837
8	Maple	0,994	0,000	1,000	0,000	0,496	1,000	0,095		0,975	1,000	0,969
9	Horn Beam	1,000	0,008	0,999	0,007	0,997	0,884	0,815	0,975		1,000	1,000
10	Aspen	1,000	0,001	1,000	0,001	0,912	0,995	0,427	1,000	1,000		1,000
11	Salix	1,000	0,010	0,998	0,008	0,998	0,866	0,837	0,969	1,000	1,000	

Tukey HSD test; variable NDWI-29-09-2011
Approximate Probabilities for Post Hoc Tests
Error: Between MS = ,00484, df = 539,00

Cell No.	SPECIES	{1} ,34073	{2} ,21843	{3} ,33826	{4} ,37429	{5} ,35679	{6} ,28381	{7} ,23566	{8} ,31388	{9} ,31004	{10} ,32935	{11} ,19095
1	Birch		0,000	1,000	0,360	0,987	0,002	0,000	0,698	0,501	0,999	0,000
2	Alder	0,000		0,000	0,000	0,000	0,000	0,978	0,000	0,000	0,000	0,667
3	Oak	1,000	0,000		0,255	0,964	0,004	0,000	0,808	0,630	1,000	0,000
4	Pinus	0,360	0,000	0,255		0,976	0,000	0,000	0,001	0,000	0,049	0,000
5	Spruce	0,987	0,000	0,964	0,976		0,000	0,000	0,075	0,032	0,669	0,000
6	Linden	0,002	0,000	0,004	0,000	0,000		0,023	0,534	0,728	0,043	0,000
7	Ash	0,000	0,978	0,000	0,000	0,000	0,023		0,000	0,000	0,000	0,051
8	Maple	0,698	0,000	0,808	0,001	0,075	0,534	0,000		1,000	0,990	0,000
9	Horn Beam	0,501	0,000	0,630	0,000	0,032	0,728	0,000	1,000		0,952	0,000
10	Aspen	0,999	0,000	1,000	0,049	0,669	0,043	0,000	0,990	0,952		0,000
11	Salix	0,000	0,667	0,000	0,000	0,000	0,000	0,051	0,000	0,000	0,000	