Montane forest fire detection and post-fire forest development
(a case study in the Majella National Park, Italy)

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(a case study in the Majella National Park, Italy)

by

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Abstract

During the great wildfire event in South East Europe in the summer of 2007, a fire occurred in the montane forest belt of the Majella National Park, Italy. The fire was the largest recorded in history and the only one recorded in a beech forest in the park and Europe. The management of the park expressed its interest to use satellite remote sensing data and techniques as an alternative method to map fire scars and to assess the effect of the fire on plant biodiversity and regeneration. The study asked the following questions: (1) What are the location, time, severity and distribution of these fires? (2) Can fire scars in the montane forest belt be mapped accurately using medium resolution satellite imagery? (3) What is the species composition and diversity of tree seedlings and herbaceous plants in post-fire and in unburned beech forest and black pine plantation? (4) Does beech and black pine regenerate after forest fire?

The MODIS Terra and Aqua active fire products were successfully used to determine the dates, location, time, severity (radiative power) and distribution of the fires more accurately than by the conventional field methods applied by park management. Fire scars in beech forest and black pine plantation could be mapped with sufficient overall accuracy (87.8%) using ASTER imagery of May 2008 based on supervised maximum likelihood classification and ground truth. Species composition and diversity of tree seedlings and herbaceous plants were recorded using randomly selected sites and line transects at each site. Species diversity was analyzed using two species diversity indices, Shannon and Simpson.

Species diversity of tree seedlings did not differ significantly between post-fire and unburned beech forest. However, there was a significant difference in species diversity of herbaceous plants between post-fire and unburned beech forest. The study also showed that beech can regenerate after forest fire through seedling and stem/root sprouts. In the black pine plantation species diversity of tree seedlings was higher in the unburned black pine plantation and there was no significant difference in species diversity of herbaceous plants between post-fire and unburned black pine plantation. Natural regeneration of black pine after forest fire was absent. Comparing the two forest types; species diversity of tree seedlings was higher in unburned black pine plantation than the unburned beech forest. However there was no significant difference in species diversity of tree seedlings between post-fire black pine plantation and post-fire beech forest. Management implications of the study are discussed.

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1.0 INTRODUCTION

1.1. Background and Significance

Fire is an important environmental factor for several regions in the world and a major ecological disturbance in most vegetation zones across the world (Goldammer, 2006). Fire-prone vegetation types cover a total of 40% of the world's land surface (Chapin et al., 2002) and are common in tropical, subtropical (Bond et al., 2005) and the boreal regions (Harden et al., 2000). In many ecosystems fire is a dominant ecological factor which affects physical and biological attributes, shaping landscape patterns and influencing energy flows (Goldammer, 2006). The global biogeochemical cycles, particularly the carbon cycle is also largely influenced by fire due to its effect on terrestrial carbon (Korontzi et al., 2003).

Fires have been noted to lead to increase ecosystem productivity of forests by creating open areas, which favour germination and seedling survival (IPCC, 2001; Schaetzl et al., 1989). Studies have shown that forest fires influence regeneration of woody species by sprouting and germination of seeds stored in soils (Keeley and Keeley, 1981; Moreno and Oechel, 1991). A fire disturbance in forest ecosystems may create opportunity for change and leads to the introduction of new plant species (Gerard et al., 2003; Hanley and Fenner, 1998). The opening of forest canopy by fire could make it possible for other trees species to make the European monospecific beech forests more diverse (Peters, 1997). The germination of herbaceous species is controlled by fire-related factors, such as heat (Wicklow, 1977; Keeley and Keeley, 1981). Due to forest fires certain plant species have also developed adaptations such as thick bark, ability to sprout, and rapid post-fire colonization that enable them to thrive under such conditions (Abrams, 1992; Peterson and Reich, 2001). Fire related – forest gaps influence the increase and maintenance of species diversity by opening up growing space and resources such as sunlight (Huston, 1979). Studies have shown that fire may cause changes in soil structure in forest ecosystems (eg. Naveh, 1975; Trabaud, 1987; Johnson, 1992; Kutiel and Shaviv, 1993) and increases soil erosion rates (Anderson, 1974; Amaranthus and McNabb, 1984) and soil microorganisms (Rashid et al., 1997).

Forest fires are generally referred to as wildfires (Westerling et al., 2006). Different types of forest fires have been discussed in literature and these include surface fires and crown fires. Surface fires have been described as fires that burn the ground cover and undergrowth vegetation and could some times rise to the crown (Miller and Urban, 2000). Crown fires spread through the crowns of trees and burn all upper branches and could consume the entire forest (Turner and Romme, 1994).

In the year 2007, a total of 10639 wildfires were recorded in Italy. This affected a land area of about 227729 hectares. Out of the 10639 wildfires recorded, 274 occurred in the Abruzzo Region alone. A high number of these fires where recorded on July 24th and August 22nd and this was attributed to the high temperatures and strong irregular winds recorded on those days. Consequently, the Italian government made several request for airborne assistance to other European countries to help manage the fires which occurred on 24th July 2007 (European Commission, 2008).

1.1.1. Remote Sensing for Fire Mapping

Earth Observation (EO) satellites are uniquely capable of synoptically covering large areas of the planet in a repeatable and cost-effective manner which makes them useful for managing global and regional forest resources (Chuvieco, 1999). Remote sensing has proved to be a valuable data source for managing wildfires through the detection of active fires and mapping of fire scars (Chuvieco, 1999; Hudak and Brockett, 2004). The mapping of forest fires using remote sensing involves two general approaches; active fire detection and mapping of fire scars (Hawbaker et al., 2008). Active fire detection involves mapping the flaming front of fires at the time of satellite overpass (Hawbaker et al., 2008) and provides information on the date, location, timing, spatial distribution and characteristics such as the Fire Radiative Power (FRP) (Justice et al., 2006, Kaufman et al., 1998). However, active fire detection does not give any information on the size of the fires and the burned area (Siegert and Hoffmann, 2000). In contrast to active fire detection, fire scar mapping involves identifying the spatial extent of the burned areas affected by fire after the fire has occurred (Hawbaker et al., 2008).

Earth observing satellite systems used for global active fire detection and mapping includes; the Advanced Very High Resolution Radiometer (AVHRR) (Li et al., 1997), Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Earth Observing System (EOS) Terra and Aqua satellites (Justice et al., 2002; Wang et al., 2008) and System Pour l'Observation de la Terre (SPOT) – (Fraser et al., 2000). For regional fire mapping, medium resolution sensors, such as Landsat (MSS, TM and ETM) (Chuvieco and Congalton, 1989; Minnich, 1983) and Advanced Spaceborne Thermal Emission and Reflection Spectrometer (ASTER) (Keramitsoglou et al.,

2008) have been used. For example, Hudak et al. (2004) mapped fire scars in savanna areas of Southern Africa using Landsat imagery to determine the trends in fire patterns. Yu et al. (2004) in their study, determined burn severity based on pre-burn and post-burn Landsat TM images and analyzed forest biomass change. Keramitsoglou et al. (2008) also mapped forest wildfires using ASTER and Hyperion images. The advent of new sensors with improved spatial, spectral and temporal resolutions has improved the mapping of forest fires (Chuvieco and Congalton, 1989).

1.1.2. MODIS Active Fire Detection

Satellite systems widely used for active fire detection includes the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors onboard the Terra and Aqua satellites, which were designed to include characteristics specifically for fire detection (Justice et al., 2006). The Terra and Aqua satellites are in sun-synchronous orbit with differences in local overpass time (Lillesand et al., 2004).

Active fires are detected since radiant energy of fire pixels increases with increase temperatures, providing a high contrast fire pixel relative to surrounding non-fire pixels (Giglio et al., 2003). A fire pixel or hotspot refers to pixels which have higher temperatures than a threshold value in a satellite data and indicates the presence of fire within an area (Siegert and Hoffmann, 2000). The radiative power of a detected fire gives information on the radiant heat output (Wooster et al., 2005). For the purpose of this study fire severity is used as an indication of the radiative power, which reflects the amount of energy released by an active fire detected.

The MODIS active fire detection is carried out using a contextual algorithm developed by Kaufman et al. (1998) and improved by Giglio et al. (2003). The algorithm uses brightness temperatures derived from the 4 (3.9) - and 11 (10.8) -µm channels, denoted by T_4 and T_{11}. The MODIS sensors have two 4 (3.9)-µm channels (21 and 22), both used for fire detection using the algorithm. The channel 21 saturates at nearly 500 K and channel 22 saturates at 331 K. The low-saturation channel (22) is less noisy and has a smaller quantization error; hence T_4 is often derived from this channel (Giglio et al., 2003). However, when channel 22 saturates or has missing data, it is replaced with the high saturation channel (21) to derive T_4. The T_{11} is derived from the 11-µm channel (channel 31), which saturates at approximately 400 K for the Terra MODIS and 340 K for the Aqua MODIS (Giglio et al., 2003).

The algorithm examines each pixel of the MODIS swath, and ultimately assigns to each one of the following classes: *missing data*, *cloud*, *water*, *non-fire*, *fire*, or *unknown*. A daytime pixel is identified as potential fire pixel if $T_4 > 310$ K, ΔT>10K, where $\Delta T = T_4 - T_{11}$. For nighttime pixels, T_4 threshold reduces to 305 K (Giglio et al., 2003). This preliminary test is used to eliminate obvious non-fire pixels. The next phase involves using a valid neighbouring pixels in a window centered on the potential identified fire pixels to estimate a background value. A series of contextual thresholds are used to perform a relative fire detection using signature of an active fire after the background characterization in which both the 4-µm brightness temperature (T_4) and 4- and 11(10.8)-µm brightness temperature difference (ΔT) depart substantially from that of the non-fire background (Giglio et al., 2003).

According to Ward et al. (1992) there are two main stages in forest fire combustion; the flaming and smouldering stages, which are characterized by different fire intensity and temperatures. Studies by Lobert and Warnatz (1993) indicated that flaming temperatures can be between 800 K and 1200 K. Pyne et al. (1996) also recorded flaming temperature as high as 2500 K and explained that smouldering combustion occurs at lower temperatures and can be 600 K ± 100 K. Flaming and smouldering combustion of forest fires can vary considerably depending on fuel moisture and structure, and on the development of the flame front, therefore it is important to be able to distinguish between these two phases (Langmann et al., 2009). The MODIS active fire algorithm and sensitivity studies were based, therefore, on the assumption that the flaming temperature is 1000 K ± 200 K and the smouldering temperature is 600 K ± 100 K (Hawbaker et al., 2008).

The MODIS fire products derived from the active fire algorithm provides important information for fire management, however the algorithm has some limitations since a number of false fire alarms have been identified. Hence a detection confidence estimate is provided for each fire pixel detected as part of the fire product (Justice et al., 2002; Giglio et al., 2003).

1.1.3. Fire Scar Mapping

Fire scars have been mapped from remotely sensed imagery based on the surface reflectance characteristics (Chuvieco, 1999). According to Robinson (1991) post-fire forests can be characterized by two different signals: the formation and deposition of charcoal, or surface charring and the alteration of vegetation structure (scar) and abundance, and plant canopies. Studies have shown that burned areas have lower reflectance and relatively dark in the visible spectral range (eg. Jakubauskas et al., 1990; Langaas and Kane, 1991; Chuvieco, 1999). According to Chuvieco (1999) mapping burned areas using the visible spectral region is not very effective since burned areas like other landcover types (conifer forests, some soil types, water bodies and wetlands) are dark in the visible region and this similarity makes it difficult to discriminate burned areas from other landcover types. Studies have shown that the near infrared (NIR) is the spectral region where signal of burned areas are strongest and considered the best spectral region for mapping forest fire scars (Langaas and Kane, 1991; Chuvieco, 1999). Pereira (1999) explained that, forests usually have high reflectance in the NIR regions and there is significant decrease in reflectance of post-fire forests in the NIR region after fire occurrence. Methods for mapping fire scars have been discussed in literature and these includes supervised classification (Hudak et al., 2004; Keramitsoglou et al., 2008), vegetation index thresholding (Li et al., 2000; Yu et al., 2004) and Normalised Burn Ratio (NBR) (Key and Benson, 2005).

1.1.4. Fires in the Majella National Park

Within the Majella National Park, fire is a recognized environmental disturbance and available records on fire disturbance indicate about 92 occurrences of fires from 1997 – 2007. These fires are usually caused by anthropogenic factors such as burning of farm residues by farmers, activities of herdsmen (pastoralists) and occasionally by natural factors including lightening (Officials of the Park, Personal Communication). In the summer of 2007 fire occurred in the montane forest belt of the Majella National Park. This was the only fire event recorded in a beech forest and the largest in a black pine plantation within the National Park (Officials of the Park, Personal Communication). Fires were also recorded in the natural grasslands and abandoned arable lands.

The montane belt is defined by several factors including; elevation, aspects, high relief and climate (Martin, 2001). The climate of the montane belt is characterized by low temperatures, cooler summer, high rainfall than adjacent lowlands which is evenly distributed throughout the year, and harsh winter conditions (Braun, 1980; Kitayama, 1995). The montane forest belt in the Majella National Park stretches from approximately 930 – 1600 m a.s.l. (van Gils et al., 2008).

Figure 1-1: The montane forest belt of the Majella National Park; acquired: 12-09-2008, 02:15pm (GMT +1)

A ground survey carried out by the officials of the National Park to determine the spatial extent of the burned areas indicated 1813 hectares. This however includes the burned areas in the beech forest, black pine plantation, natural grasslands and abandoned arable lands. The management of the park wished to know the spatial extent of the fire scars in the beech forest and black pine plantation (Officials of the Park, Personal Communication). However, using ground survey to determine the spatial extent of the fire scars will be expensive and time consuming due to terrain difficulty and accessibility. The management has therefore expressed the interest to use satellite remote sensing data and techniques as an alternative method to map fire scars in the beech forest and black pine plantation and to assess the effect of the fire on species diversity and forest regeneration (Officials of the Park, Personal Communication).

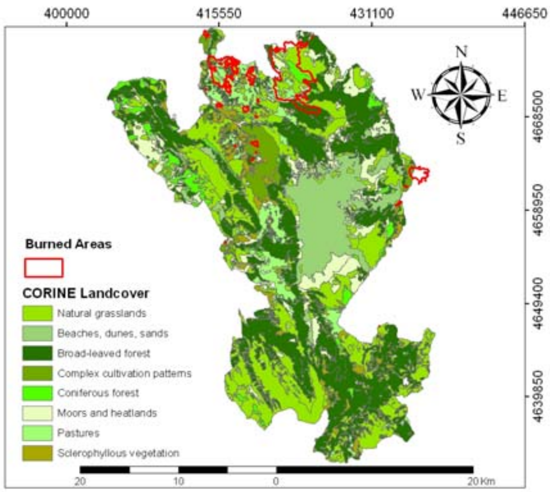

Figure 1-2: Map of burned areas which occurred in year 2007 within the Majella National Park. The burned areas where digitize through ground survey using iPAQ GPS by officials of the National Park.

1.1.5. Beech and Black Pine Forest

With reference to its natural abundance, European beech (*Fagus sylvatica* L.) is the most important broad-leaved tree species in Europe (Lendzion and Leuschner, 2008) covering about 12 million hectares (Buiteveld et al., 2007). The species is classified as shade tolerant, with the ability to regenerate below a closed canopy, and have a high tolerance against drought, snow pressure and high ecological competitiveness (Dittmar et al., 2003). According to Gilman and Watson (1993) beech trees are naturally low-branched and produces a deep shade and dense forest canopy, resulting in little amount of light reaching the forest floor. Beech reaches a reproductive maturity at 50 years (Piovesan et al., 2005a), reproduces both vegetatively and sexually (Beaudet and Messier, 2008). Vegetative propagation of beech is mainly through root or stump sprouts (Beaudet and Messier, 2008). Root sprouts of beech tend to have higher growth rates than seed origin individuals (Houston, 2001). Seeding of beech is through intermittent yields of nuts referred to as mast (van Gils et al., 2008). According to Godefroid et al. (2006) beech seeds are short-lived and can be considered absent in soil seed banks under beech forests even if not consumed. Van Gils et al. (2008) explained that beech seeds (masts) are usually consumed by *Ursus arctos marsicanus* (Marsican brown bear), *Sus scrofa* (Wild boar) and *Cervus elaphus* (Red deer) since it is rich in calories. According to Nakashizuka and Numata (1982) regeneration of beech forest after forest disturbance is low since seeds are absent in soil seed banks. Beech trees are noted to grow in environments with fewer occurrences of wildfires (Piovesan et al., 2005a).

Beech stands in Europe have been managed under different silvicultural systems since the 18th century (Peters, 1997), including the coppice with standards and the coppice selection system widely practiced in the Apennines of Italy (Coppini and Hermanin, 2007). Mannozzi-Torini (1949), described the coppiced selection system as based on two kinds of rotation: moderate with short rotation, or strong with long rotation, with rotation periods of 6 to 8 years and full cycle lengths between 18 and 24 years respectively. A coppiced beech forest stand consists of stumps with multiple stems (Coppini and Hermanin, 2007). The coppice system used in the beech forest under this study is however not known.

The study looks at the coppice beech forest within the Roccamorice municipality in the montane belt of the Majella National Park. The coppice beech forest was used for household needs (domestic cooking and heating) in rural communities since it is a municipal owned forest but under the management of the *Corpo Forestale* and the office of the Majella National Park. In recent years there is an effort by the *Corpo Forestale* to convert the coppice beech forest into a high forest stand.

Pinus nigra commonly known as black pine is a substantial forest plant species element across the Mediterranean Basin, covering approximately 3.8 million hectares (Barbero et al., 1998). It grows in thermo-Mediterranean to oro-Mediterranean conditions and strives well in bioclimatic conditions that limit competitions from broadleaved taxa (Barbero et al., 1998). The species compared to other pines can be considered as shade tolerant (Fyllas et al., 2008). *Pinus nigra* is a non resprout species and regeneration largely depends on their seed bank (Pausas et al., 2004). However, unlike other pine species black pine lack serotinous cones which ensures the germination of non-dormant seeds in post-fire environments (Fyllas et al., 2008). The species releases its seeds early at the beginning of spring and does not maintain a soil seed bank when summer wildfires occur (Habrouk et al., 1999). According Escudero et al. (1999) seeds of *P. nigra* are sensitive to high temperatures of wildfires.

The study looks at the black pine plantation within the Lettomanoppello municipality in the montane belt of the Majella National Park. The black pine plantation under this study is a result of reforestation carried out in the park during the past century (Officials of the Park, Personal Communication). However, there is a single area of black pine forest with natural occurrence in the Majella National outside the specific research area.

1.1.6. Plant Biodiversity

The Convention on Biological Diversity (CBD) defined biological diversity as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (CBD, 1992). Magurran (1988) in his study on measurement of ecological diversity also defined biodiversity as a measure of species richness and/or relative abundance within a sample or community. Plant biological diversity within forest ecosystems have been wildly estimated using different species diversity indices (Gorelick, 2006; Günter et al., 2007; Tolera et al., 2008). Species diversity indices give information on the species variation and composition and not only information on species richness (Tolera et al., 2008). Several diversity indices have been developed for species diversity studies however, the Shannon index (Shannon, 1948) and the Simpson index (Simpson, 1949) are the most widely and acceptable measures of biodiversity (Mouillot and Leprêtre, 1999). Measuring species diversity using diversity indices requires data on the number of species and their abundance in a sampled area (Tolera et al., 2008).

1.2. Research Problem

The Intergovernmental Panel on Climate Change based on future climate estimates has provided evidence that predict an increase of wildfires in South East Europe (IPCC, 2001). Scholze et al. (2006) in their study on modeling future fire occurrences also suggested an increase in wildfires and their impacts on forests in the Mediterranean Basin in the 21st century under wide range of scenarios. However, significant amount of information is still required to better understand the spatial and ecological impacts of wildfires (Chuvieco, 1999).

Traditionally, burned areas have been mapped using ground survey and also by using colour infrared aerial photos (Miller and Yool, 2002; Schwartz et al., 2003). However, acquiring reliable information on forest resources in the montane belt using ground survey can be expensive, time consuming and difficult due to terrain characteristics and accessibility (Ismail and Jusoff, 2008). The use of aerial photos for mapping forest resources is also very expensive (Miller and Yool, 2002). Hence, accurate, cost-effective, and minimal time-consuming methods of mapping forest resources are required. Chuvieco (1999) stated that satellite remote sensing provides the opportunity to map forest resources at a relatively lower cost and time.

Satellite remote sensing offers the opportunity to map changes in forest resources (Ghitter et al., 1995) which could be caused by fire disturbance (eg. Chuvieco, 1999; Hudak et al., 2004). Determining the size and impact levels of burned areas can be done in an efficient way using satellite remote sensing, from which ecological and economic impacts can be evaluated (Siegert and Hoffmann 2000). The mapping of forest resources in the montane belt using satellite remote sensing will however be influenced by factors such as background and shadow and the spectral and spatial ranges at which a satellite operates, as the observed pixels are usually a combination of canopy reflectance of both disturbed and healthy trees (Lefsky and Cohen, 2003).

A number of studies have been carried out to map burned areas using satellite remotely sensed data (eg. Jakubauskas et al., 1990; Razafimpanilo et al., 1995; Siljestro¨m and Moreno, 1995). However, a study on the possibility of mapping fire scars in the montane belt using medium resolution satellite data is limited. Mapping of disturbed forests in the montane belts is important for forest management

(Chuvieco, 1999) and biodiversity conservation (Scarth et al., 2000). The study focuses on the use of medium resolution satellite data since most of the medium resolution satellite data can be obtained at a relatively lower cost compared to high resolution satellite data.

Since the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, the European Union (EU) has developed a number of policies to ensure sustainable development of forest resources and the protection and maintenance of native forest species (Leone and Lovreglio, 2004), including beech and black pine. However, the implementation of such policies on forest sustainability will be difficult if there is limited information on the effect of fire on species diversity and regeneration in the forests of these native tree species.

Several studies have been conducted on beech forests; however, there is limited information in literature on species diversity and regeneration of post-fire beech forest. The record of fire in European beech forests is lacking in literature. Peters (1997) studied beech forests in different parts of the world and only recorded a fire in a magnolia beech forest in Georgia, USA. He concluded that fire in beech forests is rare. Post-fire forest processes and regeneration of black pine forests in the Sub-Mediterranean basin are also poorly understood (Tapias et al., 2004). Iida and Nakashizuka (1995) stated that forest disturbance influences species richness and diversity. Therefore knowledge on the effect of fire on species diversity and regeneration in post-fire beech and black pine forest is of great importance for ecological and management perspective.

The study will find out if the location, time, severity and distribution of active fires in the montane forest belt can be determined using the MODIS active fire products and also if the fire scars in beech and black pine forests in the montane belt can be mapped accurately using remotely sensed medium resolutions satellite data (ASTER). The study also examines the species composition and diversity of tree seedlings and herbaceous plants in post-fire and unburned beech forest and black pine plantation.

1.3. Research Objective

The overall objective of this study is to contribute to the understanding of mapping forest fire in the montane belt and post-fire forest development in beech and black pine forests through the application of remote sensing and GIS.

To achieve the overall objective, the following specific objectives were set for the study:

1. To determine if recent fire scars in the montane forest belt can be mapped accurately using medium resolution satellite imagery (ASTER)

2. To assess species composition and diversity of tree seedlings and herbaceous plants in post-fire and in unburned beech forest

3. To assess species composition and diversity of tree seedlings and herbaceous plants in post-fire and in unburned black pine plantation

4. To compare species diversity of tree seedlings between the two forest types in post-fire and in unburned forests

5. To determine the structural characteristics of the post-fire and unburned beech forest and black pine plantation

1.4. Research Questions

1. What are the location, time, severity and distribution of the fires that occurred in the montane forest belt of the Majella National Park?

2. Can fire scars in the montane forest belt be mapped accurately using medium resolution satellite imagery (ASTER)?

3. What is the species composition and diversity of tree seedlings in post-fire and in unburned beech forest?

4. Does beech regenerate after forest fire?

5. What is the species composition and diversity of herbaceous plants in post-fire and in unburned beech forest?

6. What is the species composition and diversity of tree seedlings in post-fire and in unburned black pine plantation?

7. Does black pine regenerate after forest fire?

8. What is the species composition and diversity of herbaceous plants in post-fire and in unburned black pine plantation?

9. Is there a difference in species diversity of tree seedlings between the two forest types for post-fire and unburned forests?

10. What are the structural characteristics of the post-fire and unburned beech forest and black pine plantation in the montane forest belt?

1.5. Research Hypotheses

The study tested the following hypotheses:

Hypothesis 1

H_o: The location, time, severity and distribution of active fires in the montane forest belt can be determined using the MODIS active fire products

H_1: The location, time, severity and distribution of active fires in the montane forest belt cannot be determined using the MODIS active fire products

Hypothesis 2

H_o: Forest fire scars in the montane forest belt can be mapped accurately using medium resolution satellite imagery (ASTER)

H_1: Forest fire scars in the montane forest belt cannot be mapped accurately using medium resolution satellite imagery (ASTER)

Hypothesis 3

H_o: There is no significant difference in species diversity of tree seedlings between post-fire and unburned beech forest

H_1: There is a significant difference in species diversity of tree seedlings between post-fire and unburned beech forest

Hypothesis 4

H_o: There is no significant difference in species diversity of herbaceous plants between post-fire and unburned beech forest

H_1: There is a significant difference in species diversity of herbaceous plants between post-fire and unburned beech forest

Hypothesis 5

H_o: There is no significant difference in species diversity of tree seedlings between post-fire and unburned black pine plantation

H_1: There is a significant difference in species diversity of tree seedlings between post-fire and unburned black pine plantation

Hypothesis 6

H_o: There is no significant difference in species diversity of herbaceous plants between post-fire and unburned black pine plantation

H_1: There is a significant difference in species diversity of herbaceous plants between post-fire and unburned black pine plantation

Hypothesis 7

H_o: There is no significant difference in species diversity of tree seedlings between unburned beech forest and unburned black pine plantation

H_1: There is a significant difference in species diversity of tree seedling between unburned beech forest and unburned black pine plantation

Hypothesis 8

H_o: There is no significant difference in species diversity of tree seedlings between post-fire beech forest and post-fire black pine plantation

H_1: There is a significant difference in species diversity of tree seedlings between post-fire beech forest and post-fire black pine plantation

2.0. METHODS AND MATERIALS

2.1. Selection of Research Area

The research area was chosen for number of reasons. A review of literature prior to this study revealed that there were only few studies on post-fire beech forest. The fires which occurred in the montane forest belt of the Majella National Park in July, 2007 is the only record of fire in a beech forest and the largest in a black pine plantation within the park. The research area provided the opportunity to study a post-fire beech forest and post-fire black pine plantation and compared it to unburned beech and unburned black pine plantations respectively. The research area also provided the opportunity to compare between the two different forest types. Also the ASTER data sets and GIS data needed for this study in the research area was readily available without any cost.

2.2. Research Area

The study was undertaken in the Majella National Park, Italy (latitude $41^0$51' N to $42^0$15' N, longitude $13^0$50'21.209"E to $14^0$14'46.21"E) (Figure 2-1). The National Park was established in 1995 covering an area of 740.95 km^2, divided into 39 municipalities and forms part of the Abruzzo protected area system. The Majella National Park is one of the largest National Parks in Europe and home to 45% and 36% of both animals and plants species in Italy respectively (Majella National Park, 2007). The park is characterized by several mountain peaks, prominent peaks includes Mount Majella and Mount Morrone, which are located on the east and the west side of the park respectively (Majella National Park, 2007). The highest peak being Mount Amaro, reaches to about 2794m a.s.l. altitude (Cho et al., 2007). Between Mount Majella and Mount Morrone, there are valleys and floodplains of River Orta and River Orfento (Majella National Park, 2007). The Majella National Park is characterized by different bioclimatic belts: the subalpine and alpine humid types (Blasi, 2001). In terms of altitude vegetation zonation, the park consist of the oak (*Quercus pubescens*) woodlands (400–1000m), beech forest (*Fagus sylvatica*) (1000 – 1700m), SubAlpine (>1700m) and Alpine (> 2000m) (Cho et al., 2007; van Gils et al., 2008). There is no meteorological station within the Majella National Park (Van Gils et al., 2008) and the closest weather station to the research area is a private initiative (not part of the National Park) at Roccacaramanico (altitude - 1050 m a.s.l) and has only operated for the last two years. The station recorded a high temperature of 36.6 ^oC and 36.9 ^oC on 23rd and 24th July 2007 respectively. The station also recorded 1.2^oC as the mean annual temperature and 1150.9 mm as mean annual precipitations in 2008.

More specifically, the research area is within the coppice beech forest and black pine plantation in the Roccamorice and Lettomanoppello municipalities respectively (latitude $42^0$9’44.666”N to $42^0$14’8.485”N, longitude $14^0$2’15.289”E to 14^0 6’31.575”E) covering an area of 26.58km^2. Figure 2-1 below shows the specific research area within the Majella National Park.

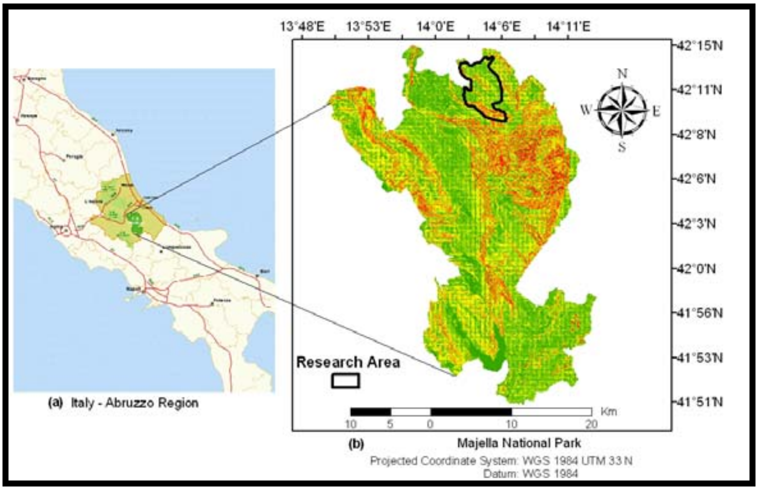

Figure 2-1: Map of the research area; (a) Indicates the Majella National Park within the Abruzzo Region in Italy (b) Is the slope map of the Majella National Park and also shows the location of the specific research area, the steeper slopes and flat terrain are shaded red and green respectively.

2.3. Satellite Data and Pre-processing

2.3.1. MODIS Active Fire Data

The MODIS Terra (MOD14) and Aqua (MYD14) daily Thermal Anomalies and Fire 5-Min L2 Swath 1km (15th July 2007 to 15th August 2007) were acquired from the USGS Land Processes Distributed Active Archive Center (LP DAAC). The MODIS fire products were used since it is one of the active fire products widely used and validated by the scientific community (eg. Justice et al., 2002; Hawbaker et al., 2008). The MOD14 and MYD14 data sets were selected based on the period which fire was reported in 2007. The MOD14 and MYD14 Thermal Anomalies and Fire Products were acquired in the HDF format in a sinusoidal WGS 84 projection and contain information on the number of cloud, water, non-fire, fire, unknown, and other pixels. The products were pre-processed and converted into hotspots vector file through batch processing using the Integrated Land and Water Information System (ILWIS 3.3). The files were then projected to the UTM coordinate system (World

Geodetic System WGS 1984, 33 N) and the research area was clipped out from the fire hotspots vector layers by using ArcGIS 9.2.

2.3.2. ASTER Data

Two ASTER multispectral data (1B level pre-processing) of 15m spatial resolution acquired on 6th September, 2001 and 27th May, 2008 were used for this study (Figure 2-2). The ASTER 2001 image was obtained from the International Institute for Geo-Information Science and Earth Observation (ITC). The ASTER 2008 was obtained from USGS Earth Resources Observation and Science Centre (EROS) through ITC. ASTER data was used because the spatial resolution is suitable for this study and due to the limited research budget. The images were selected based on the period which the fire was reported in 2007. The ASTER 2001 and 2008 images were the only cloud-free images among the ASTER and Landsat images available. ASTER data are recorded in the 14 spectral bands from visible to thermal infrared. In this study, spectral bands in the visible and near infrared (VNIR) were used for vegetation mapping. Using the rotation parameters, the ASTER 2008 image was oriented to the north – south direction and georeferenced to the coordinate system of the ASTER 2001 image (WGS 1984, UTM projection, zone 33 N) and the two images were subset to the specific research area using the Environment for Visualising Images (ENVI 4.3) software (Research System, Inc.). The False Colour Combination (FCC) 3-2-1 in red, green and blue were utilized, since it clearly distinguishes between healthy and unhealthy vegetation (Abrams et al., 2002).

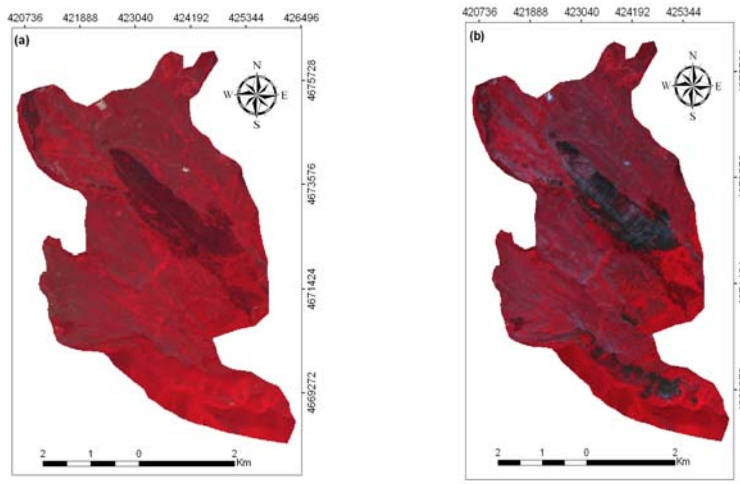

Figure 2-2: False colour composition of the ASTER images subset to cover the specific research area (red: band 3, green: band 2, blue: band 1). (a) ASTER imagery acquired on 6th September, 2001 (pre-fire) (b) ASTER imagery acquired 27th May, 2008 (post-fire)

2.4. GIS Data

A Digital Elevation Model (DEM) was obtained from the office of the Majella National Park. The DEM was used to estimate the altitude, slope and aspect of the research area. Table 2-1 summaries the GIS data sets that were available for this study.

Table 2-1: GIS Digital data used for the study

Data	Source
Digital Elevation Model of Majella National Park	office of the Majella National Park
Shape files of the municipality boundaries within the Majella National Park	office of the Majella National Park
Shape files of burned areas in the Majella National Park	office of the Majella National Park
Shape files of the CORINE Landcover Classification of Majella N.P.	office of the Majella National Park
Shape files of roads within the research area	Digitized during field work using iPAQ GPS

2.5. Field Data Collection

The field campaign was carried out from 10th September to 1st October, 2008. The aim of the field campaign was to identify the fire scars in the montane forest belt, acquire ground truth points for mapping, and undertake observations and measurements in post-fire and unburned forests. During the field campaign discussions held with the officials of the Majella National Park and local people could not determine what caused the fire and a consistent date when the fire occurred.

Based on baseline data on the forest types and location of burned areas, provided by the office of the Majella National Park, the research area was stratified according to the differences in forest types (beech and black pine). According to Kent and Cooker (1996) stratification is carried out on the basis of grouping members of a population into relatively homogeneous subgroups due to very obvious variations within the area under study. A Simple Random Sampling was then used to select sample areas for data collection in the beech forest and black pine plantation (Freese, 1990). Using Hawth’s tool an extension in ArcGIS 9.2 software a total of 120 sample points were randomly selected in both beech forest and black pine plantation. Thus a total of 120 sample points (30 post-fire beech, 30 unburned beech, 30 post-fire black pine plantation and 30 unburned black pine plantation). The unburned beech forest and unburned black pine plantation were selected based on the closeness and the fact that they were within the same geographical and environmental factors such as altitude, slope, aspect and soil substrate to the post-fire beech forest and post-fire black pine plantation respectively. The number of sampling points selected was to ensure acceptable minimum samples of thirty sampling units for statistical analysis and also due to the difficulty of terrain, time and limited research budget. An iPAQ Geographical Position System (GPS) was used to locate the randomly sampled points selected in post-fire and unburned forests. Appendix 1 and 2 shows the coordinates of points selected in beech forest and black pine plantation respectively.

To acquire data on tree seedlings and herbaceous plants a line transects was adopted (Runkle, 1982; Økland, 1990). The randomly sampled points were used as the beginning of each transect. A line transect of 50m was laid and at intervals of 25m a sample plot of 5m X 5m was established. The altitude, slope and aspect at which transects were laid in post-fire and unburned beech forest and black pine plantation were recorded using the iPAQ GPS. The line transect method was used since it is the method often used in studies on species diversity in forest ecosystems (eg. Günter et al., 2007; Tolera et al., 2008). Tree seedlings and herbaceous plant species were identified and the abundance estimated. The definition of seedling by Gracia et al. (2001) as any individual recently established and smaller than 40 cm in height was adopted for this study. This definition was used in order to have a basis to compare between post-fire and unburned forests since the post-fire forests only consisted of recently-established seedlings. For data on structural characteristics the number of trees were counted within the established plots along each transects and tree height and diameter at breast height (DBH) was measured for each tree in the post-fire and unburned beech forest and black pine plantation. The heights of trees were estimated visually. Observations made include trees with sprouts, features on tree stems, soil condition, litter depth and cover and presence of rocks. Field observations of likely fire severity were made within the beech forest and black pine plantation. The severity of the fires was evaluated based on visual evaluation of trees with burn scars, charred trees, and tree canopy condition.

The plant species were identified on-site using a previously prepared herbarium (labelled dried plant specimens on paper) and photos of plant species. The species which could not be identified on-site were sent to the office of the National Park and identified with the help of the botanist Dr. Mirella Di Cecco using the Flora d'Italia (Pignatti, 1982).

2.6. Mapping Forest Fire Scars - Classification of Satellite Data

Image classification involves labelling pixels as belonging to particular spectral classes using the spectral data available (de Jong et al., 2004). There are two main methods for image classification (unsupervised and supervised) used for digital image analysis (Campbell, 2006). Using half of ground-truth samples acquired during field campaign for training, the ASTER images were classified. The classification was performed based on a supervised approach, maximum likelihood algorithm (Lillesand et al., 2004) using ArcGIS 9.2. The maximum likelihood classifier was used since it is the method most often used for remote sensing data classification for vegetation cover (eg. Westra et al., 2005; DomaÇ and Süzen, 2006; Zhang et al., 2007).

Classification accuracy was performed on the classified ASTER 2008 image using the other half of the ground-truth data. The classification accuracy for the ASTER 2001 image could not be established due to lack of ground-truth before the fire. The fire scar map was compared to the ground-truth to create an error matrix. The error matrix is an acceptable standard for reporting the accuracy for a classified remotely sensed data (Lillesand et al., 2004). Producer's accuracy, user's accuracy, overall accuracy and Kappa statistics (Campbell, 2006) were calculated from the error matrix. The producer and user's accuracies characterize the measure of omission and commission error respectively (Campbell, 2006). The Kappa is a statistical measure which indicates the success of the classification relative to a random assignment of observations to categories and it gives the level of agreement between classification and observed ground truth (Campbell, 2006).

2.7. Data Analysis

To determine species diversity of tree seedlings and herbaceous plants in post-fire and unburned beech forest and black pine plantation, two diversity indices: Shannon's diversity index (H') (Shannon, 1948) and Simpson's diversity index (D) (Simpson, 1949) were used.

Shannon's index (H') was calculated as:

$$H' = -\sum P_i \log_2 P_i \quad \text{.........................} (1)$$

Where $\boldsymbol{P_i}$ is the relative abundance of species $\boldsymbol{i}$.

Simpson’s (D) was calculated as:

$$D = \sum \left[n_i (n_i - 1) / N(N - 1) \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where $\boldsymbol{n_i}$ is the number of individuals in the ***i***th species and N the total number of individuals. As D increases, diversity decreases and therefore Simpson’s index is usually expressed as 1-D or 1/D. In this study, the former expression (i.e. 1 -D) was used.

The Shannon and Simpson indices were both used to estimate species diversity in this study in order to avoid any bias. This is because both indices have a descriptive ability and are sensitive to sample size as well. For example, Tolera et al. (2008) reported that the Shannon diversity index gives more weight to rare species. Onainda et al. (2004) also described the Simpson diversity index as heavily weighted towards the most abundant species in the sample, while being less sensitive to species richness. Both the Shannon and Simpson diversity index estimates diversity based on species richness and evenness (Onaindia et al., 2004). Species richness refers to number of species within a community, while species evenness is a function of the relative abundance of the different species (Izsa´k, 2007). According to Lande et al. (2000) Simpson index is particularly useful for rapidly assessing areas for conservation because of its rapid convergence towards the limit diversity value for small sample sizes. The Shannon diversity index and Simpson diversity index are suitable for this study since both considers species richness and species evenness to estimate species diversity. To determine the structure characteristics of post-fire and unburned forests the arithmetic mean was calculated for tree count, tree height and diameter at breast height of trees in post-fire and unburned forest stands.

Two-sample student t-test was used to test for significant differences between post-fire and unburned beech forest and pine plantation sites while using a critical value α=0.05. The two sample t-test was used since it is an appropriate statistical test for comparing two means of equal sample size. According to Moore and McCabe (2006) the two-sample t-test is most robust against non-normality using equal sample sizes and the conservative probability values are most accurate. All statistical tests were done in SPSS. The *t*-statistic for the t test associated with the Shannon index developed by Magurran (1988) was not used in this study because studies have shown that it is biased with small sample sizes (Mouillot and Leprêtre, 1999; Liu, 2006). According to Danoff-Burg (2003) a simple student t-test can be used to show significant differences in Shannon diversity between two samples. Figure 2-3 below shows the methodological flow chart for the processes which were undertaken in this study.

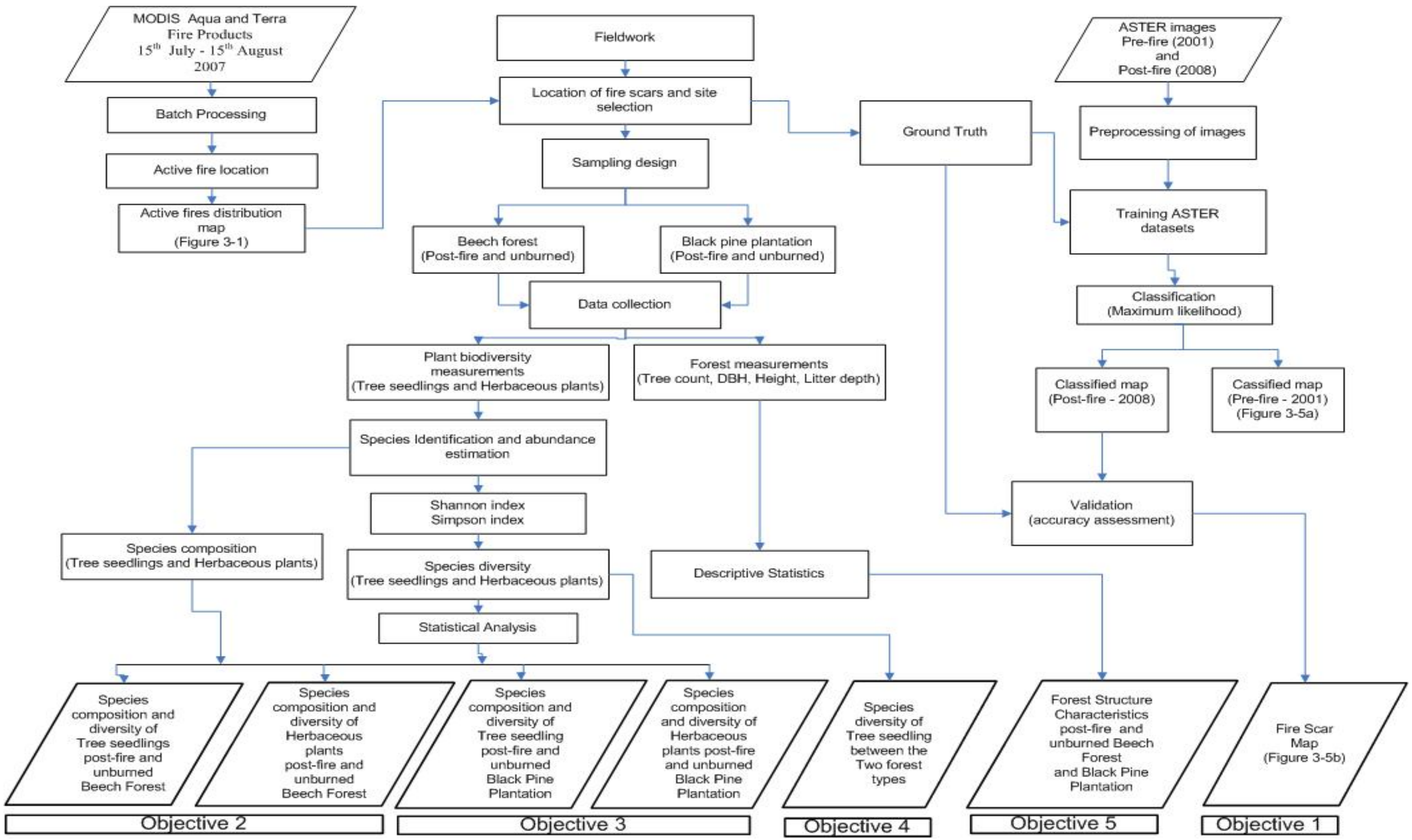

Figure 2-3: Flow chart of the methodology

3.0. RESULTS

3.1. Location, time, severity and distribution of the fires that occurred in the montane forest belt of the Majella National Park

The location, time, severity, distribution and dates of occurrence of the fires in the montane forest belt were determined using the MODIS Terra and Aqua active fire products. Figure 3-1 below shows the locations and distribution of the active fires detected.

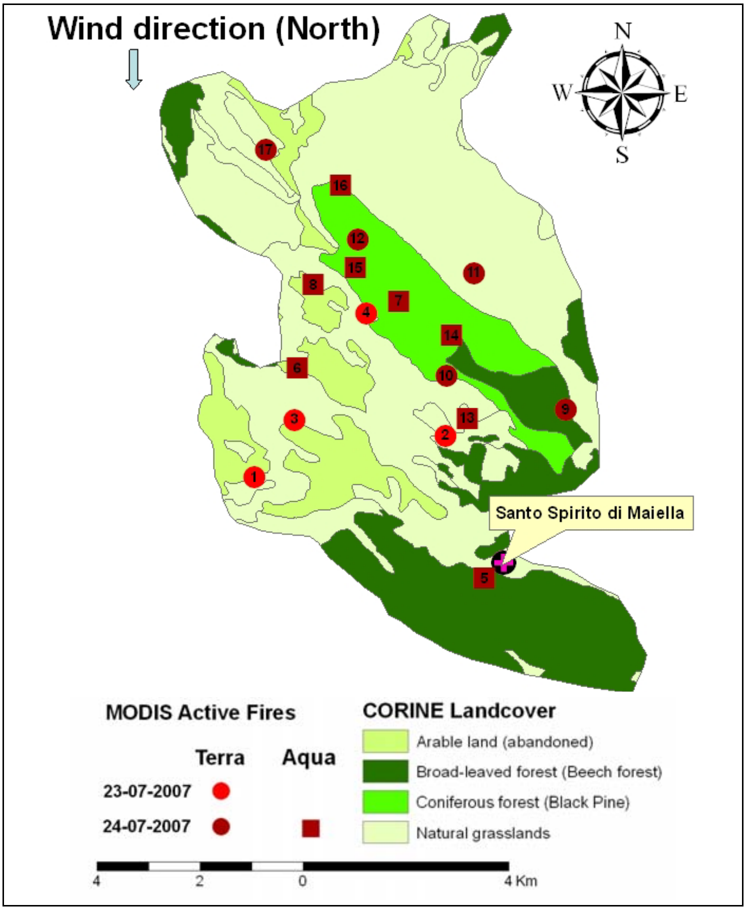

Figure 3-1: Geographical distribution of active fires detected by MODIS Terra and Aqua active fire products within the specific research area. Refer to Table 3-1 below for information on time and Radiative Power of each fire detected using the corresponding number indicated. The wind direction recorded for the days fires occurred were north and the highest wind speed recorded was 14 and 13 km/hr for 23rd and 24th July 2007 respectively. Santo Spirito di Maiella is a hermitage. Source of data: MODIS active fire products LP DAAC, CORINE Landcover: office of the Majella National Park.

Table 3-1: Characteristics of active fires detected within the research area by MODIS Terra and Aqua sensors

Number	Acquisition Date	Satellite	Time (UTC)[a]	Location (Geographical Coordinates) X	Y	Brightness[b] Temperature (K)	Detection Confidence (%)	FRP[c] (W m^{-2})
1	23-07-2007	Terra	2050	421698.342	4670793.152	317	91	18
2	23-07-2007	Terra	2050	423975.691	4671310.731	309	55	11
3	23-07-2007	Terra	2050	422201.133	4671502.975	329	96	41
4	23-07-2007	Terra	2050	423058.836	4672774.741	319	74	24
5	24-07-2007	Aqua	0100	424448.906	4669565.749	315	88	17
6	24-07-2007	Aqua	0100	422230.709	4672138.858	332	100	37
7	24-07-2007	Aqua	0100	423443.323	4672907.833	318	95	17
8	24-07-2007	Aqua	0100	422408.165	4673114.865	325	100	26
9	24-07-2007	Terra	1025	425454.489	4671636.066	367	367	215
10	24-07-2007	Terra	1025	424005.267	4672020.554	399	100	504
11	24-07-2007	Terra	1025	424345.390	4673233.168	372	100	250
12	24-07-2007	Terra	1025	422940.532	4673662.020	375	100	268
13	24-07-2007	Aqua	1205	424256.662	4671502.975	340	80	37
14	24-07-2007	Aqua	1205	424079.207	4672508.557	341	79	38
15	24-07-2007	Aqua	1205	422925.744	4673321.896	351	96	53
16	24-07-2007	Aqua	1205	422733.500	4674297.903	394	100	206
17	24-07-2007	Terra	2135	421831.433	4674726.755	317	91	48

[a]Universal Time (UTC) , also known as Greenwich Mean Time (GMT); [b] The brightness temperature are derived from channel 22; [c]FRP is the Fire Radiative Power.

Figure 3-2: Active fires captured by MODIS Aqua on July 24, 2007 in some parts of Italy. Active fires are marked in red. The research area is marked with yellow (Source: NASA Earth Observatory, available: http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=18775, acquire: 24-09-2008).

The fires which occurred in the montane forest belt of the Majella National Park were detected on the 23rd and 24th of July, 2007 by the MODIS active fire products (Figure 3-1, 3-2). The fire which was detected on the 23rd of July by the MODIS Terra active fire product was largely within the abandoned arable lands and natural grasslands. Fires which occurred in the black pine plantation and beech forest were detected on the 24th of July, 2007. The fire which occurred in the black pine plantation was detected by both the MODIS Terra and Aqua active fire products whilst the fire in the beech forest was only detected by the MODIS Aqua active fire product and not by the MODIS Terra active fire product.

The fire which occurred in the beech forest was generally detected at a lower brightness temperature and had a lower emitted radiative power (Table 3-1). Ground observation during field campaign confirmed that the fire which occurred in the beech forest was of low severity and could be described as a surface fire and was mainly in the forest understorey. The fire which occurred in the black pine plantation was detected at a higher brightness temperature and had a higher emitted radiative power (Table 3-1). Ground observations confirmed that the fire which occurred in the black pine plantation was of high severity and can be described as a crown fire which has resulted in a high mortality of the pine trees. Trees in the post-fire beech forest were only scarred (burned) on the bark compared to trees in the black pine plantation that were charred completely (See Appendix 8). About 20% of trees enumerated in the post-fire beech forest still had pale green leaves and 72% had deep copper-orange coloured leaves (Figure 3-3) compared to the trees in the post-fire black pine forest which had no needles in the canopy (Figure 3-4).

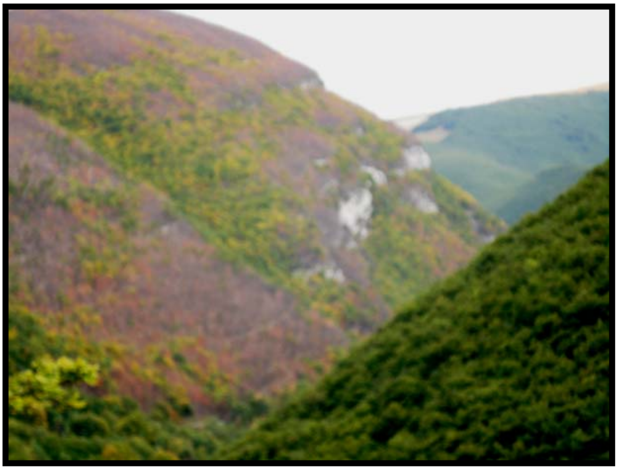

Figure 3-3: Beech forest fire scar within the Roccamorice municipality; close to Santo Spirito di Maiella; around the Orfento Valley; acquired: 12-09-2008, 03:05pm (GMT +1)

Figure 3-4: Fire scar in black pine plantation within the Lettomanoppello municipality, acquired: 12-09-2008, 02:35pm (GMT +1)

3.2. Forest fire scars in the montane forest belt

Classification maps resulting from the ASTER 2001 and 2008 data sets are shown in Figure 3-5 below. The landcover map and fire scar map are produced from the ASTER 2001 and 2008 images respectively. The landcover map shows the vegetation types and cover before the forest fires (Figure 3-5a). The fire scar map shows the fire scars in the beech forest and black pine plantation (Figure 3-5b). The spatial extent (size) of the beech forest fire scar and black pine plantation fire scar was determined as 71.2 and 232.1 hectares respectively using ArcGIS.

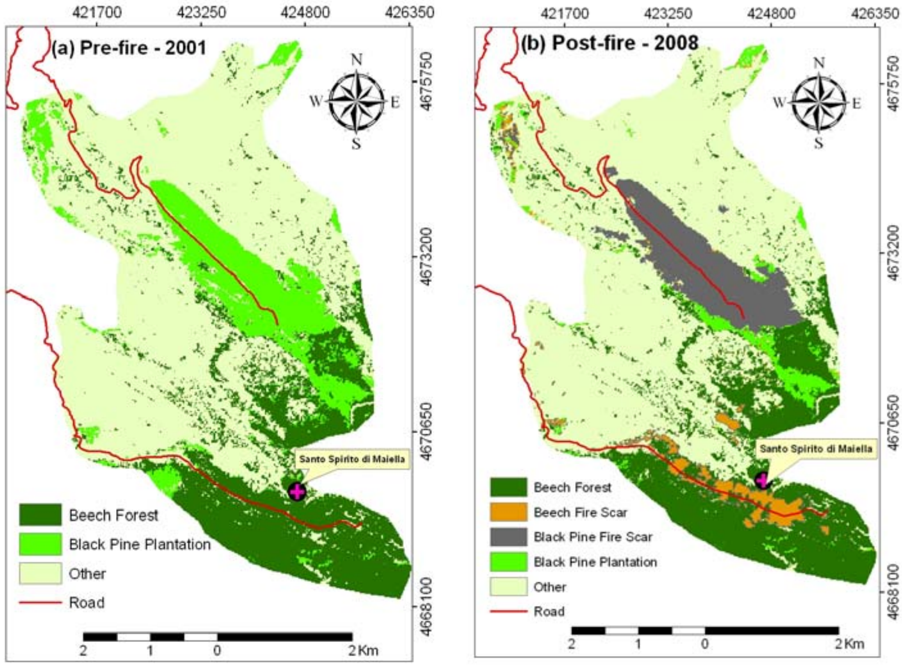

Figure 3-5: Classified maps based on maximum likelihood classification of ASTER images. (a) Landcover map from the ASTER image acquired on 6th September, 2001. (b) Fire scar map from the ASTER image acquired on 27th May, 2008. The class 'Other' consist of semi-natural grasslands and abandoned arable lands; Santo Spirito di Maiella is a hermitage

3.2.1 Accuracy Assessment of Fire Scar Map

The error matrix (Table 3-2) shows that the fire scars in the beech forest and black pine plantation were mapped with satisfactory results with respect to the overall accuracy and kappa statistics. The fire scar map produced an overall accuracy of 87.8% and Kappa statistics was 0.85. Forest fire scars in the beech forest and black pine plantation were mapped with a producer accuracy of 70.0% and 86.7% respectively. Producer's accuracy and user's accuracy for each classified vegetation type from the error matrix is shown in Table 3-2 below.

Table 3-2: Error Matrix for Fire Scar Map (Figure 3-5b)

		Ground Truth								
		Beech Fire Scar	Beech Forest	Black Pine Fire Scar	Black Pine Plantation	Others	**TOTAL**	User Accuracy (%)	Producer Accuracy (%)	Kappa
Fire Scar Map	Beech Fire Scar	21	0	3	0	0	**24**	87.5	70.0	0.64
	Beech Forest	0	28	0	3	0	**31**	90.3	93.3	0.92
	Black Pine Fire Scar	9	0	26	0	0	**35**	74.3	86.7	0.83
	Black Pine Plantation	0	2	0	27	0	**29**	93.1	90.0	0.87
	Others	0	0	1	0	28	**29**	96.6	100	1.0
	TOTAL	**30**	**30**	**30**	**30**	**28**	**148**			
	Error of Omission (%)	30.0	6.7	12.5	13.3	0.0				
	Error of Commission (%)	12.5	9.7	25.7	6.9	3.4				

Overall accuracy = 87.8%, Kappa statistics = 0.85

3.3. Species composition and diversity of tree seedlings in post-fire and in unburned beech forest

During the field campaign a total number of 9 species of tree seedlings were recorded in the beech forest belonging to 7 plant taxonomic families. The number of species of tree seedlings recorded (species richness) in the post-fire (9) was higher than in the unburned (6) beech forest. The different species of tree seedling which were recorded in the post-fire and unburned beech forest can be found in Appendix 3. The predominant tree species seedling recorded in the post-fire and unburned beech forest was beech (*Fagus sylvatica*). Ninety-seven percent of the tree seedlings recorded in both post-fire and unburned beech forest was *F. sylvatica*. Figure 3-6 below shows the abundance of the different species of tree seedlings recorded for all transects in post-fire and in unburned beech forest.

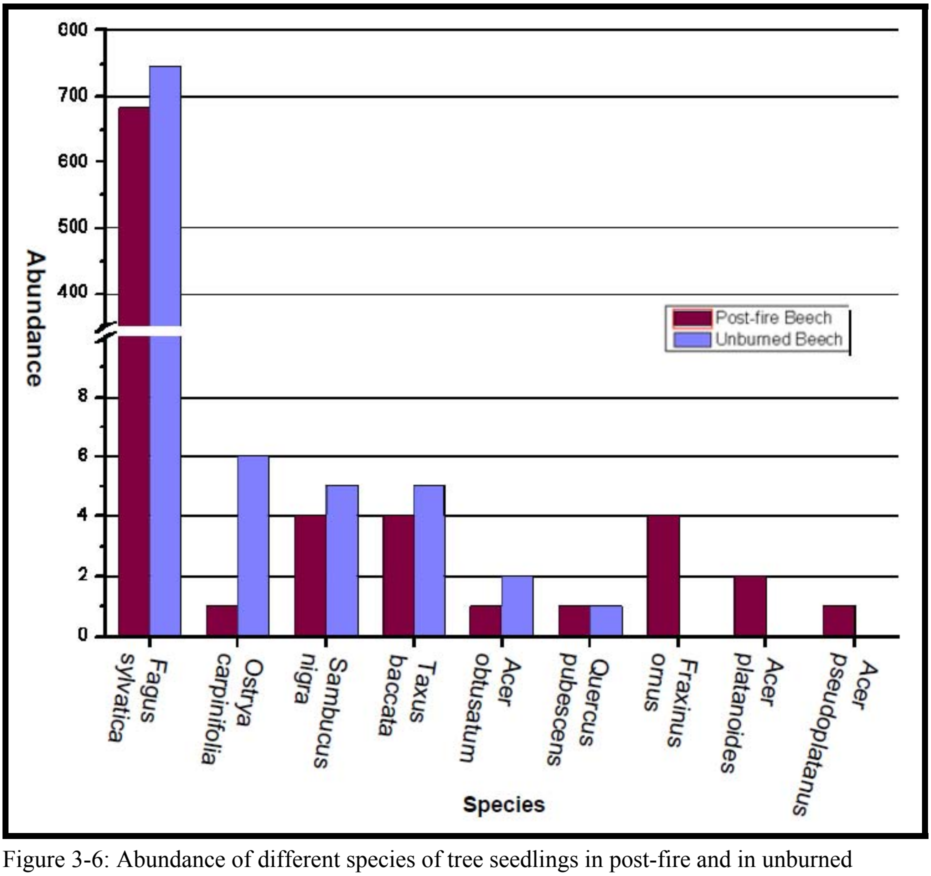

Figure 3-6: Abundance of different species of tree seedlings in post-fire and in unburned beech forest; abundance for all transects

There was no significant difference in Shannon index (H') of tree seedlings species diversity between post-fire ($\overline{X}$ =0.096, S.E=0.022, n=30) and unburned ($\overline{X}$ =0.092, S.E =0.022, n=30) beech forest (two sample t-test; t= 0.109, df=58, p=0.914). The Simpson index (1-D) followed the same trends with no significant difference in tree seedlings species diversity between post-fire ($\overline{X}$ =0.048, S.E =0.011, n=30) and unburned ($\overline{X}$ =0.047, S.E =0.012, n=30) beech forest (two sample t-test; t=0.097, df=58, p=0.923). Figure 3-7 below shows the error bar plots of tree seedlings species diversity between post-fire and unburned beech forest for the Shannon and Simpson diversity indices. A correlation analysis to determine the relationship between the Shannon's and Simpson's indices for tree seedlings species diversity showed a strong positive correlation in both post-fire (r= 0.993, p<0.001, n=30) and unburned (r= 0.980, p<0.001, n=30) beech forest. Based on the results obtained, we fail to reject the null hypothesis that there is no significant difference in species diversity of tree seedlings between post-fire and unburned beech forest.

Since tree seedlings in the post-fire and unburned beech forest was mainly *F. sylvatica*, the *F. sylvatica* seedlings were compared between post-fire and unburned beech forest. The result indicates that, there was no significant difference in *F. sylvatica* seedlings recorded between post-fire ($\overline{X}$ =22.766, S.E =1.281, n=30) and unburned ($\overline{X}$ =26, S.E=1.644, n=30) beech forest (two sample t-test; t= 1.551, df=55, p= 0.127).

(A) **(B)**

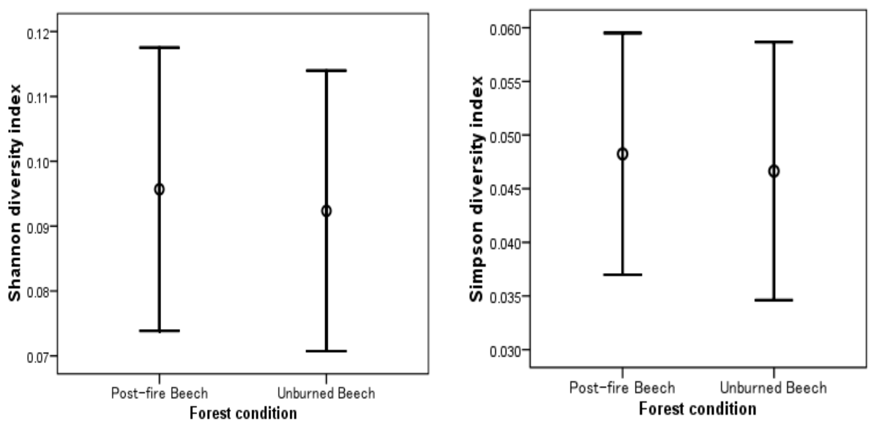

Figure 3-7: Error bar plots showing the difference in tree seedlings species diversity between post-fire and unburned beech forest; the bar represents the mean ± standard error of the (A) Shannon diversity index (B) Simpson diversity index

3.4. Species composition and diversity of herbaceous plants in post-fire and in unburned beech forest

A total number of 54 species of herbaceous plants were recorded in the beech forest belonging to 27 plant taxonomic families. The number of species of herbaceous plant recorded in the post-fire (49) was higher than in the unburned (26) beech forest (Figure 3-8). The different species of herbaceous plants recorded in the post-fire and unburned beech forest can be found in Appendix 4. The predominant herbaceous plants species recorded in the post-fire beech forest were: *Daphne laureola, Dryopteris filix-mas, Galega officinalis, Hedera helix, Pteridium aquilinum, Rubus canescens* and *Viola alba.* Within the unburned beech forest the predominant herbaceous plants species recorded were: *Daphne laureola, Hedera helix, Lathyrus venetus,* and *Sanicula europaea.*

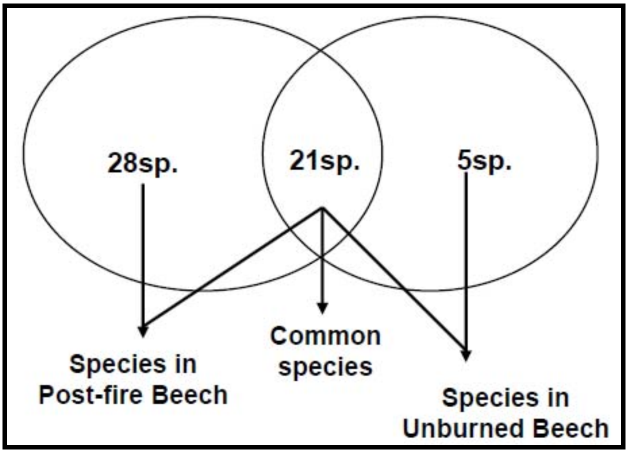

Figure 3-8: Number of herbaceous plants species and number of species overlap between post-fire and unburned beech forest

There was a significant difference in Shannon index (H') of herbaceous plants species diversity between post-fire ($\overline{X}$ =1.705, S.E=0.039, n=30) and unburned ($\overline{X}$ =1.123, S.E=0.026, n=30) beech forest (two sample t-test; t=12.271, df=48, p=2.066 X 10^{-16}). The Simpson index (1-D) followed the same trends with significant difference in herbaceous plant species diversity between post-fire ($\overline{X}$ =0.827, S.E=0.007, n=30) and unburned ($\overline{X}$ =0.676, S.E=0.012, n=30) beech forest (two sample t-test; t= 10.968, df=48, p= 1.129 X 10^{-14}). Figure 3-9 below shows the error bar plots of plants species diversity between post-fire and unburned beech forest for the Shannon index and Simpson diversity indices. A correlation analysis to determine the relationship between the Shannon's and Simpson's indices for herbaceous plants showed a strong positive correlation in the post-fire (r= 0.931, p<0.001, n=30) and a positive correlation in the unburned (r= 0.505, p<0.001, n=30) beech forest. Based on the results obtained, we reject the null hypothesis that there is no significant difference in species diversity of herbaceous plants between post-fire and unburned beech forest.

(A) **(B)**

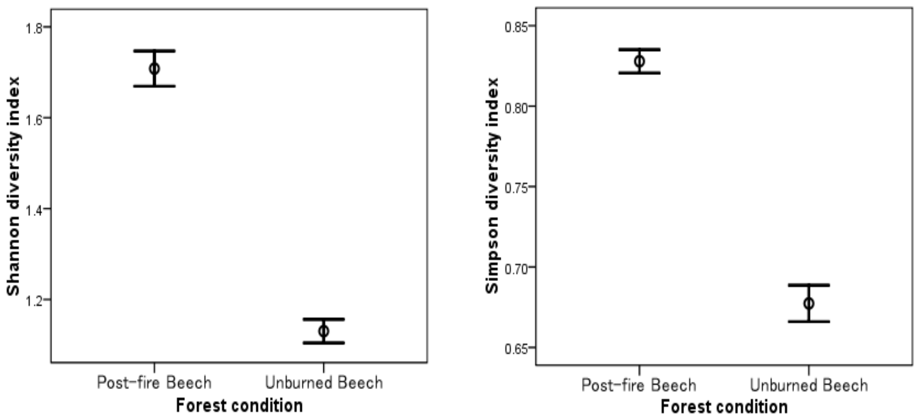

Figure 3-9: Error bar plots showing the difference in herbaceous plant species diversity between post-fire and unburned beech forest; the bar represents the mean ± standard error of the (A) Shannon diversity index (B) Simpson diversity index

3.5. Species composition and diversity of tree seedlings in post-fire and in unburned black pine plantation

A total of 9 species of tree seedlings were recorded in the black pine plantation belonging to 8 plant taxonomic families. The number of species of tree seedlings recorded in the post-fire (5) was lower than in the unburned (6) black pine plantation. The different species of tree seedlings which were recorded in the post-fire and unburned black pine plantation can be found in Appendix 5. The predominant tree species seedlings recorded in the post-fire black pine was *Fraxinus ornus*, and in the unburned black pine plantation predominant tree species seedling recorded was black pine (*Pinus nigra*). Figure 3-10 shows the abundance of the different species of tree seedlings recorded for all transects in post-fire and in unburned black pine plantation.

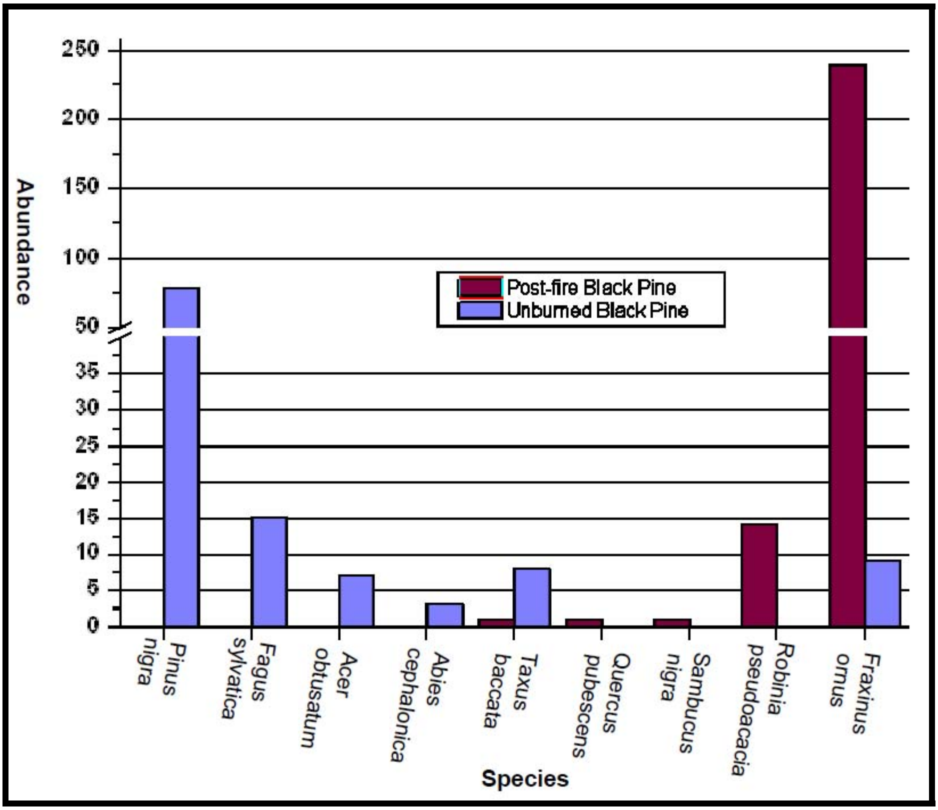

Figure 3-10: Abundance of different species of tree seedlings in post-fire and in unburned black pine plantation stands; abundance for all transects.

There was a significant difference in Shannon index (H’) of tree seedlings species diversity between post-fire ($\overline{X}$ =0.149, S.E=0.044, n=30) and unburned ($\overline{X}$ =0.527, S.E=0.057, n=30) black pine plantation (two sample t-test; t=5.248, df=54, p=0.00000264). The Simpson index (1-D) followed the same trends with a significant difference in tree seedlings species diversity between post-fire ($\overline{X}$ =0.097, S.E=0.0315, n=30) and unburned ($\overline{X}$ =0.496, S.E =0.0603, n=30) black pine plantation (two sample t-test; t=5.877, df=44, p=5.115 X 10^{-7}). Figure 3-11 below shows the error bar plots of tree seedlings species diversity between post-fire and unburned black pine plantation for the Shannon and Simpson diversity indices. A correlation analysis to determine the relationship between the Shannon’s and Simpson’s indices for tree seedlings species diversity showed a strong positive correlation in both post-fire (r=0.919, p<0.001, n=30) and unburned (r=0.833, p<0.001, n=30) black pine plantation. Based on the results obtained, we reject the null hypothesis that there is no significant difference in species diversity of tree seedlings between post- fire and unburned black pine plantation.

(A) **(B)**

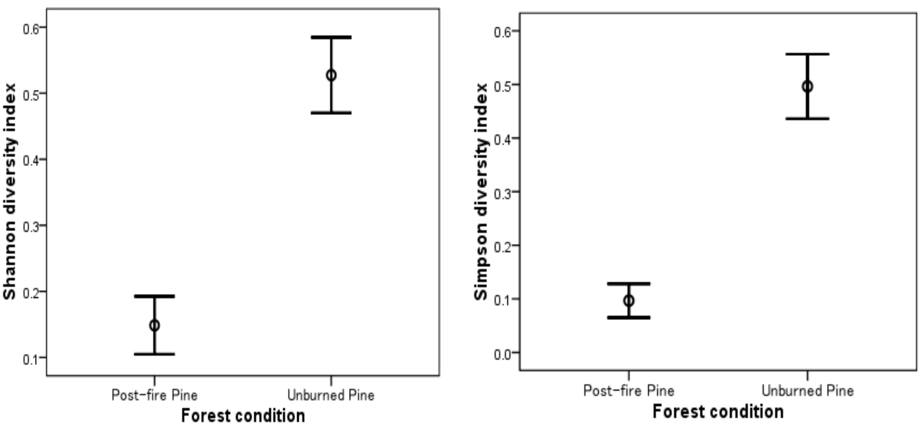

Figure 3-11: Error bar plots showing the difference in tree seedlings species diversity between post-fire and unburned black pine plantation; the bar represents the mean ± standard error of the (A) Shannon diversity index (B) Simpson diversity index

3.6. Species composition and diversity of herbaceous plants in post-fire and in unburned black pine plantation

A total number of 37 species of herbaceous plants were recorded in the black pine plantation belonging to 21 plant taxonomic families. The number of species of herbaceous plants recorded in the post-fire (13) was lower than in the unburned (29) pine plantation (Figure 3-12). The different species of herbaceous plants recorded in the post-fire and unburned black pine plantation can be found in Appendix 6. There was a high relative abundance of the herbaceous plant species recorded in the post-fire black pine plantation and species recorded includes: *Pteridium aquilinum* and *Rubus canescens*. In the unburned black pine plantation the predominant species were *Hedera helix* and *Viola alba.*

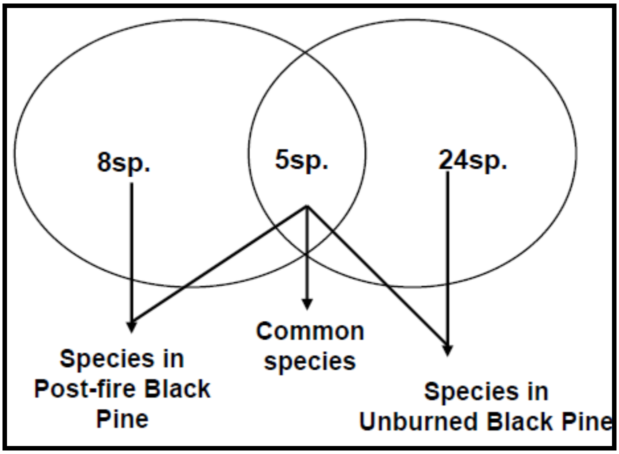

Figure 3-12: Number of herbaceous plants species and number of species overlap between post-fire and unburned black pine plantation

There was no significant difference in Shannon index (H') of herbaceous plants species diversity between post-fire ($\overline{X}$ =1.187, S.E=0.033, n=30) and unburned ($\overline{X}$ =1.099, S.E=0.052, n=30) black pine plantation (two sample t-test; t=1.434, df=47, p=0.158). The Simpson index (1-D) also followed the same trend with no significant difference in herbaceous plants species diversity between post-fire ($\overline{X}$ =0.677, S.E=0.011, n=30) and unburned ($\overline{X}$ =0.675, S.E=0.020, n=30) black pine plantation (two sample t-test; t=0.909, df=43, p=0.369). Figure 3-13 below shows the error bar plots of herbaceous plants species diversity between post-fire and unburned black pine plantation for the Shannon and Simpson diversity indices.

A correlation analysis to determine the relationship between the Shannon's and Simpson's indices for herbaceous plants showed a strong positive correlation in both post-fire ($r=0.848$, $p<0.001$, $n=30$) and unburned ($r=0.849$, $p<0.001$, $n=30$) black pine plantation. Based on the results obtained, we fail to reject the null hypothesis that there is no significant difference in species diversity of herbaceous plants between post- fire and unburned black pine plantation.

(A) **(B)**

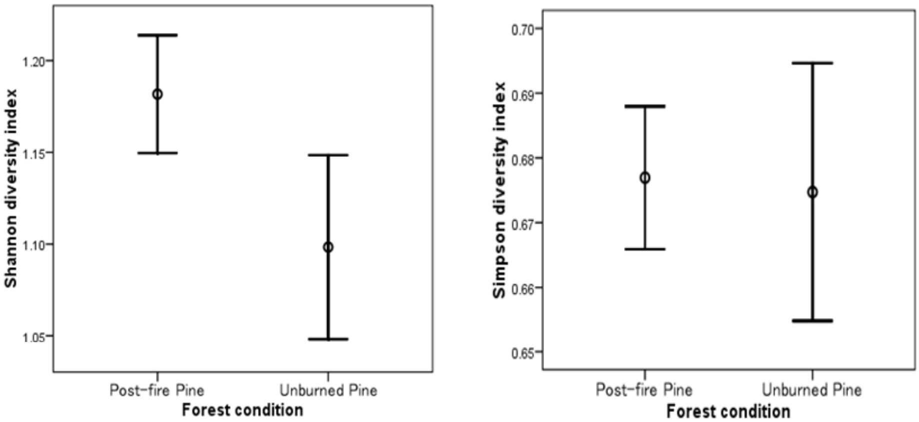

Figure 3-13: Error bar plots showing the difference in herbaceous plants species diversity between post-fire and unburned black pine plantation; the bar represents the mean ± standard error of the (A) Shannon diversity index (B) Simpson diversity index

3.7. Species diversity of tree seedlings between the two forest types for unburned and post-fire forests

Analysis on species diversity of tree seedlings between the unburned stands of the two forest types shows that there was a significant difference in Shannon index of tree seedlings species diversity between the beech forest ($\overline{X}$ =0.092, S.E=0.022, n=30) and black pine plantation ($\overline{X}$ =0.527, S.E=0.057, n=30) (two sample t-test; t=7.108, df=37, p=2.036 x 10^{-8}). The Simpson diversity index followed the same trend with a significant difference in tree seedlings species diversity between the beech forest ($\overline{X}$ =0.047, S.E =0.012, n=30) and black pine plantation ($\overline{X}$ =0.496, S.E =0.060, n=30) (two sample t-test; t=7.312, df=31, p=3.139x10^{-8}). Figure 3-14 below shows the error bar plots of tree seedlings species diversity between the unburned beech forest and unburned black pine plantation for the Shannon and Simpson diversity indices. Based on the results obtained, we reject the null hypothesis that there is no significant difference in species diversity of tree seedlings between unburned beech forest and unburned black pine plantation.

(A) **(B)**

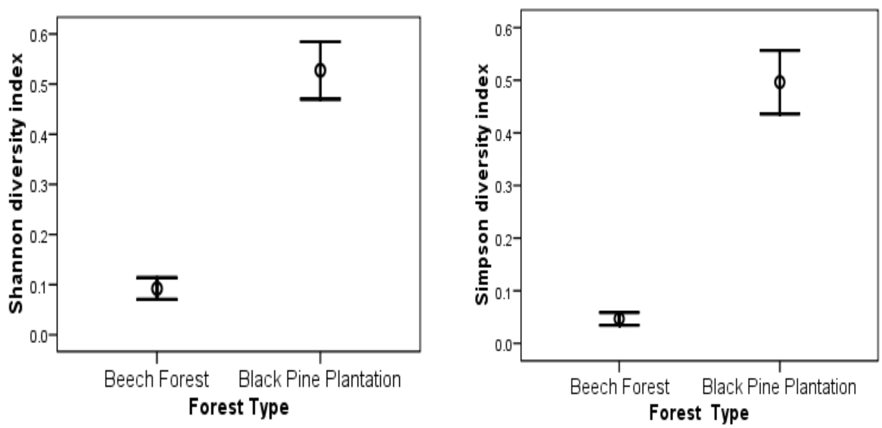

Figure 3-14: Error bar plots showing the difference in tree seedlings species diversity between unburned beech forest and unburned black pine plantation; the bar represents the mean ± standard error of the (A) Shannon diversity index (B) Simpson diversity index

Analysis on species diversity of tree seedlings between the post-fire stands of the two forest types shows that there was no significant difference in Shannon diversity index of tree seedlings species diversity between the beech forest ($\overline{X}$ =0.096, S.E

=0.022, n=30) and black pine plantation ($\overline{X}$ =0.149, S.E=0.044, n=30) (two sample t-test; t=1.080, df=43, p=0.286). The Simpson index followed the same trend with no significant difference in tree seedlings species diversity between the beech forest ($\overline{X}$ =0.048, S.E=0.011, n=30) and black pine plantation ($\overline{X}$ =0.096, S.E=0.031, n=30) (two sample t-test; t= 1.446, df= 36, p= 0.157). Figure 3-15 below shows the error bar plots of tree seedlings between the post-fire beech forest and post-fire black pine plantation for Shannon and Simpson diversity indices. Based on the results obtained, we fail to reject the null hypothesis that there is no significant difference in species diversity of tree seedlings between post-fire beech forest and post-fire black pine plantation.

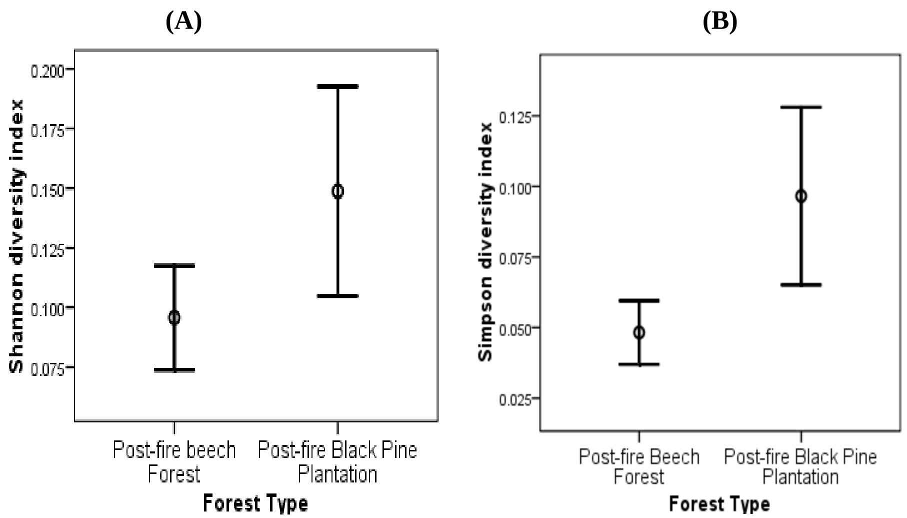

Figure 3-15: Error bar plots showing the difference in tree seedlings species diversity between post-fire beech forest and post-fire black pine plantation; the bar represents the mean ± standard error of the (A) Shannon diversity index (B) Simpson diversity index

3.8. Structure characteristics of the post-fire and unburned beech forest and black pine plantation

The coppice beech forest was dominated with stumps with multiple stems and the tree density estimated per hectare was 4163 ha^{-1}. The mean tree count in plots per transect in post-fire beech forest was 20.0 whilst the mean tree count in plots per transect in unburned was 21.5 with corresponding standard deviation of 3.5 and 2.3 respectively (Table 3-3). The mean DBH of trees in the post-fire and unburned beech forest was 14.8cm and 18.6cm with corresponding standard deviation of 5.0 and 6.8 respectively (Table 3-3). The mean height of trees in post-fire and unburned was 10.0m and 14.1m with corresponding standard deviation of 1.2 and 2.8 respectively. Despite the fact that the fire which occurred in the beech forest was mainly a surface fire, trees in the post-fire beech forest were scarred on the bark to an average height of 7.5m. Litter depth on forest floor in post-fire beech forest was 4.2cm compared to litter depth of 9.2cm in unburned beech forest (Table 3-3). Litter on the forest floor in the post-fire beech forest consisted mainly of recent leaf litter and burned residues. In the unburned beech forest litter consisted of recent and accumulated decayed leaf litter.

Table 3-3: Stand Structural Characteristics of Post-fire and Unburned Beech Forest

	Number of transects	**Post-fire Beech**			**Unburned Beech**		
		Mean	SD	Range	Mean	SD	Range
Tree count	30	20.0	3.2	13 - 25	21.5	2.4	17 - 25
DBH(cm)	30	14.8	5.0	8 - 26	18.6	6.8	7 – 30
Height (m)	30	10.0	1.2	7 - 12	14.1	2.8	7 - 17
Litter depth (cm)	30	4.2	1.0	2 - 6	9.2	1.3	5 - 11

Standard deviation (S.D.)

The black pine plantation was dominated with black pine trees and tree density estimated per hectare was 2430 ha^{-1}. The mean tree count in plots per transect in post-fire black pine was 13.0 whilst the mean tree count in plots per transect in unburned was 11.2 with corresponding standard deviation 1.7 and 2.0 respectively (Table 3-4). The mean DBH of tree in the post-fire and unburned black pine was 24.7 and 30.3 with corresponding standard deviation of 2.0 and 3.7 respectively. The mean height of trees in post-fire and unburned was 10.4 and 11.6 with corresponding standard deviation 0.6 and 0.3 respectively (Table 3-4). Litter depth on forest floor in post-fire beech plantation was 2.5 cm compared to litter depth of 4.5 cm in unburned black pine plantation (Table 3-4). The forest floor in the post-fire black pine forest consisted mainly of burned residues, rocks and litter from herbaceous plants. In the unburned black pine plantation the forest floor consisted mainly of fallen pine needles and few rocks.

Table 3-4: Stand Structural Characteristics in Post-fire and Unburned Black Pine Plantation

	Number of transects	**Post-fire Black Pine**			**Unburned Black Pine**		
		Mean	SD	Range	Mean	SD	Range
Tree count	30	13.0	1.7	10 - 17	11.2	2.0	7 - 15
DBH(cm)	30	24.7	2.0	18 - 27	30.3	3.7	24 - 38
Height (m)	30	10.4	0.6	9 - 11	11.6	0.3	11 - 12
Litter depth (cm)	30	2.5	0.4	2 - 4	4.5	0.6	3 - 6

Standard deviation (S.D.)

3.9. Other observations in the post-fire and burned beech forest and black pine plantation

Trees in the post-fire and unburned beech forest were observed to have stump sprouts. On average there were two (2) sprouts per tree in both post-fire and unburned coppiced beech forest. Results from statistical analysis showed that there was no significant difference in the number of trees recorded with sprouts between post-fire ($\overline{X}$ =8.0, S.E=0.450, n=30) and unburned ($\overline{X}$ =8.4, S.E=0.441, n=30) coppice beech forest (two sample t-test; t=0.687, df=58, p= 0.494).

Fire scarred trees in the post-fire beech forest were infested by fungi on the bark. These fungi were identified by an expert as *Daldinia concentrica* (ascomycete) (Noordeloos, 2008, personal communication) (See Appendix 8). Commonly referred to as King Alfred's cakes, *Daldinia concentrica* have been occasionally recorded on dead beech trees in Britain (Hingley, 1971).

Few *Fraxinus ornus* trees were observed in the post-fire black pine, which had developed sprouts after the fire. Few *F. Ornus* and *Fagus sylvatica* trees were also observed within the unburned black pine plantation.

4.0. DISCUSSION

4.1. Detection of active fires

The results of the study show that active fires in the montane forest belt can be detected by the MODIS active fire products and provides more precise information on the location, time, severity, distribution and date of fire occurrence than previous available at the National Park office. The fire on the 23rd of July in the natural grasslands and abandoned arable lands was only detected by the MODIS Terra active fire product and but not by the MODIS Aqua active fire product. The fire on the 24th in the beech forest was only detected by the MODIS Aqua fire product and not by the MODIS Terra fire product. This result confirms the study by Hawbaker et al. (2008) on the detection rates of the MODIS active fire products. They concluded that detection of active fires using MODIS is higher when both the MODIS Terra and Aqua are used due to the differences in the time of overpass of the two MODIS sensors.

The fire in the black pine plantation (*P. nigra*) showed a higher radiative power compared to beech forest fire. Studies have shown that the radiant heat energy produced by fire per unit time is related to the rate of fuel consumption (Wooster et al., 2005). Ground observations made during the field campaign confirmed that the fire in the black pine plantation was of high severity. Road signs made of aluminium plates along the road within the black pine plantation were melted (See Appendix 8). The melting point of aluminium is at 933.4 K (Preston-Thomas, 1990). From this it can be inferred that the fire in the black pine plantation is within the range temperatures of flaming fires (800 – 1200 K). Cruz et al. (2007) explained that silvicultural systems used in pine plantations often results in extremely flammable fuel complexes. *Pinus nigra* wood has high resin content and its needles contain flammable terpenes (Zinkel et al., 1985; Ormen˜o et al., 2009).

Low severity fires under deciduous forest canopy lack the energy needed to trigger the threshold for the MODIS active fire product algorithms and might not generate temperatures high enough for MODIS active fire detection (Giglio et al., 2003; Hawbaker et al., 2008). However the fire in the understorey of the beech forest generated enough energy to be detected by the MODIS Aqua active fire product. The possible reasons for the MODIS Terra active fire product not detecting the beech forest fire could be that this fire only lasted for a short while or was in the smouldering stage and therefore did not generate enough energy during the overpass of MODIS Terra sensor. According to Hawbaker et al. (2008) MODIS active fire detection decreased as the severity of fires decreases. Flannigan and Vonder Haar (1986) also explained that clouds reduce the detection rates of active fires.

The use of active fire hotspots in determining the location of fire is however associated with some limitations since the coordinates of the hotspot represent the centre of the detected fire pixel and not the *in situ* fire coordinates (Siegert and Hoffmann, 2000). The time of active fire detection is also dependent on the time of satellite overpass. Xiao-rui et al. (2005) explained that some fires that ignite between satellite overpasses which may result in attaining large sizes under favourable weather conditions may not be detected. The use of the MODIS fire products is however useful for research and management applications since it provides information on active fires. The study has also provided the dates which the fires occurred since no precise and consistent dates could be obtained during the field campaign.

4.2. Can fire scars in the montane forest belt be mapped accurately using medium resolution satellite imagery (ASTER)?

Forest fire scars in beech forest and black pine plantation in the montane belt of the Majella National Park have been mapped with ASTER data and digital data processing techniques and at a sufficient overall accuracy (87.8%) and Kappa statistics (0.85). A few miss-classifications have been recorded between the beech fire scar and black pine fire scar. The beech fire scar was confused with the black pine fire scar and the black pine fire scar was also confused with the beech fire scar. These miss-classifications can be attributed to the mixing spectral reflectance from the two burned forest types. The result of this study corroborates the findings by Keramitsoglou et al. (2008) in mapping forest fire scars with ASTER data obtaining an overall accuracy of 85%.

The spatial extent of the fire scars in the beech forest and black pine plantation was also determined, since this was not known to the management of the Majella National Park. Studies have shown that in mapping burned areas using satellite data the spatial extent of the burned area must be large enough and not smaller than the spatial resolution of satellite imagery (Razafimpanilo et al., 1995; Gerard et al., 2003). In this study the 15 m resolution ASTER data used was appropriate for the mapping of the fire scars in the beech forest and the black pine plantation.

The burned natural grasslands could not be detected a year after the fire using the ASTER 2008 data. Grasslands have the ability to recover within a year after fire (Morgan, 1999).

4.3. Species composition and diversity of tree seedlings in post-fire and in unburned beech forest

Tree species seedlings in the post-fire and unburned beech forest were mainly beech (*Fagus sylvatica*). Natural regeneration in the post-fire beech forest would consist mainly of *F. sylvatica*. There was no significant difference in species diversity of tree seedling in post-fire and unburned beech forest. Another study on species composition and diversity in an avalanched disturbed and undisturbed beech forest in the montane belt of the Majella National Park showed that species composition and diversity of trees in the disturbed and undisturbed beech forest was low and consisted mainly of beech trees (Donkor, 2008). Naaf and Wulf (2007) also studied a disturbed and undisturbed beech forest in the Kellerwald-Edersee National Park, Germany and concluded that, species composition and diversity of woody plants in disturbed beech forest is similar to closed or undisturbed beech forest. It appears that only few woody plants species grow under beech forest (Gilman and Watson, 1993; Naaf and Wulf, 2007) due to the deep shade and dense forest canopy and that the only woody plant growing successfully under a beech canopy is beech seedlings (Estevan et al., 2007; Schmidt et al., 2009). Mountford et al. (2006) studied the association of canopy opening with pattern of natural regeneration of beech forest at Rumerhedge Wood, Oxfordshire, and concluded that, natural regeneration in gaps of beech-dominated forests are unlikely to include other tree species unless there is a seed source located near-by. During the field campaign it was observed that the fire has not yet resulted in a significant opening of the forest canopy in the post-fire beech forest since the canopy was relatively closed and most of the beech trees have retained their dead leaves a year after fire. Fralish and Franklin (2002) explained that beech have the ability to retain dead leaves on trees.

The low species diversity of tree species seedlings recorded in both the post-fire and unburned beech forests could be attributed to the monospecific nature of the forest and also the allelopathic effect of beech. According to Piovesan et al. (2005b) *F. sylvatica* forests in the montane areas of Europe are usually single species stands and the inability of other tree species to coexist can be attributed to the monospecifity. A study by Hane et al. (2003) also showed that beech has an allelopathic relation and the phytotoxic effect of the leaves impedes the growth of other tree species. Based on the low diversity of tree species seedlings recorded in the post-fire beech forest it can be inferred that fire has not effectively removed the allelopathic effect of beech in the understorey of the post-fire forest.

Seedlings of *Fraxinus ornus*, *Acer platanoides* and *Acer pseudoplatanus* were recorded in the post-fire beech forest but were absent in the unburned beech forest. In some few years time the trees in the post-fire beech forest might lose their leaves and this would result in a significant opening in the forest canopy. This might influence the establishment of other tree species in the post-fire beech forest since there are seed source of other species close to the post-fire beech forest. And salvage cutting would enhance this canopy opening creating conditions for more mixed forest (Elliot et al., 2002).

The results show that there was no significant difference of *F. sylvatica* seedlings between post-fire and unburned beech forests. The high number of beech seedlings recorded in the post-fire beech forest a year after fire however presents an apparent paradox, since other studies have shown that beech seeds are short-lived even if unconsumed and therefore absent from soil seed banks under beech forests (Olano et al., 2002; Godefroid et al., 2006; Van Gils et al., 2008). A possible explanation is that the seeds were stored in the canopy seed bank. Lamont and Enright (2000) demonstrated that woody plants species have the ability to retain viable seeds in the canopy during disturbances and the seeds are released after fire which ensures regeneration. They further explained that, even dead standing woody trees can store matured seeds in the crown. The results also showed that beech can sprout after forest fire. According to Beaudet and Mesier (2008) the survivorship of beech sprouts is relatively higher compared to beech seedlings. Based on the results of this study it can be concluded that there is natural regeneration of beech after forest fire.

4.4. Species composition and diversity of herbaceous plants in post-fire and unburned beech forest

The results show that the number of herbaceous plants species in post-fire beech forest was higher compared to unburned beech forest. With respect to species diversity the results show that species diversity of herbaceous plants was higher in post-fire compared to the unburned beech forest, since there was a significant difference in herbaceous plants species diversity between post-fire and unburned beech forests. A study by Naaf and Wulf (2007) in a beech forest indicated that the herbaceous layer under a beech forest is sparse and poor in species. The differences in species composition and diversity of herbaceous plants recorded between the post-fire and unburned beech forests could be attributed to the effect of fire, since altitude, slope, aspect, soil substrate and tree density did not differ notably between the post-fire and unburned beech forest (Refer to appendix 7 for information on soil). The differences in species composition and diversity between the post-fire beech forest and unburned could be attributed to the low litter depth and cover in the post-fire beech forest after fire. The differences could also be attributed to increase in light availability in the post-fire beech forest since a few of the trees have lost their leaves after the fire. Seghieri et al. (1997) studied growth of herbaceous plants in a natural vegetation and concluded that, species richness of herbaceous plants increases with low litter depth and cover and decrease with high litter cover, since litter impedes developments of herbaceous plants. A number of studies in forests of the Mediterranean Basin have also shown an increase in species richness and diversity of herbaceous plants during the first three years after fire (Buhk et al., 2005; Buhk et al., 2006). Buhk et al. (2006) explained that the increase in herbaceous plants after fire is influenced by reduced competition, nutrients release from increased mineralization of organic matter and light availability. A study on herbaceous plant species in a pre-fire and post-fire forest also identified that there is increase in diversity and frequency of herbaceous species after fire (William et al., 1982). Gilliam and Christensen (1986) also worked on infertile sites in southeastern coastal plain of the United States and recorded a higher species richness and high abundance of herbaceous plants after fire.

4.5. Species composition and diversity of tree seedlings in post-fire and in unburned black pine plantation

The results show that the number of different species of tree seedlings in the post-fire black pine plantation was lower compared to the unburned black pine plantation. With respect to species diversity the results show a significant difference in tree seedlings species diversity between post-fire and unburned black pine plantation. This is an indication that species diversity of tree seedlings was lower in the post-fire compared to the unburned black pine plantation. The explanation of the low species diversity recorded in the post-fire black pine plantation is challenging since the canopy of the post-fire plantation is now more open after fire and will favour the establishment of other tree seedlings. Also altitude (1000-1300 a.s.l.), slope (10-30^0), aspect (Southwest) and soil substrate (limestone) did not differ significantly between the post-fire and unburned pine plantation. The low species diversity in the post-fire black pine plantation could be attributed to the high severity of the fire which occurred in the black pine plantation, making the condition unsuitable for the establishment of tree species seedlings. Chappell and Agee (1996) studied the effect of fire severity on tree seedling establishment and concluded that tree seedling establishment is lower in high fire severity forests. Another explanation could be the allelopathic effect of a post-fire colonizer (*P. aquilinum*) which has dominated the post-fire black pine plantation.

The results also show that tree species seedlings in the unburned black pine was mainly black pine (*P. nigra*) whilst in the post-fire black pine plantation tree species seedlings was mainly *Fraxinu ornus*. The results show that there was no natural regeneration of *P. nigra* after forest fire and natural regeneration in the post-fire black pine forest would be mainly of another woody plant species (*F. ornus*). Fule´ et al. (2008) studied a post-fire *P. nigra* forest at approximately 1000 m elevation in the Sierra Turmell, Castello´n province in eastern Spain and also concluded that regeneration in post-fire *P. nigra* forest is poor and consisted entirely of *Quercus ilex*. The *F. ornus* recorded in the post-fire black pine plantation could be attributed to the seed sources of the species within the Majella National Park. Thebaud and Bebussche (1991) described *F. ornu* as a colonizing species which has the ability to easily establish itself after fire since the seeds are wind dispersed.

The poor natural regeneration of *P. nigra* in the post-fire stand recorded in this study could be attributed to the severity of the fire which occurred in the plantation. Escudero et al. (1999) explained that seeds of *P. nigra* are sensitive to high temperatures of forest fires. Studies have shown that *P. nigra* lack serotinous cones and release its seeds in spring and do not maintain a soil and canopy seed bank when summer wildfires occur (Habrouk et al., 1999; Escudero et al., 1999). *Pinus nigra* cones observed in the post-fire black pine plantation were completely burned and some were completely charred. According to Habrouk et al. (1999) the most important factor for regeneration in post-fire pine forests is the availability of viable seeds. Calvo et al. (2008) studied a post-fire pine forest in North West Spain and concluded that natural regeneration in a post-fire pine forest depends mainly on the effects of the fire on the pine seeds which may be present in soil and canopy seed bank.

4.6. Species composition and diversity of herbaceous plants in post-fire and in unburned black pine plantation

The number of different species of herbaceous plants in the post-fire black pine plantation is lower compared to the unburned black pine plantation. Despite the significant differences in the number of different species of herbaceous plants recorded between the post-fire and unburned black pine plantation, there was no significant difference in species diversity of herbaceous plants between the post-fire and unburned black pine plantation. This can be attributed to the evenness in the relative abundance of herbaceous plants species recorded in the post-fire black pine plantation. In estimating species diversity both the measure of species richness and species evenness is used and samples with more evenness in relative abundance tends to have high species diversity compared to samples with great variation in abundance among species (Onaindia et al., 2004). This explains why there was no significant difference in the species diversity between post-fire and unburned black pine plantation. The low number of different herbaceous plants species recorded in the post-fire black pine plantation could be due to the allelophatic effect of *P. aquilinum*. *Pteridium aquilinum* and *Rubus canescens* were identified as post-fire colonizers with relative high abundance in the post-fire black pine plantation. According to de Silva and Matos (2006) *P. aquilinum* produces an allelophatic component which reduces the establishments of other plants. In the study of a forest in the National Park of Tijuca, Rio de Janeiro, de Silva and Matos (2006) also recorded a high abundance and spread of *P. aquilinum* after fire. Additionally, Boerner (1981) in his study cited *P. aquilinum* as a post-fire colonizer in pine and oak forests. *Pteridium aquilinum* has a deep underground rhizome that stores carbohydrates and immune to fire and sprouts vigorously after fires (Dolling, 1999). Fire creates an alkaline soil condition which favours the establishment of *P. aquilinum* spores (Crane, 1990). Wright and Bailey (1982) studied fire ecology of different forest types in United States and Southern Canada and stated that *Rubus spp* increases after hot fires.

(a) **(b)**

Figure 4-1: Indicating the high abundance and spread of herbaceous plants in the post-fire black pine plantation (a) *Pteridium aquilinum* (b) *Rubus canescens*

4.7. Species diversity of tree seedlings between the two forest types for post-fire and unburned forests

The results show that there is a significant difference in tree seedlings species diversity between unburned black pine plantation and unburned beech forest. This indicates that species diversity of tree seedlings in unburned black pine plantation was higher compared to unburned beech forest. This confirms other comparative studies of species richness and diversity between coniferous plantations and broad-leave forests which showed that the plantations have higher species diversity of plants (Bhuju et al., 2001; Nagaike, 2002). Estevan et al. (2007) studied species richness in a *Pinus sylvestris* and beech forest in central Catalonia (NE of Spain) and concluded that species richness was higher in the pine forests. The differences in species diversity recorded between the black pine plantation and the beech forest in this study could be due to the differences in structure properties of the canopy and composition, since the beech forest has a dense forest canopy and it is monospecific. The results of the structural characteristics shows that tree density in the beech forest was higher compared to the black pine plantation.

Comparing species diversity of tree seedlings between post-fire black pine plantation and post-fire beech forest showed that there was no significant difference in tree seedlings species diversity between the two forest types. This can be attributed to a number of reasons; including the relatively closed canopy of the post-fire beech forest a year after the fire; the allelopathic effect of the beech on other tree species and the high severity of the fire which occurred in the post-fire beech forest making condition unsuitable for other species seedling establishment. It can be inferred that fire results in the reduction of tree seedlings species diversity and establishment in a black pine plantation. This is however an assumption since there is no evidence within the data to prove this.

4.8. Structure characteristic of the post-fire and unburned beech forest and black pine plantation in the montane forest belt

The mean tree density estimated per hectare for the coppice beech forest (4163 ha^{-1}) in the research area within the Majella National Park is within range with a study by Coppini and Hermanin (2006). They studied a coppice beech forest in the Tuscan-Emilian Apennines, Italy and estimated mean tree density as 3900 ha^{-1} with a large variation from 2846 ha^{-1} to 5608 ha^{-1}. Ciancio et al. (2006) also estimated mean tree density of a coppice beech forest in the western part of Latium, Central Italy as 3848 ha^{-1}. Mean tree density for a high forest beech stand in the Majella National Park was however estimated as 1208 ha^{-1} with a variation from 222 ha^{-1} to 3089 ha^{-1} by Cho (2007). The coppice beech forest studied largely consisted of stumps with multiple stems. The differences in the mean tree height and mean DBH of trees between the post-fire and unburned beech forest could be a result of the rotation period for the coppice system used. According to Ciancio et al. (2006) differences in rotation periods can result in difference in stand structure within a coppice forest stand. The low litter depth in the post-fire beech forest can be attributed to the fire which occurred in the forest understorey. Kodandapani et al. (2008) studied the effect of fire on forest litter and concluded that surface fires significantly reduce forest litter and cover.

The study estimated mean tree density for the black pine plantation as 2430 ha^{-1}. Cantiani et al. (2005) studied a 40 year black pine plantation and estimated tree density as 2065 ha^{-1}. The differences in the mean tree height and mean DBH of trees between the post-fire and unburned black pine plantation could be a result of differences in time of plantation establishment. The differences in litter depth and cover between post-fire and unburned beech can also be attributed to the effect on the fire.

4.9. Implications and recommendation for management

Determining the location of active fires using the MODIS active fire products would be important to the Majella National Park for managing forest fires. In the event of fire, information can be obtained from the MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/) which provides information on the location of active fires in near real time using MODIS Terra and Aqua. The Fire Information for Resource Management System (FIRMS) (http://maps.geog.umd.edu/firms/#) also provides global MODIS hotspot/fire location in near real time to natural resource managers around the world without any cost. The management of the Majella National Park can develop a monitoring mechanism using the MODIS active fire products and all the resources and methods discussed in this study to detect active fires especially during the summer since most fires in the park occur in summer.

Satellite remote sensing data and techniques can provide a cost effective and accurate method in determining the spatial extent of forest fire scars in the montane forest belt which will be needed to evaluate the ecological and economic impact of the fire. For the management of the Majella National Park to acquire financial support from the Italian Ministry of the Environment to be used for restoration projects of a burned forest, it is required to justify the need in economic terms (Personal Communication). It was noted that both the beech and pine fire scars were close to roads, a further research is therefore recommended to determine how physical and geographical factors such as roads, topography and elevation could influence the occurrence and spread of fires in the montane belt of the Majella National Park.

Pinus nigra is very susceptible to fire. Post-fire natural regeneration of black pine is poor. Therefore the management of the Majella National Park may consider to adopt a strategy to convert the monospecific black pine plantations into mixed stands using fire-resilient species. A few grazing activities where also observed in the post-fire black pine plantation and it is recommended that the management of the Majella National Park should control such the grazing activities since it will influence development and regeneration in the post-fire black pine plantation. According to Richard (1992) grazing influences species diversity and forest developments in different ways. He further explained that this influence of grazing is however based on the intensity of the grazing activity. Rozas (2003) proved that certain level of grazing can facilitate tree seedling establishment.

Local communities in the Majella National Park applied to the national park for permit to log the burned beech trees (Personal Communication). This request must be evaluated with reference to the outcome of this study which suggests that there is natural regeneration of the post-fire beech forest from seedlings and sprouts. Reich et al. (2001) explained that logging affects regeneration of forests through soil and forest floor disturbance and results in the death of seedlings and stump sprouts. A study by Attiwill also (1994) showed that logging influences forest productivity through the loss of nutrient. The management of the park could however allow a salvage cutting with the objective to open the forest canopy to create opportunities for a mixed forest.

4.10. Limitations of research

The underlying assumption of this study is that fire is the factor influencing the differences in species diversity of tree seedlings and herbaceous plants between post-fire and unburned forest of beech and black. However other factors not considered in this study may contribute to the differences in species diversity. Therefore, a further research is recommended to consider all factors simultaneously (environmental factors and fire characteristics) and be able to evaluate the relative importance of each.

5.0. CONCLUSION

The study was conducted to determine the location, time, severity and distribution of active fires in the montane forest belt of the Majella National Park and demonstrated the possibility of mapping forest fire scars using off-the-shelf medium resolution satellite data. The fire in the beech forest at the montane belt is the first record on European beech forest fire. This study provides information on post-fire regeneration and succession in beech forest and black pine plantation which is limited in literature. The study examined species composition and diversity of tree seedlings and herbaceous plants in post-fire and unburned beech forest and black pine plantation. Our findings lead to the following conclusions.

Active fires can be detected by the MODIS active fire products. The MODIS Terra and Aqua active fire products provided information on the location, time, severity and distribution of the fires. Fire scars in beech forest and black pine plantation can be mapped with sufficient accuracy using ASTER data. Species diversity of tree seedlings in both post-fire and unburned beech forests is low and the main tree seedling is beech. Beech can regenerate after forest fire by seedlings and stump or root spouts. Species diversity of herbaceous plants is higher in post-fire beech forest as compared to unburned beech forest. Species diversity of tree seedlings in post-fire black pine plantation is lower compared to the unburned black pine plantation. Natural regeneration of black pine after forest fire is poor. There is no significant difference in herbaceous plant species diversity between the post-fire and unburned black pine plantation. Species diversity of tree seedlings is higher in unburned black pine plantation compared to unburned beech forest and there is no significant difference in species diversity of tree seedlings between the post-fire forests of the two forest types. The Shannon and Simpson diversity indices showed similar trends and a high correlation in post-fire and unburned forests.

The study recommends to the management of the Majella National Park the application of satellite remote sensing and GIS infrastructure in the detection of active fires and mapping of forest fires scars in the montane forest belt.

6.0. REFERENCES

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7.0. APPENDICES

Appendix 1: Ground observation coordinates (UTM) in post-fire and unburned coppice beech forest

Transect Number	Post-fire Forest			Unburned Forest		
	X	Y	Altitude	X	Y	Altitude
1	423450.251	4669976.647	917.787	423153.951	4669870.830	997.858
2	423376.673	4670025.664	886.556	423254.372	4669828.751	977.381
3	423351.906	4669898.211	895.114	423216.190	4669799.726	998.754
4	423318.505	4669934.150	884.270	423342.672	4669675.993	1032.539
5	423838.658	4669810.229	1082.768	423613.264	4669560.161	996.334
6	423737.095	4669872.296	1083.844	423683.876	4669514.765	969.674
7	423805.019	4669762.119	1027.431	423576.485	4669502.113	1046.116
8	423990.756	4669635.393	1090.161	423871.351	4669364.785	1010.852
9	424051.926	4669632.686	1137.030	424073.824	4669334.789	1055.212
10	424085.107	4669533.395	962.594	424238.802	4669297.294	1049.028
11	424123.537	4669592.899	1076.764	424684.992	4669031.080	1130.936
12	424381.850	4669490.404	1066.189	424838.721	4669034.829	1123.050
13	424277.331	4669429.356	983.161	425262.414	4668982.336	1245.106
14	424448.838	4669093.245	1043.651	425356.152	4669109.819	1152.847
15	424404.939	4669148.936	1035.407	425377.304	4668986.743	1219.073
16	424544.268	4669223.369	1027.610	425446.169	4669016.396	1211.545
17	424600.843	4669310.990	1077.974	425540.180	4668938.267	1272.842
18	424662.351	4669359.176	1156.477	425444.355	4668915.572	1277.368
19	424427.913	4669401.263	1049.028	425700.871	4668974.822	1258.459
20	424510.576	4669438.020	1147.650	425812.328	4668987.128	1299.995
21	424686.447	4669438.408	1224.719	425661.992	4668894.512	1311.690
22	424763.152	4669164.472	1060.723	425938.585	4668962.721	1361.337
23	424929.370	4669158.040	1105.306	425746.100	4669019.831	1247.212
24	424826.648	4669182.528	1088.056	425933.574	4669042.328	1299.189
25	425037.208	4669121.810	1085.009	425844.432	4669056.264	1276.158
26	425211.243	4669169.693	1132.639	425752.663	4669121.126	1233.994
27	424919.578	4669282.028	1166.334	426042.310	4668959.839	1337.320
28	425026.686	4669251.094	1159.972	425920.879	4669154.121	1274.141
29	425087.052	4669298.628	1205.631	423554.147	4669894.802	945.567
30	424811.373	4669311.498	1119.555	425833.076	4669133.431	1248.332

Appendix 2: Ground observation coordinates (UTM) in post-fire and unburned black pine plantation

Transect Number	Post-fire Plantation			Unburned Plantation		
	X	Y	Altitude	X	Y	Altitude
1	424811.764	4672294.978	1217.697	425557.183	4671631.702	1323.654
2	424785.706	4672464.355	1258.697	425461.469	4671697.505	1322.982
3	424575.319	4672305.682	1153.632	425529.267	4671719.440	1330.599
4	424633.610	4672444.279	1217.139	425553.195	4671775.273	1334.990
5	424383.402	4672505.433	1123.704	425395.665	4671769.291	1323.385
6	424461.446	4672636.917	1196.634	425385.695	4671837.089	1321.548
7	424523.266	4672482.967	1181.649	425352.827	4671984.648	1296.321
8	424244.075	4672548.112	1042.014	425288.503	4672061.848	1284.940
9	424141.705	4672633.731	1081.956	425125.399	4671976.625	1275.799
10	424295.449	4672656.334	1123.811	424993.413	4671958.726	1235.114
11	423993.998	4672807.358	1041.177	424990.874	4671857.029	1229.782
12	424211.528	4672807.004	1128.216	425128.462	4671795.220	1276.113
13	423887.032	4672991.428	1060.722	425240.130	4671689.529	1290.362
14	423841.330	4673093.944	1046.513	425377.719	4671587.833	1268.809
15	423857.102	4672892.965	1009.097	425473.518	4671412.849	1319.039
16	423698.273	4673065.029	979.610	424851.465	4671709.086	1220.641
17	423808.571	4673215.034	1053.024	425444.935	4671334.205	1340.188
18	423645.330	4673219.446	996.539	425361.508	4671438.711	1304.566
19	423539.444	4673219.446	957.100	425183.973	4671387.722	1292.378
20	423455.618	4673303.273	956.937	425351.623	4671278.735	1338.888
21	423543.856	4673365.039	1011.724	425353.060	4671218.357	1346.999
22	423654.154	4673440.042	1081.883	425232.517	4671248.760	1315.544
23	423535.032	4673515.044	1046.141	425280.911	4671348.248	1319.263
24	423402.675	4673413.570	962.471	425085.922	4671415.832	1266.031
25	423301.201	4673484.161	946.356	424886.408	4671559.727	1244.837
26	423301.201	4673598.871	982.680	424931.778	4671440.919	1257.742
27	423154.873	4673660.883	929.055	424989.178	4671339.780	1289.062
28	423256.837	4673739.317	987.261	425119.821	4671302.345	1291.796
29	422856.823	4673888.341	885.011	425038.274	4671287.357	1299.323
30	424670.985	4672580.943	1245.767	425556.029	4671358.546	1325.312

Appendix 3: List of tree species seedlings recorded in the post-fire and unburned beech forest

Post-fire Forest		**Unburned Forest**	
Species name	**Family**	**Species name**	**Family**
Acer obtusatum	Aceraceae	*Acer obtusatum*	Aceraceae
Acer platanoides	Sapindaceae	*Fagus sylvatica*	Fagaceae
Acer pseudoplatanus	Sapindaceae	*Ostrya carpinifolia*	Betulaceae
Fagus sylvatica	Fagaceae	*Quercus pubescens*	Fagaceae
Fraxinus ornus	Oleaceae	*Sambucus nigra*	Adoxaceae
Ostrya carpinifolia	Betulaceae	*Taxus baccata*	Taxaceae
Quercus pubescens	Fagaceae		
Sambucus nigra	Adoxaceae		
Taxus baccata	Taxaceae		

Appendix 4: List of herbaceous plant species recorded in the post-fire and unburned beech forest

Post-fire Forest		**Unburned Forest**	
Species name	**Family**	**Species name**	**Family**
Artemisia vulgaris	Asteraceae	*Aremonia agrimonoides*	Rosaceae
Aremonia agrimonoides	Rosaceae	*Carlina acaulis*	Asteraceae
Asperula purpurea	Rubiaceae	*Cruciata laevipes*	Rubiaceae
Atropa belladonna	Solanaceae	*Cyclamen europaeum*	Primulaceae
Clematis vitalba	Ranunculaceae	*Daphne laureola*	Thymelaeaceae
Cruciata laevipes	Rubiaceae	*Digitalis micrantha*	Scrophulariaceae
Cyclamen europaeum	Primulaceae	*Dryopteris filix-mas*	Dryopteridaceae
Cyclamen hederifolium	Myrsinaceae	*Galeopsis angustifolia*	Lamiaceae
Cynoglossum magellense	Boraginaceae	*Geum urbanum*	Rosaceae
Daphne laureola	Thymelaeaceae	*Hedera helix*	Araliaceae
Dryopteris filix-mas	Dryopteridaceae	*Helianthemum nummularium*	Cistaceae

Post-fire Forest		Unburned Forest	
Species name	**Family**	**Species name**	**Family**
Emerus majus	Fabaceae	*Helleborus foetidus*	Ranunculaceae
Euphorbia amygdaloides	Euphorbiaceae	*Hepatica nobilis*	Ranunculaceae
Galega officinalis	Fabaceae	*Hieracium caespitosum*	Asteraceae
Galeopsis angustifolia	Lamiaceae	*Laburnum anagyroides*	Fabaceae
Geum urbanum	Rosaceae	*Lathyrus venetus*	Fabaceae
Geranium spp	Geraniaceae	*Linaria purpurea*	Scrophulariaceae
Hedera helix	Araliaceae	*Lotus corniculatus*	Fabaceae
Helianthemum nummularium	Cistaceae	*Pteridium aquilinum*	Dennstaedtiaceae
Helianthemum oelandicum	Cistaceae	*Rubus canescens*	Rosaceae
Helleborus foetidus	Ranunculaceae	*Rubus idaeus*	Rosaceae
Hepatica nobilis	Ranunculaceae	*Rubus saxatilis*	Rosaceae
Hieracium caespitosum	Asteraceae	*Sanicula europaea*	Apiaceae
Hieracium sylvaticum	Asteraceae	*Silene italica*	Caryophyllaceae
Juniperus communis	Cupressaceae	*Silene vulgaris*	Apiaceae
Laburnum anagyroides	Fabaceae	*Viola alba*	Violaceae
Lamium garganicum	Lamiaceae		
Lathyrus venetus	Fabaceae		
Lotus corniculatus	Fabaceae		
Mycelis muralis	Asteraceae		
Pteridium aquilinum	Dennstaedtiaceae		
Ptilostemon strictus	Asteraceae		
Pyrola minor	Ericaceae		
Rosa canina	Rosaceae		
Rubus canescens	Rosaceae		
Rubus idaeus	Rosaceae		

Post-fire Forest		Unburned Forest	
Species name	**Family**	**Species name**	**Family**
Rubus ulmifolius	Rosaceae		
Sambucus ebulus	Caprifoliaceae		
Sanicula europaea	Apiaceae		
Seseli viarum	Apiaceae		
Silene vulgaris	Caryophyllaceae		
Solidago virgaurea	Asteraceae		
Stachys sylvatica	Lamiaceae		
Teucrium chamaedrys	Lamiaceae		
Trifolium fragiferum	Fabaceae		
Trifolium scabrum	Fabaceae		
Ulmus canescens	Ulmaceae		
Urtica dioica	Urticaceae		
Viola alba	Violaceae		

Appendix 5: List of tree species seedlings recorded in the post-fire and unburned black pine plantation

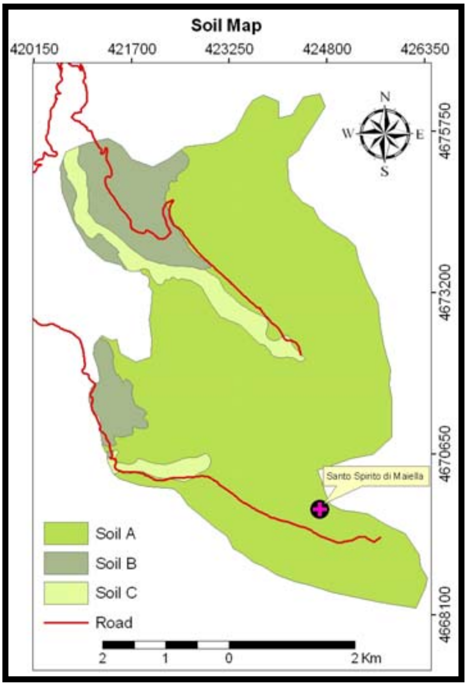
Post-fire Forest		Unburned Forest	
Species name	**Family**	**Species name**	**Family**
Fraxinus ornus	Oleaceae	*Abies cephalonica*	Pinaceae
Quercus pubescens	Fagales	*Acer obtusatum*	Aceraceae
Robinia pseudoacacia	Fabaceae	*Fagus sylvatica*	Fagaceae
Sambucus nigra	Caprifoliaceae	*Fraxinus ornus*	Oleaceae
Taxus baccata	Taxaceae	*Pinus nigra*	Pinaceae
		Taxus baccata	Taxaceae

Appendix 6: List of herbaceous plant species recorded in the post-fire and unburned black pine plantation

Post-fire Plantation		Unburned Plantation	
Species name	**Family**	**Species name**	**Family**
Anthyllis vulneraria	Fabaceae	*Asperula purpurea*	Rubiaceae
Arctium spp	Asteraceae	*Carlina acaulis*	Asteraceae
Centaurea ambigua	Asteraceae	*Clematis vitalba*	Ranunculaceae
Colchicum neapolitanum	Liliaceae	*Cyclamen europaeum*	Primulaceae
Cota tinctoria	Asteraceae	*Daphne laureola*	Thymelaeaceae
Linaria vulgaris	Plantaginaceae	*Digitalis spp*	Scrophulariaceae
Lotus corniculatus	Fabaceae	*Galeopsis angustifolia*	Lamiaceae
Origanum vulgare	Lamiaceae	*Galium odoratum*	Rubiaceae
Pteridium aquilinum	Dennstaedtiaceae	*Geum urbanum*	Rosaceae
Rubus canescens	Rosaceae	*Hedera helix*	Araliaceae
Sambucus ebulus	Adoxaceae	*Helianthemum nummularium*	Cistaceae
Verbascum spp	Scrophulariaceae	*Helianthemum oelandicum*	Cistaceae
Viola alba	Violaceae	*Hepatica nobilis*	Ranunculaceae
		Hieracium caespitosum	Asteraceae
		Lanium spp	Orchidaceae
		Lathyrus venetus	Fabaceae
		Linaria purpurea	Scrophulariaceae
		Lotus corniculatus	Fabaceae
		Pteridium aquilinum	Dennstaedtiaceae
		Pyrola minor	Monotropoideae
		Rubus caesius	Rosaceae
		Rubus canescens	Rosaceae
		Rubus idaeus	Rosaceae
		Rubus saxatilis	Rosaceae
		Sambucus ebulus	Caprifoliaceae

Post-fire Plantation		Unburned Plantation	
Species name	**Family**	**Species name**	**Family**
		Sanicula europaea	Apiaceae
		Seseli viarum	Apiaceae
		Silene vulgaris	Caryophyllaceae
		Viola alba	Violaceae

Appendix 7



Description of soil map legend for the research area

Soil A	Slope with morphology and profile mostly regular and slope from steep to very steep. (No soil type given; suspect Lithnic Rendolls); elevation 100-1700 m; dry, shallow, very steep hillslope, calcareous
Soil B	Lower slope to very steep (no soil type indicated)
Soil C	Landslides/ice induced cryoclastic surface on very

Appendix 8

Charred black pine trees

Melted road sign within the post-fie black pine plantation

Fire scarred beech trees

Daldinia concentrica identified on the bark of scarred beech trees