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Preven-T

PREVEN-T DELIVERABLE 3.2. Development of capacity for dealing with forest fires.

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PREVEN-T Project Profile

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Abbreviations and acronyms

Deliverable	D
Expected Outcomes	EO
International Hellenic University	IHU
Non-governmental organization	NGO
Land Use Land Cover	LULC

Executive Summary

PREVEN-T is a 18 month duration project funding from the Interreg IPA Cross-border Cooperation Programme: PREVEN-T – CN2 – SO2.4 – SC049.

The overarching objective of the PREVEN-T project is to improve the operational efficiency and the administrative capacity of relevant services in natural disasters management. At the same time project's goal is to enable education, awareness and sensitization of the local population, so that in cooperation with the competent authorities to have a coordinated action to deal with Natural and Technological Disasters and Risks.

The main purpose of this document is to investigate the diachronic vegetation changes, since the early 1980s, in the Pelister NP using multitemporal landsat data. Furethermore, it aims in the spatially explicit assessment of fire risk in the area and provide recommendation for its management and protection.

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1 Introduction

1.1 Purpose of the document and background

Pelister NP is not considered a typical fire prone area, similar to the ones observed in the Mediterranean region. However, in recent years several publications demonstrate a significant change in fire behaviour with its area of distribution being constantly expanding at higher altitudes and latitudes. This trend has been attributed to two major drivers. The increase of vegetation cover due to agricultural land abandonment and urbanisation and the observed climatic trends of increased summer temperature and decreased summer precipitation leading to increased drought conditions during summer. The purpose of this document is to investigate the diachronic vegetation changes, since the early 1980s, in the Pelister NP using multitemporal landsat data. Furthermore, the document presents the results of a fire risk assessment based on fire behaviour simulation and mapping of fuel loads for the entire national park. Based on the results presented the document provides recommendations for the management of the park in order to avoid fire caused disasters in the future. The specific objectives are a) to investigate the degree of vegetation densening and loss of open habitats using a number of vegetation indices which are often employed for long term monitoring and b) to thematically and spatially map the fuel types of the park using state of the art mapping methods, c) perform fire risk assessment using spatially explicit indices and d) to discuss the observed results and provide recommendations for reducing fire risk and promoting the long term sustainability of the national park.

1.2 Intended audience

The intended audience of this document consists of the following target groups:

- PREVEN-T project partners and the Project Officer at the Managing Authority
- Land managers and practitioners in Pelister National Park

1.3 Work Package Objective

The current technical report refers to WP3.2 where its main objective is the Monitoring of forest, early detection of forest fires, warning of relevant institutions for dealing with forest fires and spread forecasting systems since all of them are very important part of the circles of dealing with forest fires.

1.4 Structure of the document

In chapter 2, this report describes the applied methodology for the current research conducted in Pelister National Park using remote sensing methodologies and data and in situ observations

In chapter 3, this report presents the results achieved from the current research.

In chapter 4, this report discusses the results in relation to the elevated risk of wildfires due to the increase in biomass and vegetation cover.

2 Research aims and methodology

2.1 Research aims

Fire is an important ecological factor that has affected both the structure and distribution of numerous plant communities across the globe. Fire probably first appeared, as a natural disturbance factor, as soon as there was any existing terrestrial vegetation (Pausas & Keeley, 2009). Prior to human influence the main ignition sources were lightning, volcanic and earthquake activity (Edwards, 1984; Kruger & Bigalke, 1984; Whelan, 1995). Fire was therefore a natural process occurring periodically in the natural vegetation cycle of succession, causing the continued rejuvenation and promoting the productivity of many plant communities and ecosystems (Trabaud, 1994). The periodicity of ecosystem burning was determined by the availability of a fuel load able to sustain a fire after a natural ignition event. Fuel load and consequently the flammability of an ecosystem increases with age ensuring that the ecosystem will be burned at a relatively mature stage. The effect of fire on landscape and ecosystems has been so determinative that the distribution, composition and structure of many biomes across the globe could not be explained by climate and soil alone and fire needs also to be taken into account (Bond & Keeley, 2005; Bond et al., 2005).

Later, fire became a very important human tool, widely used or misused for the improvement of living conditions. Archaeological evidence from the Petralona caves of northern Greece and elsewhere indicate that fire has been used by man for at least half a million years (Naveh, 1990). The Palaeolithic hunter and food gatherer used fire not only as a source of energy but also as a vegetation and landscape management tool. By creating open landscapes it was easier to attract and hunt game and the use of fire allowed him to improve his diet with grasses, legumes and geophytes (Naveh, 1990). Both fire frequency and intensity increased dramatically with considerable impacts on the natural ecosystems and the Mediterranean flora. This change in fire characteristics has shifted the equilibrium between fire and ecosystem function, transforming fire from a natural ecological factor that initiates succession into a human- induced land degradation factor (Naveh & Dan, 1973). Despite the major human intervention in the relationship between fire and ecosystem function, the Mediterranean ecosystems and vegetation types retain the ability to recover from fire quite rapidly (Trabaud, 1994), assuming fire frequency does not greatly exceed the natural return interval (Blondel & Aronson, 1995). Wildfires, however, are not just a vegetation and ecosystem degradation factor but also a factor which can have significant social and economic consequences, especially when they occur in the rural urban interface.

The occurrence of wildfires and especially large ones is the result of the combined action of two driving forces, namely fuel availability and continuity and weather patterns. Over the last years significant efforts have been made to study the historic and current trends in fire regime and identify the relevant significance of the above driving forces in determining the past and current fire regime (Dimitrakopoulos et al. 2011; Pausas & Fernandez-Munoz, 2012; Koutsias et al. 2013; Turco et al. 2016). Despite the differences in the employed approaches regarding the sources of data used, the extent of the period studied and the relevant uncertainty when using historical data dating back at the beginning of the 20th century, all studies come to the same conclusion. There is an observed change in the fire regime of the Mediterranean Europe after the 1970s with a significant increase both in total number of fires (NF) and area burned (AB). Although, a correlation is observed between wildfire activity and weather conditions, with drought conditions favoring wildfires, this correlation is much stronger after the 1970s. This is a clear indications that wildfires have changed from fuel driven, before the 1970s, to weather driven after that date.

The outbreak of the Industrial Revolution in Europe in the 19th century signified the beginning of two very important changes in Western societies. The urbanization of the population and the intensification of production, whether it concerned the newly-entered industrial production or agricultural and pastoral production (Diamond, 2005). The combination of these two factors gradually intensified, in the early 20th century. The abandonment of mountainous and semi-mountainous areas and the establishment of these populations in cities and urban areas allowed the intensification of agriculture and stock breeding and production increase (Kulakowski et al. 2017). This phenomenon was further intensified during the second half of the 20th century and reached the decade 1990 - 2000 involving the abandonment of 20 Mha in 20 European countries, marking significant changes in land cover and use (Mantero et al. 2020). This Land Use/Land Cover (LULC) change has increased the extent of forests in Europe by 9% in the last 30 years. Approximately 227 Mha, more than the third of Europe's land, is now forested [Forest Europe, 2020). The Republic of North Macedonia had a different sociopolitical status, compared to western European countries, which may have prevented or delayed the landscape changes described above. As a result it is important to investigate the landscape dynamics of the study area in order to asses the potential risk of fire or other natural disasters related to the landscape structure and composition.

Land abandonment is considered as one of the main drivers of LULC changes with significant environmental and socio-economic implications which can be positive or negative, depending on local factors and conservation objectives (Lasanta et al. 2015). Recovery of forests can reduce soil erosion, increase biodiversity and create carbon reservoirs (Ustaoglu & Coller, 2018). However, it can also lead to the reduction of many semi-natural, open habitats previously maintained by traditional land management, causing a significant impact on the landscape, biodiversity, ecosystem, dynamics and sustainability of mountainous landscapes Vacchiano et al 2017).

Keenleyside and Tucker (2010), reported that, in some cases, the re-colonization of plants and the disappearance of open spaces endanger semi-natural habitats by causing reduced biodiversity. However, in other cases, abandonment can be beneficial as it helps to restore natural habitats, especially in landscapes that are highly fragmented by human activity (Haddad et al. 2015). Consequently, systematic monitoring and detailed recording of LULC change and trends is becoming increasingly necessary, both for economic and environmental reasons, as they can be key indicators of environmental / ecological change at different spatial and temporal scales (Koko et al. 2020). Monitoring land use changes with time and cost efficient manners is essential for reducing biodiversity loss and for implementing Streamlining European Biodiversity Indicators 2020 (SEBI 2020) (EEA, 2012) and for forest fire prevention.

Recent advances in remote sensing data availability, quality and methods offer a great tool for the long term monitoring of LULC trends (Sohl & Sleeter, 2012). Remote sensing data, covering a wide part of the electromagnetic spectrum, including near and short-wave infrared channels, allow the calculation of a large number of vegetation indices. The latter, are designed to enhance the vegetation signal to allow reliable spatial and temporal comparisons of terrestrial photosynthetic activity and canopy cover (Bannari et al. 1995).

In recent decades, LULC monitoring using remote sensing data has significantly improved spatial and thematic accuracy of the resulted products, mainly because of the development of new technologies and applications along with appropriate algorithms for data analysis. Crucial in this area is NASA's Landsat program, which, since 1972, has provided the repetitive acquisition of multi-spectral, high-resolution Earth Observation data on a global basis leading to the largest database of the Earth's surface (Banskota et al. 2014; Bright, et al. 2019; Kibler et al. 2019; Meneses 2021; Morresi at al. 2019; Vogelmann et al. 2016). The release of the program data for public use free of charge, through the Earth Resources Observation and Science (EROS) center made possible to easily access an unprecedented volume of data, opening new horizons in the detection of changes on the earth's surface (Zhu et al 2019).

The abandonment of agricultural land in the mountainous and semi-mountainous areas, the decrease of livestock, the increased urbanization, a significant decrease to the use of wood as an energy source and the recovery of vegetation in the abandoned field, have all caused significant changes in the landscape structure and composition. Rural communities depended a lot to the local production of goods and to the local sources of energy, maintaining a heterogeneous mosaic of semi-natural ecosystems, cultivated agricultural land, pastures and small settlements. The abandonment of fields initiated a process of secondary succession and the establishment of flammable vegetation formations especially at the early stages. The decrease of livestock and the change in the pastoral practices, from extensive to intensive forms, also allowed the encroachment of pastures by shrubs and trees and the subsequent increase of forest and woodland cover (Vacchiano et al., 2017). This process resulted in the creation of more homogenous landscapes where forest and shrub formations prevail, the average patch size increases, fragmentation decreases and fuel continuation increases. At the same time the decreased density of extensive livestock farms resulted in the continuation of the catastrophic practice for pastoral improvement which is the deliberate set of fires by shepherds in order to decrease shrub and tree encroachment and to improve the composition of grasslands in terms of their nutritional value.

Another significant consequence of the changed fire regime in Mediterranean Europe is the expansion of fire to regions and ecosystems that are not considered fire prone and the vegetation components do not possess fire adaptive traits. An analysis of the fire characteristics in Greece for the year 2007 (Kontoes et al. 2013) revealed that 9.3% of the burned area falls in an altitudinal zone exceeding 1000m, confirming previously reported similar trends of an increased occurrence of fires at higher altitudes. Furthermore, an analysis of landscape dynamics in the nature reserve of Dadia Forest National Park (Xofis & Poirazidis, 2018), revealed that during 2001-2011 large wildfires became a significant destruction factor, threatening the long-term sustainability of the reserve, although low intensity fires could be a mechanisms for maintaining landscape heterogeneity.

The urbanization of population apart from land abandonment led also to an increased and urgent need for residential areas in the receptor cities, which in turn led to their expansion in the surrounding agricultural areas, bringing the city borders close to semi-natural ecosystems and subsequently increasing the wildland-urban interface (WUI). Furthermore, the improvement of the economic status, a trend associated with urbanization, and in order to avoid the negative aspects of living in a densely populated city, led to the creation of settlements in forested areas, often maintaining extensive parts of semi-natural vegetation formations creating a rather deadly WUI. The most dreadful example of such a situation is the recent fire in eastern Attica which led to the death of 100 people and significant loss of properties and infrastructures. Finally, the increase of tourism in recent decades led to an increase of the residential zones in coastal areas increasing again the WUI and frequency of ignitions (Keeley et al. 1999).

Despite the above changes in fire regime and the catastrophic incidences experienced in southern Europe, the wildfire management continue to rely almost exclusively on fire suppression and traditional means of fire detection. An analysis of the fire characteristics in the neighbouring country of Greece during the period 2007-2011 revealed some interesting findings regarding the efficiency of the currently applied wildfire management (Kontoes et al. 2013). In 2007 the great majority of fire events burnt relatively small areas lower than 1000 ha. However, 11% of the events evolved to megafires resulting in the worst year ever recorded in terms of area burnt (more than 200.000 ha), although the number of fires was almost equal to the one in 2011, and according to the Forest Fires in Europe 2007 report (Joint Research Center, 2008) it was high but not the highest since 1980. In the period 2008-2011 the percentage of megafires did not exceed 3.5% in any year. The entire year of 2007 and the summer period in particular was characterized by extreme weather conditions with the highest temperatures recorded for almost a century, three consecutive heat waves from June to August and wind patterns that favored the spread and intensity of fires (Founta & Giannakopoulos, 2009; Tolika et al. 2009). If these extreme weather conditions were an isolated incident with very low probability to happen again in the future, then the problem of wildfire management could be perhaps resolved with some minor alterations to the one currently applied, but this is far from what it is expected. As stated in Founta & Giannakopoulos, (2009) and Tolika et al. (2009), 2007 represents an example of how the weather conditions will be like by the end of the century as a result of climate change. The best proof for the validity of this predictions is the weteher conditions that prevailed in the summer 2023 which is the second worst year obxerved in terms of forest forest in Greece.

The almost 90% efficiency of the currently employed fire management in keeping most wildfires at relatively small sizes, even under the most favorable for fire conditions, reveals that this approach, which relies exclusively on fire suppression and traditional methods of fire detection has reached its efficiency limits. This is because it is a small number of fire events which turn into megafires and destroy ecosystems, properties, infrastructures and most importantly have a high cost in human lives, and such events unfortunately are not avoided. Thus, a new approach is needed in wildfire management which will not rely exclusively on fire suppression but it will utilize the technological advancements, the wide availability of remote sensing data and the large amount of research related to risk assessment and fire detection.

The increased amount of resources allocated in fire suppression and yet the inability to prevent the catastrophic megafires imposes the need to rethink of the problem and pay serious attention to fire prevention and quick fire detection. An important step towards a holistic approach in wildfire management is the identification of the most vulnerable areas and ecosystems which can then be managed in a way that it will prevent the evolvement of an ignition incident into a megafire. Advanced applications and methods which involve geographic information systems, remote sensing data and methods, geospatial statistics, existing knowledge on fire behaviour in various fuel types, reliable records of the pyric history and weather data offer a great tool to land managers to plan for fire management under any scenario.

Wildalnd Urban Interface form particularly vulnerable areas today for the reasons described above. Although in these areas fires rarely turn into megafires they inflict serious damages to human properties and often cost human lives. Various methods have been proposed to assess the relevant vulnerability of WUI to wildfires. Some of them focus on landscape structure, studying the vegetation and build environment spatial patterns, using typical methods of landscape ecology and landscape analysis (Marzano, 2008). Such methods especially when they involve the existence of escape routes or fire barriers can provide significant service in planning more fire resistant settlements in the WUI. Molina et al. (2017) proposed an ignition index for application in the WUI which integrates fuel components, such us fine fuel moisture content, physiographic parameters, weather data and flammability of vegetation components which results in a reliable estimation of the potential risk of fire and, therefore, it can help in prioritizing areas for strict protection and budget allocation.

The Fire Weather Index (FWI), a component of the Canadian Forest Fire Danger Rating System (CFFDRS) is another widely used method for estimating fire risk. It has been tested in several fire prone areas across the globe and, with some adjustments related to the peculiarities of each region, it provides relatively accurate estimations on the possibility of a wild fire (Dimitrakopoulos et al. 2011; Ager et al. 2014). The FWI integrates some important aspects of wildfires regarding fuel moisture, weather conditions and fire behavior, resulting in an index which can then be classified into danger classes from low to extreme. This knowledge can be used in order to increase or decrease the degree of preparedness and alert.

Remote sensing data and methods are also often employed in an effort to manage wildfires in an effective manner by providing mapping products with high spatial accuracy and predictive value in relation to potential fire behaviour and fire risk (Keramitsoglou et al. 2008;

Pan et al. 2016; Sanchez et al. 2018). Today there is wide availability of remote sensing data and methods and many of them are offered free of charge. Sentinel 2 data at a spatial resolution of up to 10m can be employed for land mapping at a high spatial scale, while its temporal resolution of 5 days ensures updatability of the resulting products. Landsat data on the other hand apart from landcover mapping they can also be employed for the calculation of surface temperatures and moisture, both important determinants of fire behaviour, during the vulnerable period.

Under the situation of increased fuel load and increased potential for intensive hot fires the development and use of accurate tools for early assessment of fire risk and the potential behaviour of fire is of particular importance. It could lead to the adoption of appropriate measures for managing the most vulnerable areas, towards decreasing the fuel load or developing appropriate strategies for the effective suppression of fire. Therefore, accurate fire propagation models can be used in the operational support of forest fires suppression, in the development of fire propagation scenarios, in the training of volunteer fire fighters, in the planning of actions to be taken by Civil Protection Agencies and in the decision support of local competent authorities.

The fire behavior simulation models FARSITE (Finney, 1998) and Flammap (Stratton, 2004; Finney, 2006) are employed in many studies both for assessing potential fire behavior and fire danger with promising results. FARSITE is a two dimensional model which simulates fire behavior in both space and time under varying site and weather conditions. It is based on Rothermel's (1972) fire spread model while it incorporates various other models from the international literature that deal with other aspects of fire behavior such as spotting, fire spread of ground and crown fires e.t.c. The great advantage of this model is that it allows the simulation of fire behavior under real time conditions, while at the same time it allows the simulation of the fire fighting tactics and forces. The results of fire behavior simulation with FARSITE are spatial and non spatial data regarding fire intensity and spread, flame height and others.

Unlike FARSITE, Flammap is a one-dimensional model which simulates fire behavior only in space independently of the prevailing weather and other conditions during the event. While FARSITE allows the simulation of fire behavior under real conditions, with the advantages mentioned above, Flammap allows the identification of potential hotspots with extreme fire behavior, in terms of intensity and rate of spread. Such hotspots might not be detected properly using FARSITE simply because at the particular time that fire passes from them the weather conditions, among others, may not favor a fire with extreme behavior. Such spots, however, might be the ones that need careful management for fire prevention and future protection of an area.

It is now widely accepted that wildfires need the integration of several disciplines, including forest and landscape ecology, fire ecology, pyrology, environmental modeling, remote sensing and others in a supplementary manner for an effective management. Furthermore, particular attention needs to be paid in the pyric history of a region, local knowledge, historical land uses and current trends in order to unravel the mysteries of wildfire and increase the effectiveness of fire prevention and fire suppression. An effective wildfire management strategy should aim not in the complete elimination of wild fires, which is practically impossible, but in the restriction of their ecological, economic and social cost.

The aim of this research is to investigate the diachronic vegetation changes, since the early 1980s, in the Pelister NP using multitemporal landsat data and estimate the current fire risk in a spatially explicit manner. The specific objectives are a) to investigate the degree of vegetation densening and loss of open habitats using a number of vegetation indices which are often employed for long term monitoring and b) to thematically and spatially map the fuel types of the park using state of the art mapping methods, c) perform fire risk assessment using spatially explicit indices and d) to discuss the observed results and provide recommendations for reducing fire risk and promoting the long term sustainability of the national park.

2.2 Methodological framework

2.2.1. Study area

Pelister National Park covers relatively small area (18.845 ha) on the northern side of the Baba Mountain massif, in the south-western part of North Macedonia, at altitude of 891 to 2601 m. The territory of the Park includes various glacial and periglacial geomorphological formations, some of which are rare in the Balkans, preserved in their natural state and of high attractiveness to Park' visitors. Because of the geological composition, specific terrain and the local mountain climate, various habitat types have been formed in the Park supporting rich and important biological diversity. Of these the most prominent are the extensive forests of the Balkan Pine (*Pinus peuce*) the most important habitat of its type in the Balkans and therefore in the World, the glacial lakes and the alpine grasslands. In addition to the nine local endemics – species that can only be found in the Park's territory – there are also several rare and/or threatened species. In addition to the natural, within the territory of Pelister National

Park there are also numerous cultural values among which the architectural and cultural heritage of the village Malovishta stands out.

2.2.2. Climate

The climate of the south-western part of North Macedonia where Pelister Mountain is located can be characterized as moderate continental. However, because Pelister National Park is situated at altitudes higher than 900 m its local climate is typically mountainous. The winters are long, cold and with lots of snowfalls, whereas the summers are short and rather cold. January and February are the coldest months whereas July and August are the warmest. The precipitation is highest in October and December, but there is another peak in May. The precipitation during the summer season accounts for 16.5% of the annual amount. The snow cover stays from November to April, in the higher parts to May, and in small remnants up to June. The data on precipitation levels and temperature in Pelister National Park are available only for the period from 1934 to 1940 when there was a weather station in the Park.

2.2.3. Geology

The bedrock in Pelister National Park is primarily Paleozoic and Mesozoic in age, with few glacial and fluvioglacial overlays dating from Quaternary. Among the Paleozoic rocks, the series of green shale are the oldest and most ubiquitous stratigraphic unit. Typical for the Park is the “Pelister Granite”, Paleozoic alkaline-granite dating from the Ordovician, some 456 millions years ago, and usually embedded within the Paleozoic shale. Other Paleozoic rocks found in the Park include quartz- and quartz-sericite schists. The gabbro is the most ubiquitous among the Mesozoic rocks, found in several places, including a large mass with a surface area of 5 km2, situated south-east of the village of Malovishta. Other Mesozoic complexes are also found, such as diabase and mermekitic granite and dolerite veins. Due to the nature and compactness of the bedrock as well as the vegetative cover and lack of human activities the erosion in the Park is negligible.

2.2.4. Geomorphology

The glacial landforms are an important part of the landscape in Pelister National Park. Within the boundaries of the Park there are three fine examples of cirque fields two of which contain lakes. The most spectacular is the cirque between the peak Veternica and the R’bet ridge, having north-east exposition, some 1.0 km in width and 1.6 km in length. In the westernmost part of the cirque, lays the Greater Lake. The second, the Smaller Lake, lays in the cirque situated between the peaks Shiroko Stapalo and Partizanski. During the Würm glaciation period the glaciers were hanging over the shoulders of Pelister Mountain. The block streams are most prominent among the periglacial landforms in Pelister National Park. They typically extend from above the forest margin down slope to 1.200 m above the sea level; some of them are more than 2 km in length and between 100 and 300 m wide. This feature is indicative of their high activity during the Pleistocene epoch (1.8 million to 8.000 years ago). Although the block streams in the Park are still active, many of them have been overgrown by the quickly expanding molika forest. To the north-east of the peak Pelister (2.601 m) and towards the peak Stiv (2.468 m) is found a typical block field – a periglacial form of frost-shattered granite blocks, scattered over a slightly bent area. Other glacial and periglacial landforms in the Park include nivation hollows, garlands, solifluction lobes, and ploughing blocks. The latter consist of Paleozoic alkaline granites and can be found on the eastern, north-eastern and the northern side of the massif. Typical examples of the ploughing blocks are found in the cirque of the Smaller Lake.

2.2.5. Soils

Through the interaction of the topography and climate in the Park, as well as the biological agents, there are three major soil types in the Park: (a) humic-silicate (rankers); (b) acid brown (cambisols); and (c) ilimerised (brunipodzols, brownised cambisols). Within the areas covered by forest, i.e. Balkan pine, beech and oak forests, the acid-brown soils prevail; several varieties and different evolutionary stages can be distinguished within these soils. The humicsilicate soils are found in the sub-alpine and the alpine zone and less frequently in the forest zone. The third soil type is found in the sub-alpine zone in places overgrown by molika trees.

2.2.6. Waters

The area of Pelister National Park is part of the river Crna watershed and includes two glacial lakes and seven rivers: Malovishka (Shemnica), Manastirska, Caparska, Rotinska, Magarevska, Crvena and Ezerska. The Greater Lake lies at 2.218 m altitude, elliptical in shape (3.7 ha), is 223 m long, 162 m wide and 14.5 m deep. The Smaller Lake lies at 2.180 m altitude, of irregular shape (0.66 ha), is 97 m in length, 68 in width and 2.6 m in depth. Groundwater in the Park feeds the numerous springs throughout its territory. There are also few intermittent surface water courses, mainly on the Prespa side of the Park.

2.2.7. Ecosystems and habitats

The geology and soils in an interaction with differences in altitude, temperature, rain and snowfall, but also the livestock grazing, contribute to the high variety of ecosystems in the park which in turn sustain a wide range of plant and animal life. All major types of ecosystems which are typical for Macedonia are also found in the Park: forests, dry grassland, mountain ecosystems and fresh-water ecosystems. The vegetation ranges from heat and scrubs through broadleaved deciduous (the oak and beech) and coniferous (molika pine) woodland to dry siliceous, alpine and sub-alpine grasslands, as well as riparian source edge grassland communities and aquatic habitats. There are thirty-two different natural habitat types in total the Park (see Table 1, Annex I in the Supplement of this Plan) nine of which are forest communities and sixteen grass communities. The systematic classification of the plantcommunities within the Park is shown in (see Table 2, Annex I in the Supplement of this Plan). Among these two are local endemic communities, that is, they can be found only in the Park, others have restricted distribution (parts of Macedonia or only in the Balkans), and nine are protected by the Bern Convention of the Council of Europe2 as habitats that require special conservation measures. It should be noticed that the number of habitat types in the park would be larger if the habitats which are created through human influence and interference as well as the habitats which are not described due to lack of data are added to the list.

Pelister National Park is widely known for its extensive Balkan pine forest. Balkan pine establishes two plant communities in the Park: the mountainous Balkan woodland (Digitali viridiflorae – Pinetum peuces), found between 900 and 1.600 m altitude, and the sub-alpine molika woodland (Gentiano luteae – Pinetum peuces) inhabiting its primary habitats between 1.500 and 2100 m altitude and higher in some places.

2.2.8. Fauna

The diversity of landforms and plant communities in Pelister National Park results in a wide range of wildlife habitats. The Park is especially important for its mammals, particularly the large predators, which their populations are decreasing or are threatened throughout Europe. There are forty-one mammal species registered in the Park, that is, one half of all mammal species registered in North Macedonia. It is important to notice the presence of the lesser mole rat (*Nannospalax leucodon*), which is considered to be a globally threatened species, and seven other species considered to be threatened in Europe. Several mammal species have been discovered and described for the first time by specimens collected in the Park: *Talpa stankovici, Clethrionomys glareolus makedonicus* and *Talpa caeca beaucournui*. Two species are considered rare and found only in some parts of the Balkans: *Talpa stankovici* and *Microtus felteni*. Twenty-four of the mammal species registered in the Park are protected by the Bern Convention. It should also be noticed that the bats (*Chiroptera*) in the Park are poorly investigated.

There are ninety-four bird species registered in the Park (30% of all bird species found in North Macedonia) out of which eighty-eight are protected by the Bern Convention, and twenty are protected by the Bonn Convention. Ten species in total are considered to be threatened in Europe.

Pelister National Park is an important refuge for ten amphibian species which represent 67% of all amphibian species in North Macedonia. Also, occurring in the Park are sixteen species of reptiles, that is, half of all know reptile species in North Macedonia. All amphibian and reptile species are protected by the Bern Convention. There is only one species of fish registered in the Park – *Salmo pelagonicus* (pelagonide trout) – a rare species with distribution in Pelister, Greece, Crete and some islands in the Aegean See, and considered to be threatened in Europe.

The invertebrate fauna is very rich and diverse, represented by more than 588 species and subspecies with many among them being found only in Baba Mountain. For instance, the amphipode species *Niphargus pancici pancici* can be found only in the mountain springs in Pelister and Baba massif. The group of freshwater crabs is insufficiently investigated and there are indications that the number of local endemic species may be higher. Among the insects the carabides are represented by eighty-seven species and subspecies, out of which six are local endemics. There is detailed information on other groups of invertebrate animals (*Curculionide, Ropalocera, Odonata, Orthoptera, Syrphidae, Chrionomidae, Chironomids, Aranea, Gastropoda, Diptera, Lepidoptera*, and others) among which there is a great number of Balkan endemics. On the other hand, some groups have not been investigated in the Park yet, such as *Heteroptera*, *Neuroptera*, *Hymenoptera*, *Plecoptera* and others.

2.2.9. Remote Sensing Data used for identifying vegetation trends

Overall, more than 100 Landsat images (Path:185, Row:032) were downloaded from the EROS center and 38 of them were selected to build a time-series dataset covering a period of 35 years (Table 1). The rest were excluded from the analysis, either due to extensive cloud cover/shading or line stripping of Landsat 7. The sensing period of the selected images was between the 1st of August and 16th of September. This particular time window was selected because it corresponds to the driest period in the study area where annual herbaceous vegetation has died out. Since the study focuses on the densening of woody vegetation the absence of live herbaceous vegetation is expected to aid the analysis which is based on vegetation indices. All images were obtained pre-processed at level 2A (geometrically and atmospherically corrected to BoA reflectance) by the EROS cen-ter. These images, provided by the Landsat program, apart from being geometrically and atmospherically corrected, they have a radiometric resolution of 16-bit which makes it easier to compare between the three sensors.

The Landsat series provides earth observation data since 1972 at varying spectral and spatial resolutions (Table 2). Since 1982, when Landsat 4 was launched, the spatial resolution is stable at 30m for the multispectral products. Due to the long time span of Landsat data availability they are quite extensively used to build time series datasets for long term monitoring of vegetation dynamics (Banskota et al. 2014; Bright, et al. 2019; Kibler et al. 2019; Meneses 2021; Morresi at al. 2019; Vogelmann et al. 2016). The Thermal and Coastal/Aerosol bands were excluded from the analysis as well as the panchromatic image.

Table 1. Satellite Images used in the study

	LANDSAT IMAGE	DATE
1	LT05_L2SP_185032_19840717_20200918_02_T1	17_07_1984
2	LT05_L2SP_185032_19850906_20200918_02_T1	06_09_1985
3	LT05_L2SP_185032_19860824_20200918_02_T1	24_08_1986
4	LT05_L2SP_185032_19870811_20201014_02_T1	11_08_1987
5	LT05_L2SP_185032_19880829_20200917_02_T1	29_08_1988
6	LT05_L2SP_185032_19890731_20200916_02_T1	31_07_1989
7	LT05_L2SP_185032_19900819_20200915_02_T1	19_08_1990
8	LT05_L2SP_185032_19910721_20200915_02_T1	21_07_1991
9	LT05_L2SP_185032_19920909_20200914_02_T1	09_09_1992
10	LT05_L2SP_185032_19930827_20200913_02_T1	27_08_1993
11	LT05_L2SP_185032_19940814_20200913_02_T1	14_08_1994
12	LT05_L2SP_185032_19950902_20200912_02_T1	02_09_1995
13	LT05_L2SP_185032_19960803_20200911_02_T1	03_08_1996
14	LT05_L2SP_185032_19970721_20200910_02_T1	21_07_1997
15	LT05_L2SP_185032_19980825_20211205_02_T1	25_08_1998
16	LT05_L2SP_185032_19990812_20200918_02_T1	12_08_1999
17	LT05_L2SP_185032_20000729_20200907_02_T1	29_07_2000
18	LT05_L2SP_185032_20010716_20200905_02_T1	16_07_2001

19	LE07_L2SP_185032_20020711_20200916_02_T1	11_07_2002
20	LT05_L2SP_185032_20030722_20200905_02_T1	22_07_2003
21	LT05_L2SP_185032_20040910_20200903_02_T1	10_09_2004
22	LT05_L2SP_185032_20050719_20200914_02_T1	19_07_2005
23	LT05_L2SP_185032_20060908_20200914_02_T1	08_09_2006
24	LT05_L2SP_185032_20070717_20200830_02_T1	17_07_2007
25	LT05_L2SP_185032_20080812_20200913_02_T1	12_08_2008
26	LT05_L2SP_185032_20090714_20200911_02_T1	14_07_2009
27	LT05_L2SP_185032_20100818_20200910_02_T1	18_08_2010
28	LT05_L2SP_185032_20110829_20200820_02_T1	29_08_2011
29		
30	LC08_L2SP_185032_20130919_20200912_02_T1	19_09_2013
31	LC08_L2SP_185032_20140704_20200912_02_T1	04_07_2014
32	LC08_L2SP_185032_20150723_20200912_02_T1	23_07_2015
33	LC08_L2SP_185032_20160709_20200912_02_T1	09_07_2016
34	LC08_L2SP_185032_20170712_20200912_02_T1	12_07_2017
35	LC08_L2SP_185032_20180715_20200912_02_T1	15_07_2018
36	LC08_L2SP_185032_20190819_20200912_02_T1	19_08_2019
37	LC08_L2SP_185032_20200906_20200912_02_T1	06_09_2020
38	LC08_L2SP_185032_20210808_20200912_02_T1	08_08_2021
39	LC09_L2SP_185032_20220819_20200912_02_T1	19_08_2022

Table 2. Spectral and Spatial characteristics of the Landsat images used in this study

Bands (wavelength μm) - Spatial Resolution		
Landsat 5-TM	**Landsat 7-ETM**	**Landsat 8-OLI**
		B1-Coastal/Aerosol (0.435-0.451) – 30m
B1-Blue (0.45-0.52) – 30m	B1-Blue (0.441-0.514) – 30m	B2-Blue (0.452-0.512) – 30m
B2-Green (0.52-0.60) – 30m	B2-Green (0.519-0.601) – 30m	B3-Green (0.533-0.590) – 30m
B3- Red (0.63-0.69) – 30m	B3- Red (0.631-0.692) – 30m	B4- Red (0.636-0.673) – 30m
B4-NIR (0.76-0.90) – 30m	B4-NIR (0.772-0.898) – 30m	B5-NIR (0.851-0.879) – 30m
B5-SWIR 1 (1.55-1.75) -30m	B5-SWIR 1 (1.547-1.749) – 30m	B6-SWIR 1 (1.566-1.651) – 30m
B7-SWIR 2 (2.08-2.35) – 30m	B7-SWIR 2 (2.064-2.345) – 30m	B7-SWIR 2 (2.107-2.294) – 30m
B6 –TIR (10.40-12.50) – 120m	B6 –TIR (10.31-12.36) – 60m	B10-TIR 1 (10.60-11.19) – 30m B11-TIR 2 (11.50-12.51) – 30m
		B9-Cirrus (1.363-1.384) – 30m
	B8-Pan (0.515-0.896) – 15m	B8-Pan (0.503-0.676) – 15m

2.2.10. Remote sensing data analysis

Vegetation Indices (VI's) were employed to monitor the vegetation trends and forest densening in the study area. Recording and monitoring vegetation changes using Vegetation Indices is a relatively fast process that allows a good understanding of changes in space and time. In the current study five VI's were used, which were selected based on their capability to capture vegetation variation in an image, as it is documented in the literature. The specific properties of each of the employed vegetation indices are provided in the following paragraphs. The five indices were the Normalized Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index 2 (EVI2), Normal-ized Difference Water Index (NDWI) and Bare Soil Index (BSI; Table 3).

Table 3. Vegetation Indices and Spectral Ratios employed in the study.

Vegetation Index	Formula
NDVI	((NIR-RED))/((NIR+RED))
SAVI	((NIR-RED))/((NIR+RED+0.5))* (1+0.5)
EVI2	2,5 *((NIR-RED))/((NIR+2.4*RED+1))
NDWI	((NIR-SWIR))/((NIR+SWIR))
BSI	((SWIR2+RED)-(NIR+BLUE))/((SWIR2+RED)+(NIR+BLUE))

NDVI is one of the vegetation indices that combines the two opposite properties of canopy. It is known that the spectral profiles from green vegetation represent two spe-cific areas where the highest discrepancy occurs (red to nir region) (Rouse et al. 1974). Because of this property, NDVI is considered an appropriate vegetation index to study vegetation patterns across temporal or spatial scales and it has been extensively used in such studies (Huete, 1988; Jiang et al. 2008; Gao, 1996; Diek et al. 2017; Viedma et al. 1997; Volkova et al. 2021; Storey et al.

2016; Abraam et al. 2016). SAVI is based on the original NDVI formula and it is a transformation technique to minimize the effect of soil brightness. It has been found to give better re-sults than NDVI in cases of high variation in soil color and moisture (Huete, 1988). EVI was developed to optimize the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a decoupling of the canopy background signal and a reduction in atmosphere influences (Jiang et al. 2008). NDWI(Gao, 1996)is an index derived from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. The SWIR reflects variation in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content (Ceccato et al. 2001). Bare Soil Index (BSI) is a numerical indicator that combines blue, red, near infrared and short wave infrared spectral bands to capture soil variations. These spectral bands are used in a normalized manner. The short wave infrared and the red spectral bands are used to quantify the soil mineral composition, while the blue and the near infrared spectral bands are used to enhance the presence of vegetation. The original BSI (Rikimaru et al. 2002) used SWIR1 reflectance, but recent research by Diek et al. (2017) suggests the SWIR2 band may be more appropriate for calculating BSI. For this reason, the SWIR2 band was used in this study to calculate BSI index.

One thousand points were randomly located across the entire study area, using the Sampling Design Tool, available as a plugin in ArcMap 10.8, and they formed the basis for the determination of vegetation dynamics across the time span of the study. The vegetation index values of the pixel corresponding to each particular point are then assigned as attributes to the point. Linear regression was employed to test for significant relationships between the tested vegetation indices and time.

2.2.11. Fire Risk Assessment

In the current study the Fire Danger Index (FDI) developed by Xofis et al. (2020a,b) was employed which is based on two important components of fire regime, the fuel availability and burnability and the anthropogenic activities, while it also integrates the pyric history, which can provide significant indications on the potential vulnerability of an area. The fuel availability was determined by the integration of remote sensing data and methods and field data on the vegetation structural and compositional characteristics. The anthropogenic activities were integrated in the FDI with the use of the distance to the nearest road or settlement. The pyric history was integrated after collecting from the local forest services and transforming them into a Raster GIS.

The model Flammap was employed to simulate fire behavior. Flammap is a two-dimensional fire simulation model which estimates fire behavior under uniform weather conditions. It calculates important components of fire behavior including fireline intensity, rate of spread, flame height, crown fire activity. Although flammap does not take into account the ignition points or the variation of weather conditions during a fire event, it as a powerful method typically used to estimate fire risk based on the vegetation and topographic characteristics (Calkin et al. 2010). In that sense, it is more appropriate for a study like this, compared to other simulators, such as Farsite , because it allows the identification of areas with high potential of giving a high-intensity fire, once appropriate weather conditions exist.

Fire behavior simulation using flammap generates a number of different parameters of fire behavior including fireline intensity (often called Byram's intensity), rate of spread, flame length e.t.c. Fireline intensity describes the heat release per meter of fire front and is calculated by the following equation which is an adjustment of the original equation developed by Byram:

$I=0.007\ H*W*R$

Where:

I=Fireline intensity in Kw/m

H=Heat yield in cal/g

W=Fuel loading in tonnes/ha

R=Rate of spread in m/min

Fireline intensity estimations were rescaled to a scale between 0 and 1 to form the Fire Intensity (FI) component of the Fire Danger Index (FDI) formula (1). Rate of Spread (ROS) is also an important component of fire behaviour since it determines to a great extent the time required for an ignition to turn into a large size and hard to supress wildfire. A preliminary analysis in two study areas showed that fireline intensity and rate of spread are significantly and positively correlated to a degree of around 60%. However, various landcover types, such as grasslands and meadows, have a low amount of released energy, due primarily to the low fuel load but still a high ROS. In a complex landscape mosaic, such as the one in the study area, and in the wider Mediterranean region, these landcover types impose a high fire hazard due to the increased possibility a wildfire to quickly spread into a nearby area of high fuel load and high potential for a high intensity fire. Given that the purpose of the FDI is not only to identify the most vulnerable to high intensity wildfires areas but also to increase the level of organisation of suppression forces, the ROS is included as a separate component in the FDI formula, with a relatively low weight, despite the fact that it constitutes a component of fireline intensity equation, and in a sense it is already included in the FDI formula. ROS values were also rescaled to a scale between 0 and 1 and formed the ROS component of the FDI formula (1)

$$FDI=0.5*FI+0.2*ROS+0.2*HI+0.1*PH \qquad (1)$$

The above formula integrates two more important components of fire risk, the Human Index (HI) and the Pyric History Index (PH), which serve as proxies of fire ignition probability. The HI attempts to capture the relevant risk for a fire event associated with anthropogenic activities. As a proxy of anthropogenic activities, the distance to roads was adopted, with values ranging from 0, for areas at a distance of 200m or more from roads, to 1 for areas at immediate proximity to them. Distance to roads has been reported to be positively associated with ignition frequency (Ricota et al. 2018; Catry et al. 2009). The Pyric History does not have a direct relationship with fire hazard, especially if one takes into account that a past wildfire may reduce the fuel load and subsequently the intensity of a fire event. However, it provides an indication of the fire pattern of an area which might indicate trends related to specific land uses and spatial locations. For instance, in eastern Mediterranean region where free range pastoralism is still practiced in the mountainous and semi-mountainous regions, it is very common deliberate fires to be set by shepherds for the improvement of grazing condition. This trend results in a clustering of past fire episodes indicating the higher risk for fire in such areas. Although these fires rarely become high-intensity ones, because they primarily occur in autumn and in areas with low fuel load, the possibility to spread into nearby more flammable ecosystems and vegetation formation always exist. The inclusion of the PH index in the above formula will allow the identification of areas where a specific spatial pattern of past fires does exist. The PH was calculated using data on ignition events of the last 25 years provided by the local Forest Service. A Kernel Density Estimation Function was applied to convert the point ignition data to a raster file with values ranging from 0 for areas away from a past ignition point to 1 for area at immediate proximity to a past ignition. The FDI calculated with the above formula varies between 0 and 1 with higher values indicating a higher fire hazard.

The fire risk assessment is directly linked to the correct mapping of the biomass of which the fuel is a part. It is therefore particularly important to accurately map the fuel dispersion. The first step in this process is to determine the fuel models present in the study area. Based on field collected data the fuel models shown in table the attribute to each of the 11 samples a fuel model that expresses the biomass characteristics as accurately as possible. Based on the observations made in the field, the data collected and the data described in the international literature on Mediterranean vegetation types, the following fuel models were determined for the 11 sampled areas (Table 4).

For the identification and mapping of fuel models, present in the area a Seven High Resolution (HR) Sentinel-2 Images were employed (Figures 1-7) and analysed in an Object Oriented Analysis (OBIA) environment using the software eCognition (Trimple, 2014). Sentinel 2 is a constellation of two polar-orbiting satellites launched by ESA under the program Copernicus (formerly known as GMES; Drush et al. 2012). They deliver multispectral data at spatial resolution of up to 10m in the visual and near infrared bands and a great thematic resolution at 20 and 60 m spatial resolution, and with a revisiting frequency of 5 days. Table 3 shows the spatial and spectral characteristics of Sentinel-2 images. All images were processed at Level 2A and the 10 bands at 10 and 20m spatial resolution were used. Apart from the spectral bands of the original image the following indices were also calculated and integrated in the analysis.

Table 4. Spectral and Spatial characteristics of Sentinel-2 images

Spectral Band	Color description	Wavelength range (nm)	Spatial Resolution (m)
Band 1	Coastal aerosol	433–453	60
Band 2	Blue	458–523	10
Band 3	Green	543–578	10
Band 4	Red	650–680	10
Band 5	Red Edge 1	698–713	20
Band 6	Red Edge 2	733–748	20
Band 7	Red Edge 3	773–793	20
Band 8	Near Infrared	785–900	10
Band 8A	Narrow Near Infrared	855–875	20
Band 9	Water vapour	395–955	60
Band 10	Shortwave infrared-Cirrus	1360–1390	60
Band 11	Shortwave infrared 1	1565–1655	20
Band 12	Shortwave infrared 2	2100–2280	20

$$Normalised\ Difference\ Vegetation\ Index\ (NDVI) = \frac{\text{Band 8} - \text{Band 4}}{\text{Band 8} + \text{Band 4}}$$

$$Green\ Normalised\ Difference\ Vegetation\ Index\ (GNDVI) = \frac{\text{Band 8} - \text{Band 3}}{\text{Band 8} + \text{Band 3}}$$

$$Normalised\ Difference\ Moisture\ Index\ (NDMI) = \frac{\text{Band 8} - \text{Band 11}}{\text{Band 8} + \text{Band 11}}$$

$$Normalised\ Difference\ Water\ Index\ (NDWI) = \frac{\text{Band 3} - \text{Band 7}}{\text{Band 3} + \text{Band 7}}$$

$$Modified\ Anthocyanin\ Reflectance\ Index\ (mARI) = \left(\frac{1}{\text{Band 3}} - \frac{1}{\text{Band 5}}\right) * \text{Band 7}$$

$$Moisture\ Stress\ Index\ (MSI) = \frac{\text{Band 11}}{\text{Band 8}}$$

$$Soil\ Adjusted\ \ Vegetation\ Index\ (SAVI) = \frac{\text{Band 8} - \text{Band 4}}{(\text{Band 8} + \text{Band 4} + 0.428) * (1 + 0.428)}$$

$$Plant\ Senescence\ Reflectance\ Index\ (PSRI) = \frac{\text{Band 4} - \text{Band 2}}{\text{Band 5}}$$

Table 5. Fuel Models present in Pelister National Park

				Fuel Load (t/hectare)						SAV Ratio (m^2/m^3)					
	EFFIS	FMCode	FM#	1-hr	10-hr	100-hr	Live Herb	Live Woody	Fmtype	Dead 1-hr	Live Herb	Live Woody	Fuel bed Depth (cm)	Dead Fuel Extinction Moisture (%)	Heat Content (J/g)
Balkan Pine	FM8	CFM1	21	5.08	2.13	4.47	2.44	0.00	Static	5174	1124	0	115.2	35	18600
Beech	FM10	CFM3	22	7.05	3.40	6.19	2.47	0.00	Static	8200	0	0	30.4	25	15000
Oak	FM9	CFM4	23	6.55	0.77	0.27	0.04	0.27	Static	2427	1124	5960	70.8	25	19460
Alpine Grasslands	FM1	CFM5	24	1.81	0.00	0.00	0.00	0.00	Dynamic	1150	0	0	55	14	16500
Grassland - Shrub	FM5	GS3	123	0.74	0.62	0.00	3.58	3.09	Dynamic	5905	5249	5249	55	40	18608
Agricultural land		NB3	93	0	0	0	0	0	0	0	0	0	0	0	0
Inland Water		NB8	98	0	0	0	0	0	0	0	0	0	0	0	0
Rocks		NB9	99	0	0	0	0	0	0	0	0	0	0	0	0

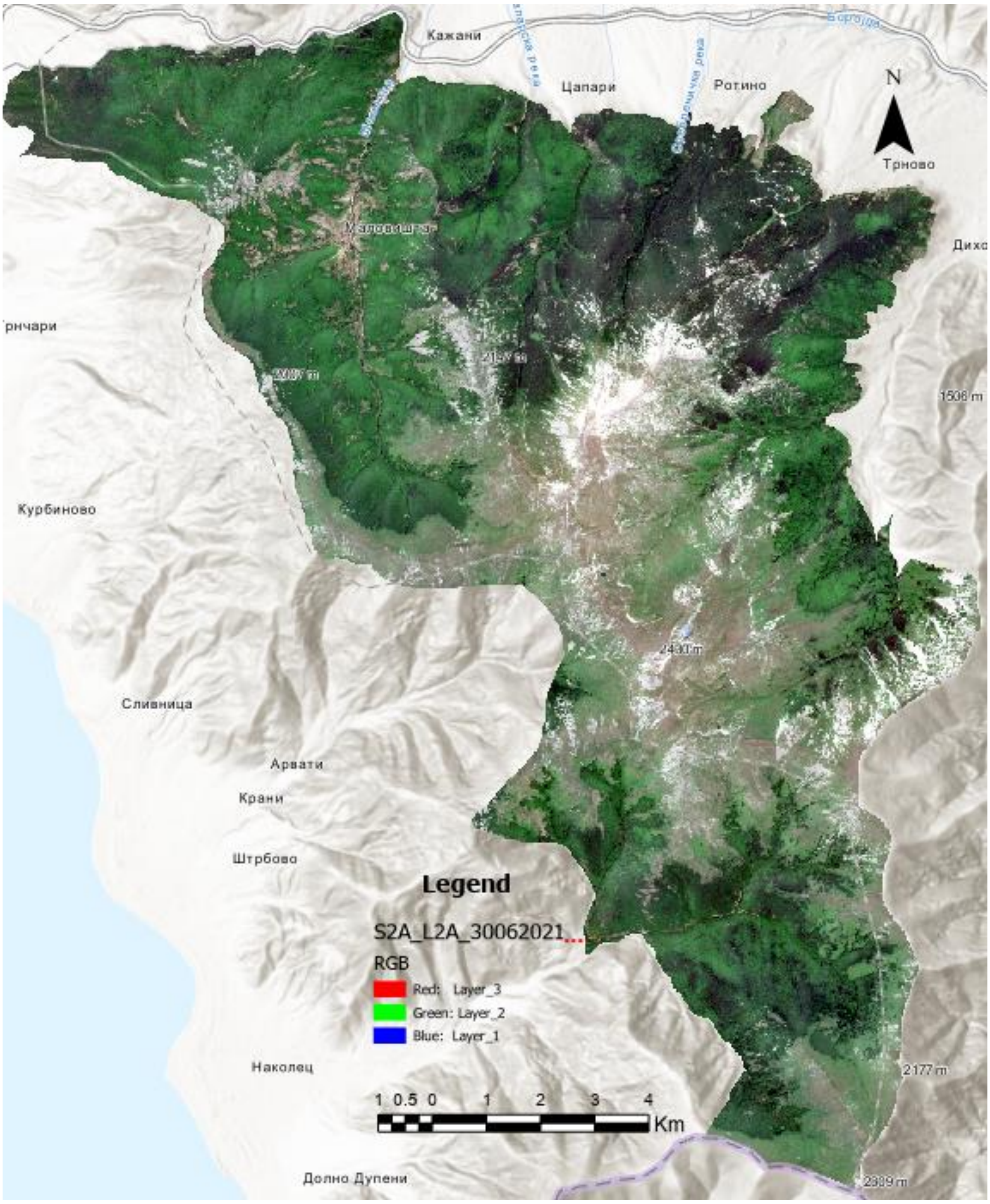

Figure 1. Sentinel-2 Image sensed on 30/06/2021

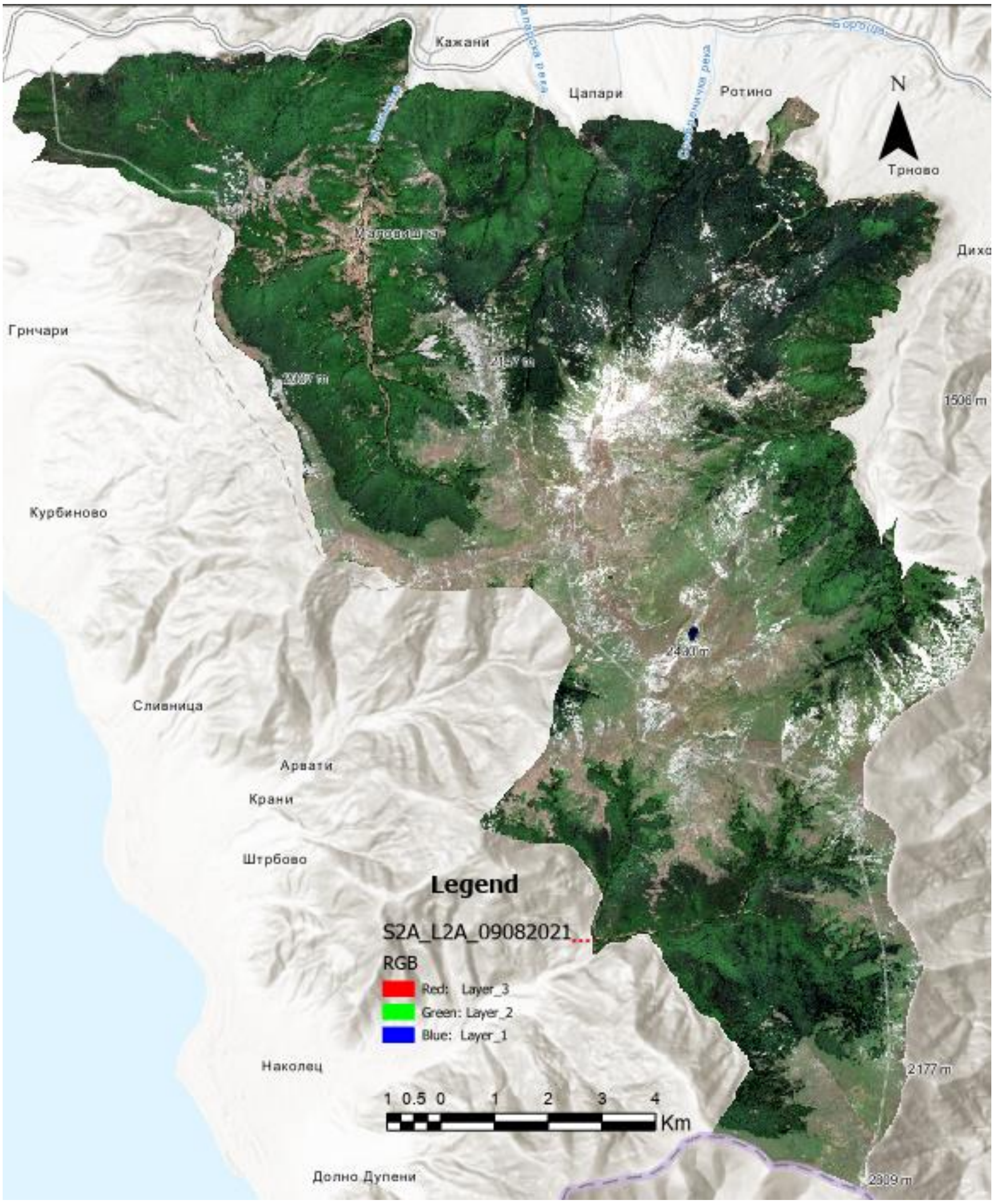

Figure 2. Sentinel-2 Image sensed on 09/08/2021

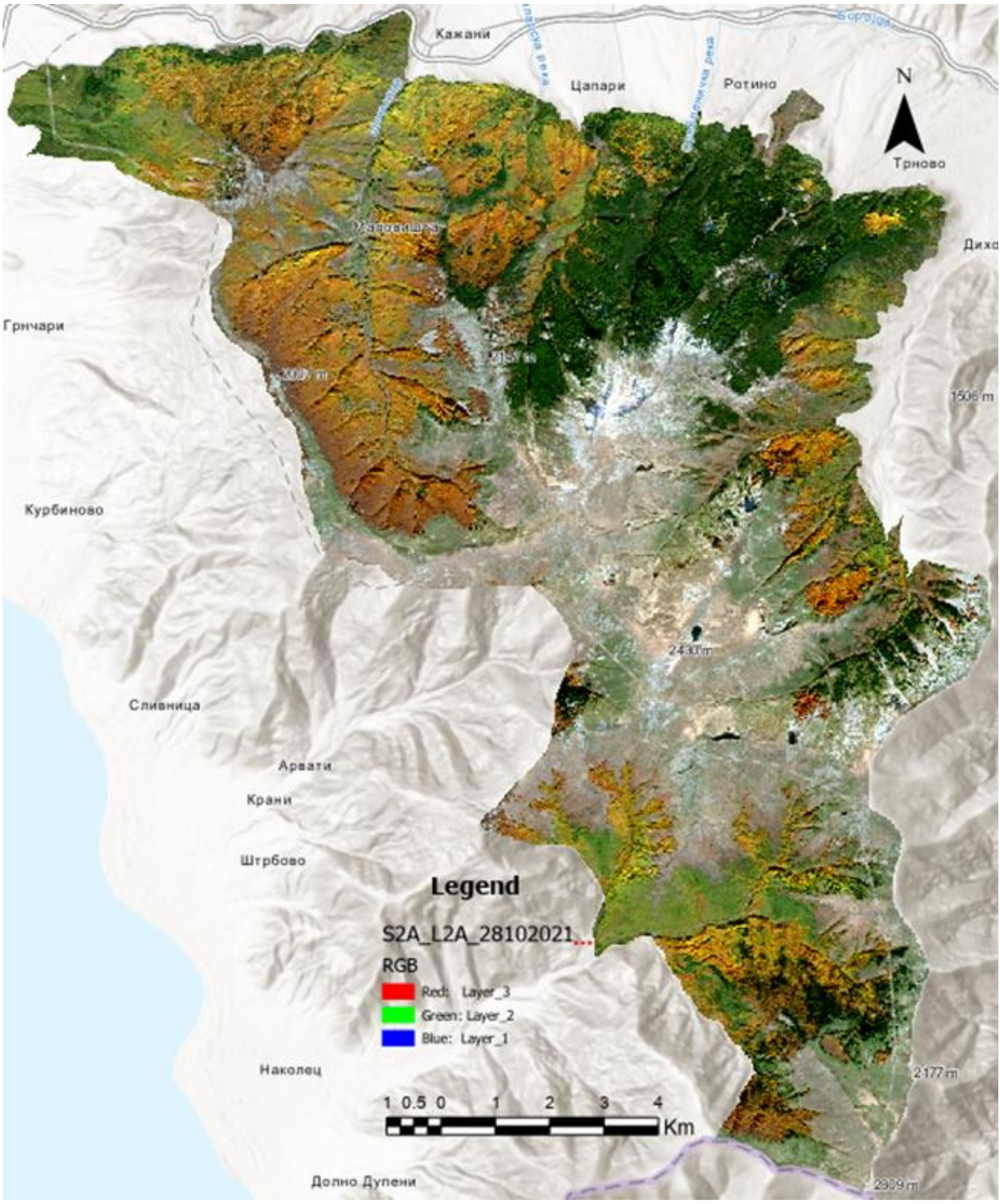

Figure 3. Sentinel-2 Image sensed on 28/10/2021

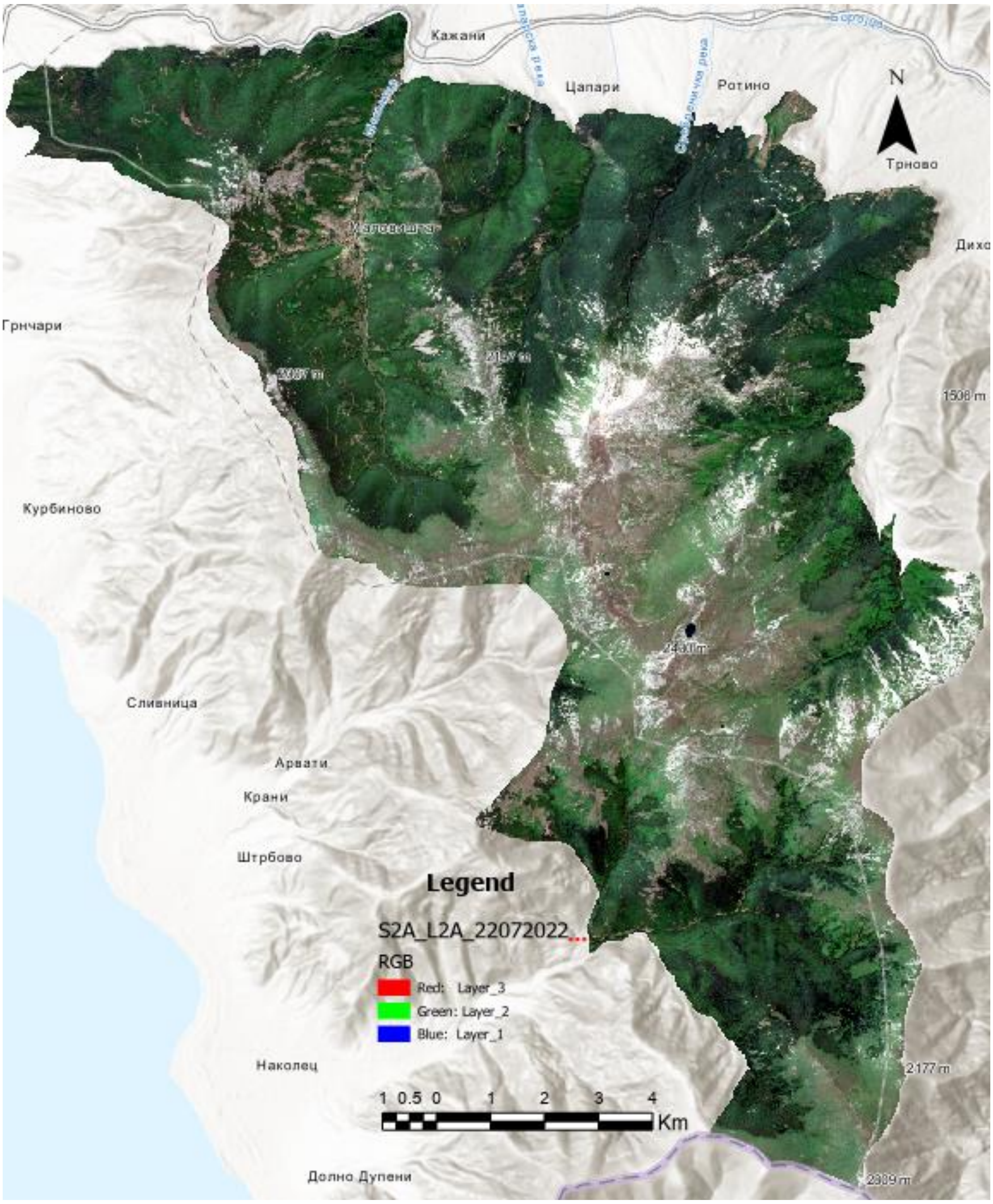

Figure 4. Sentinel-2 Image sensed on 22/07/2022

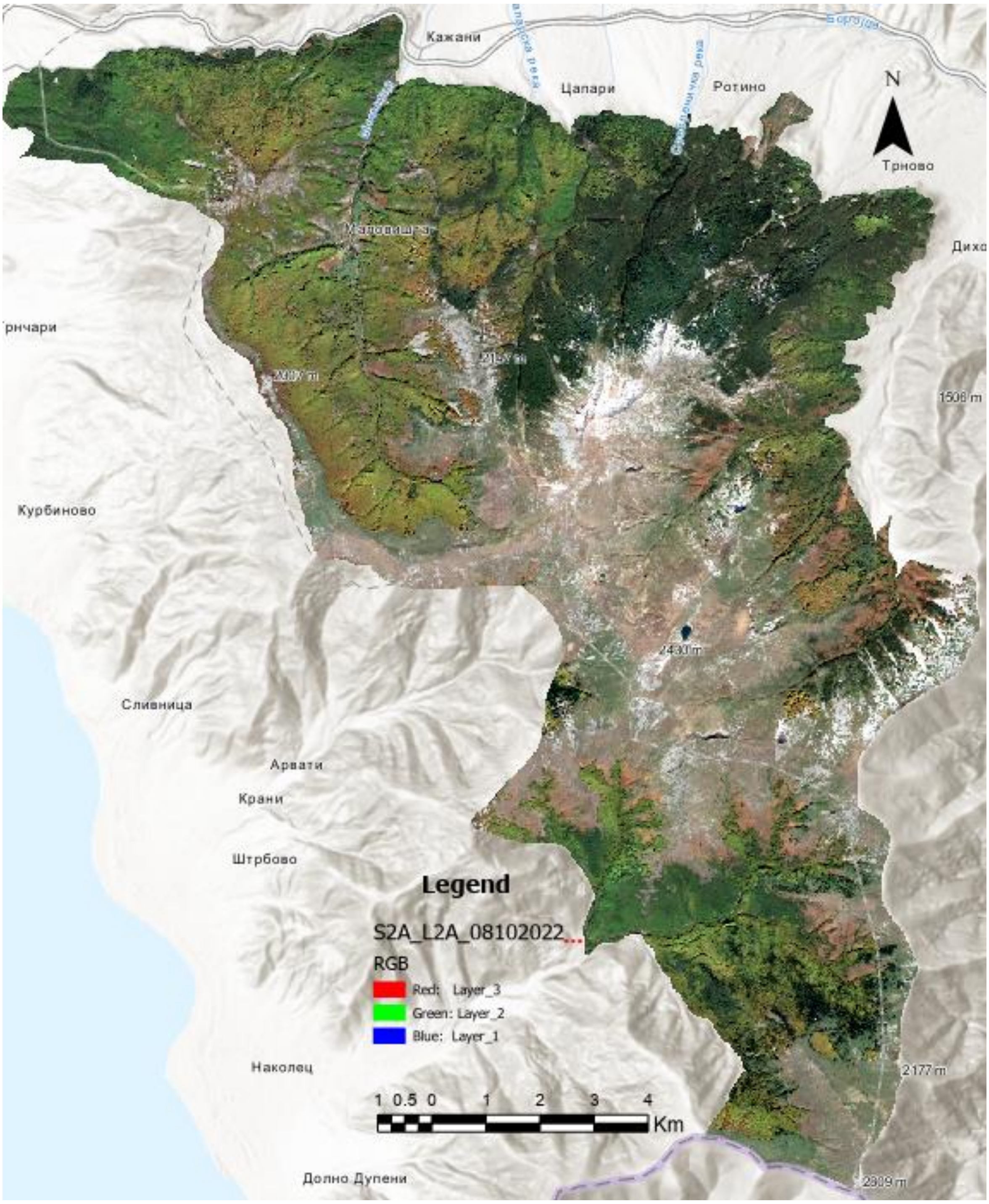

Figure 5. Sentinel-2 Image sensed on 08/10/2022

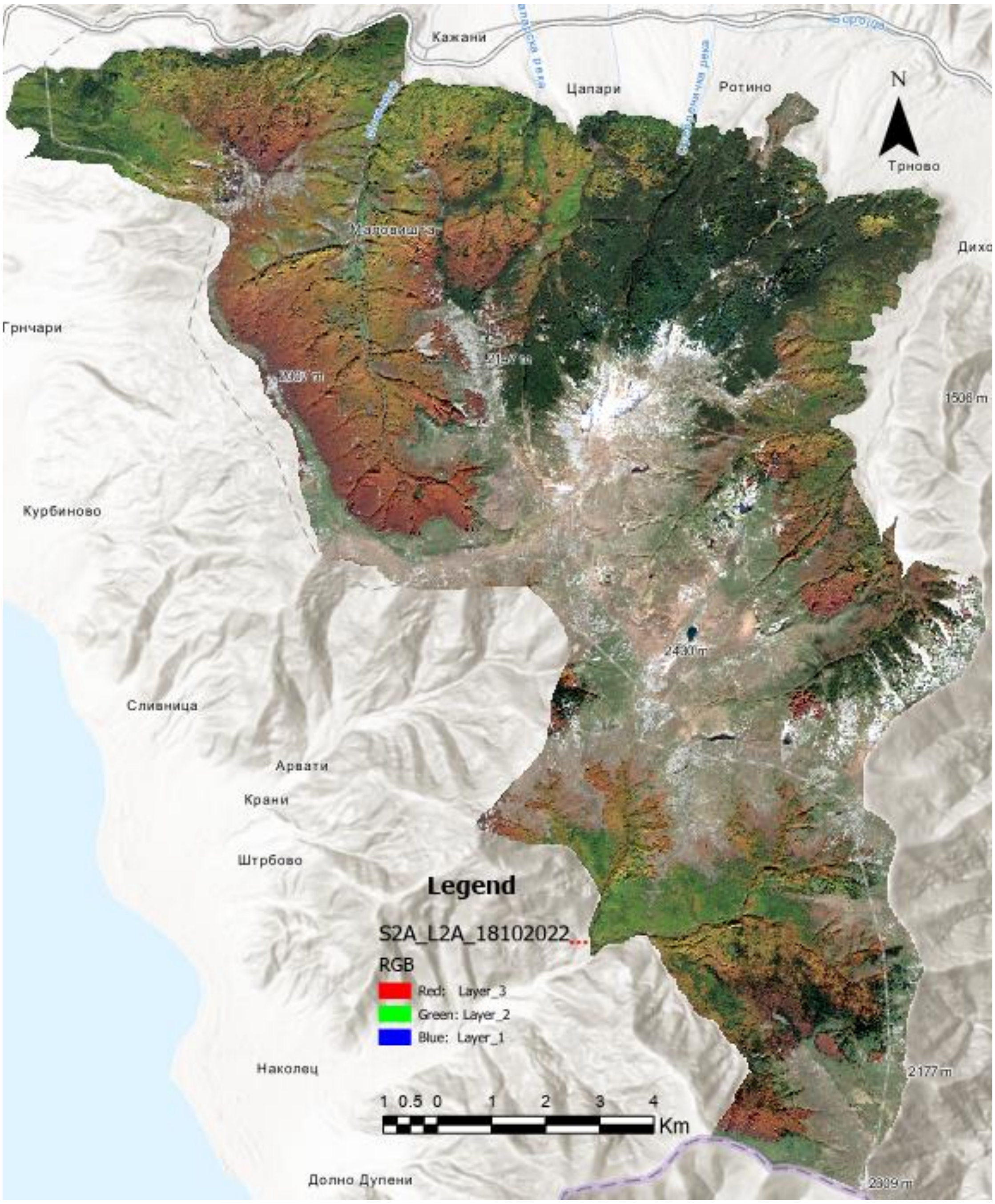

Figure 6. Sentinel-2 Image sensed on 18/10/2022

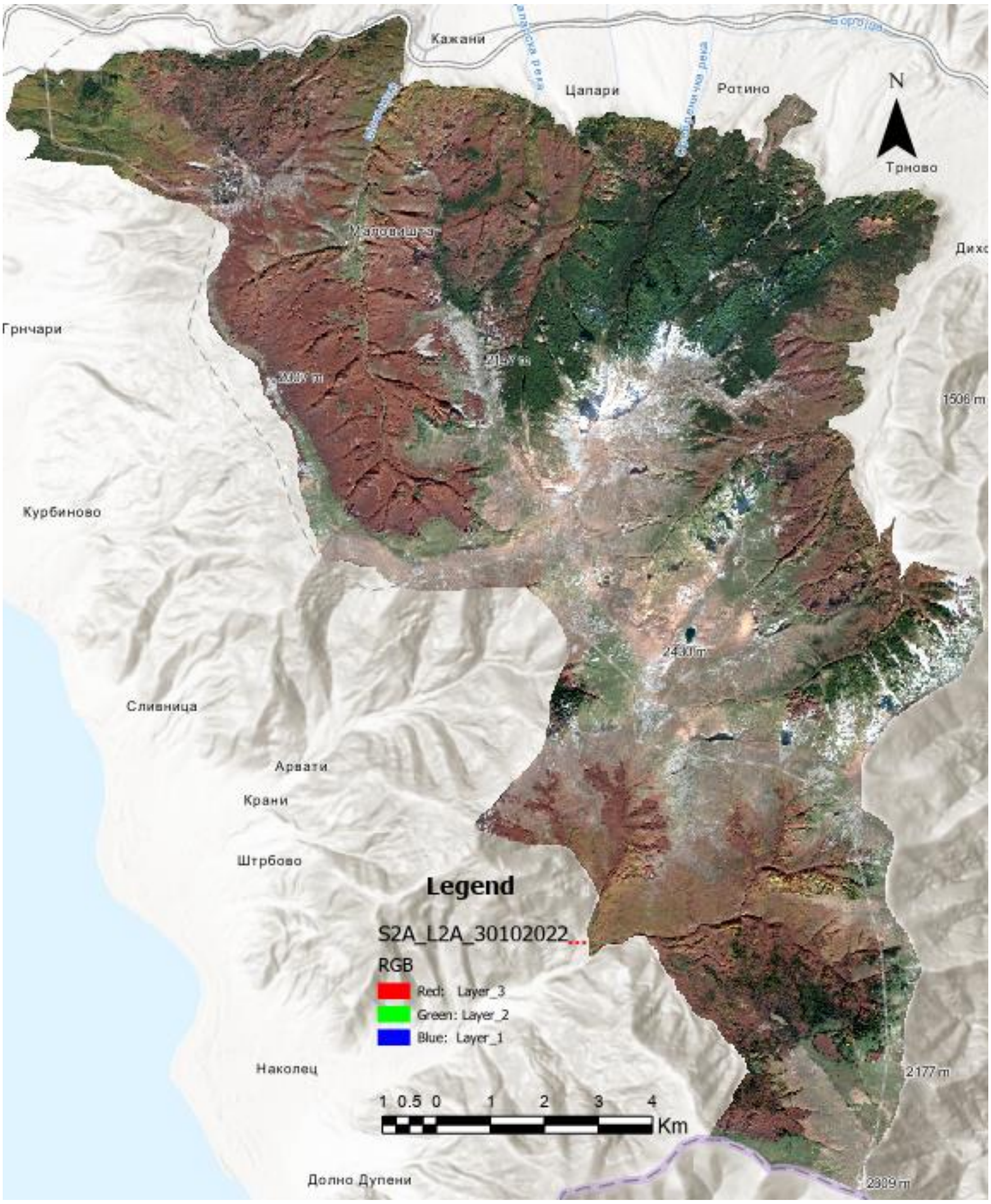

Figure 7. Sentinel-2 Image sensed on 30/10/2022

Ancillary data were also employed for the delineation of Agricultural and urban areas while the Tree Cover Density Data downloaded from the Copernicus Database were also employed. The classification process was assisted by the collected ground truth data. Sample data were also collected by the visual inspection of VHR aerial photographs. Various classifiers were tested for their effectiveness in identifying the selected fuel models. The assessment of each classifier's performance, was assessed by the efficiency in reproducing the training set.

Random Forests was the classifier which was found to perform better in this study area and with the data used, compared to Classification Trees, Support Vector Machines and K Nearest Neighbor. Various post-classification refinements were employed in order to avoid a “salt and pepper” result. Isolated objects surrounded by one particular class and with the size smaller than the minimum mapping unit (0.25ha) were reclassified at the enclosing class. Furthermore isolated objects with the size smaller than the minimum mapping unit, neighboring more than one class were classified to the one where it had the longest common border. Eight classes were totally identified which represent the fuel models including in table 5. The accuracy of the final product was assessed by means of an error matrix. The classification process is shown in figure 8 and 9.

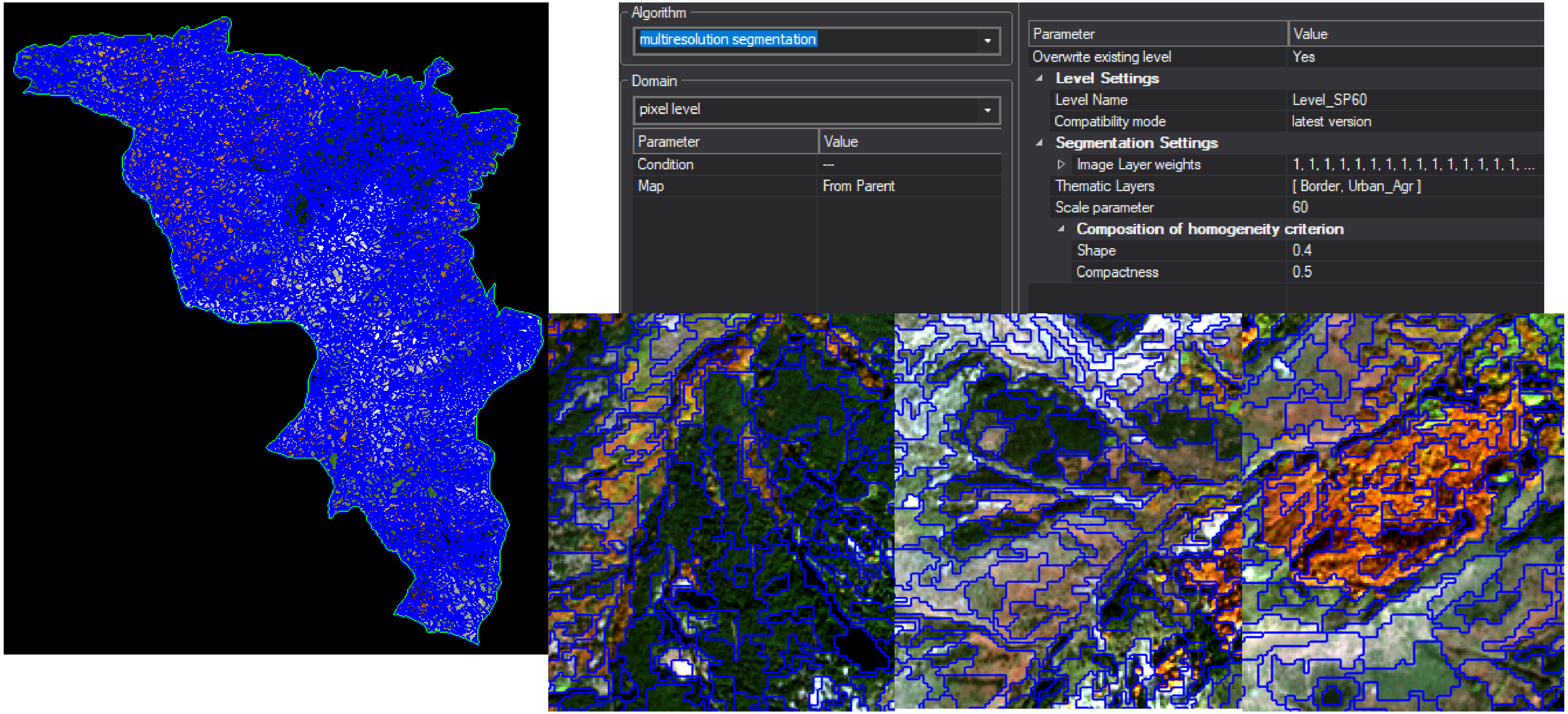

Figure 8. Segmentation process in the environment of OBIA

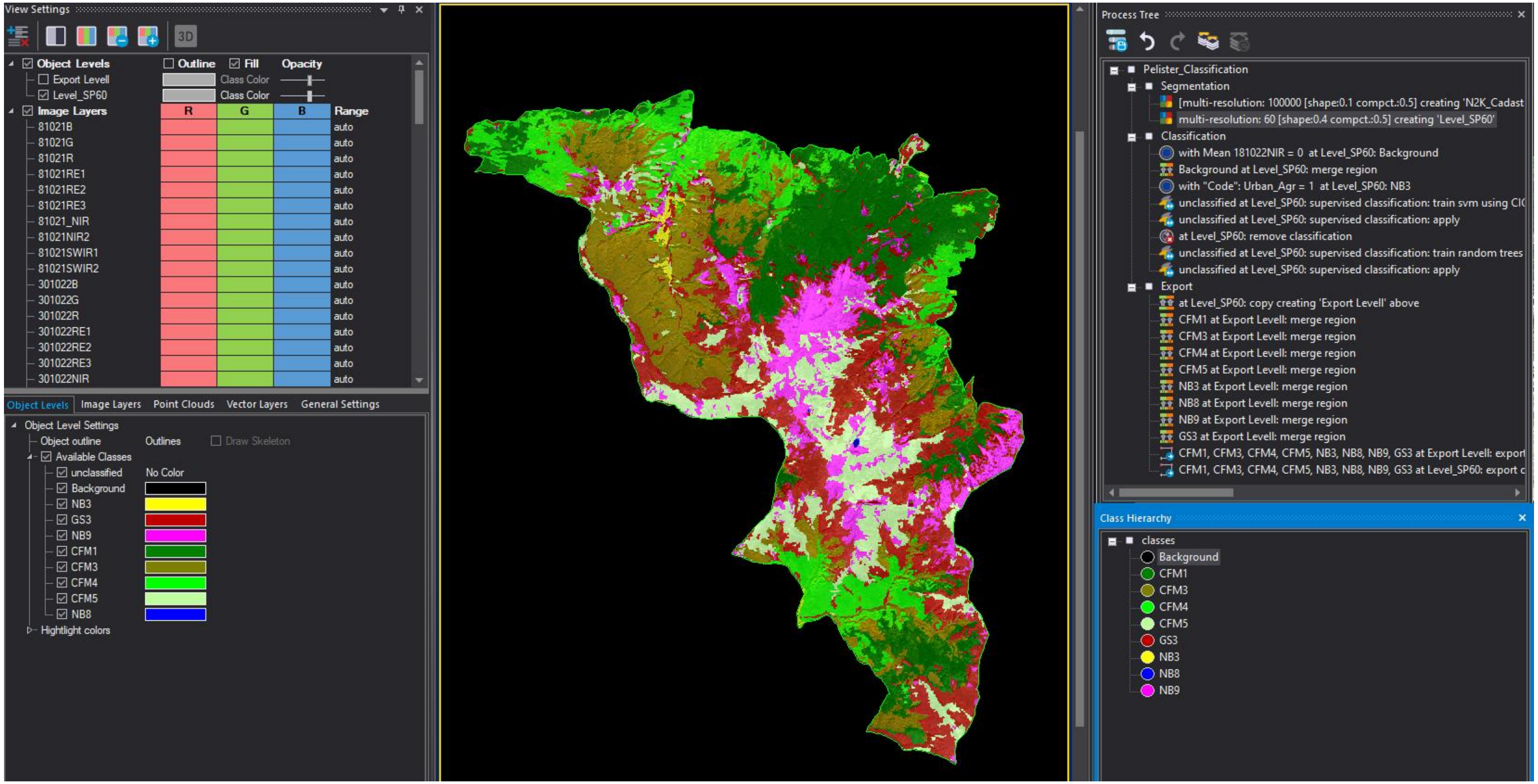

Figure 9. Classification algorithm in OBIA

The first step of OBIA is the generation of objects based on the spectral similarity of neighboring pixels. The degree of homogeneity of each object is determined by the user by setting an appropriate scale parameter (Bock et al. 2005). Normally at the final stage of the classification process, neighboring objects belonging to the same class are merged. In this case this was not done and the objects generated in the classification process were also used at the next stages of generating data for fire simulations. Canopy height for each polygon was obtained by the Global Forest Canopy Height, 2019 Potapov et al. 2020). Canopy Base Height (CBH) was assigned on each polygon based on the nearest sampled point while Crown Bulk Density was calculated in arc fuels. As a result five raster data sets were generated which are necessary for the implementation of fire simulation.

The generated raster data, along with a Digital Elevation Model (DEM), a Digital Aspect Model (DAM) and Digital Slope Model (DSLM) were used in the fire simulation model Flammap (Finney, 2006), to provide an estimation of the potential Fireline Intensity and fire Rate of Spread. The aim of the study is to assess the fire hazard in the area, in a spatially explicit manner, and under condition that favor a high-intensity fire. The largest fires that have recently occurred in the Eastern Mediterranean region (Evros, Greece) occurred in the summer of 2023 which was the hottest ever recorded in the area, with three consecutive heatwaves from June to August and wind patterns that favored the spread and intensity of fires. These extreme weather conditions are more likely to occur more often in the future than to be an exceptional case of extremely rare occurrence (Founta & Giannakopoulos 2009; Tolika et al. 2009). For this reason, the fire behavior simulation was decided to be performed, under an extreme scenario of a wind speed of 35 km/h. A south wind was assumed which is the prevailing wind direction during the summer period. The fuel moisture parameters were set at 3, 4, 5, 30 and 60% for 1-h, 10-h, 100-h, live-woody and live-herbaceous fuel respectively. . Two simulations were employed. One with a canopy base height for molika pine at 15m and one at 8m, in order to see the effect of this parameter on the conditions of burn. All the data used in the fire simulation process are shown in figures 10-18

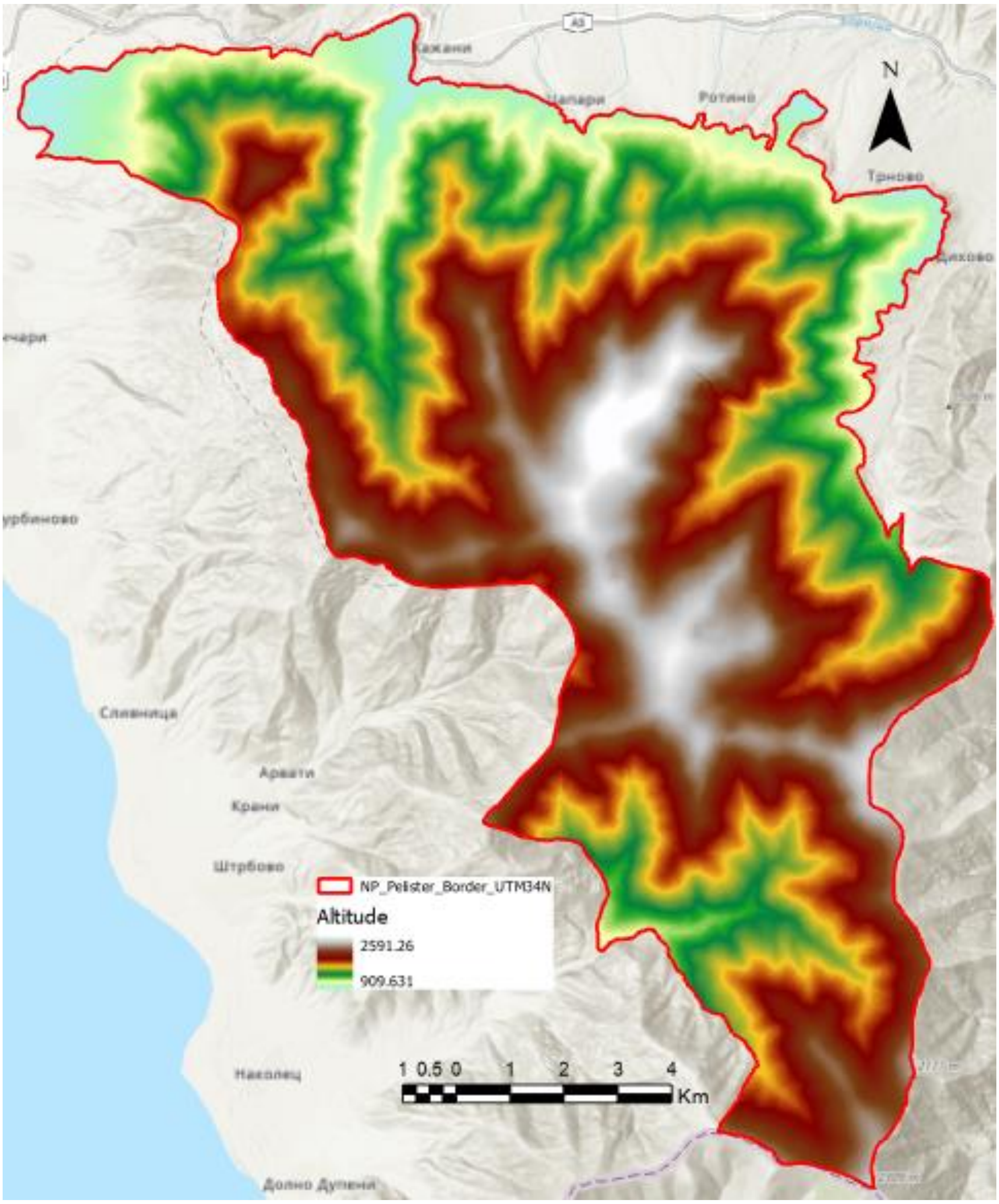

Figure 10. Digital Elevation Model of Pelister National Park.

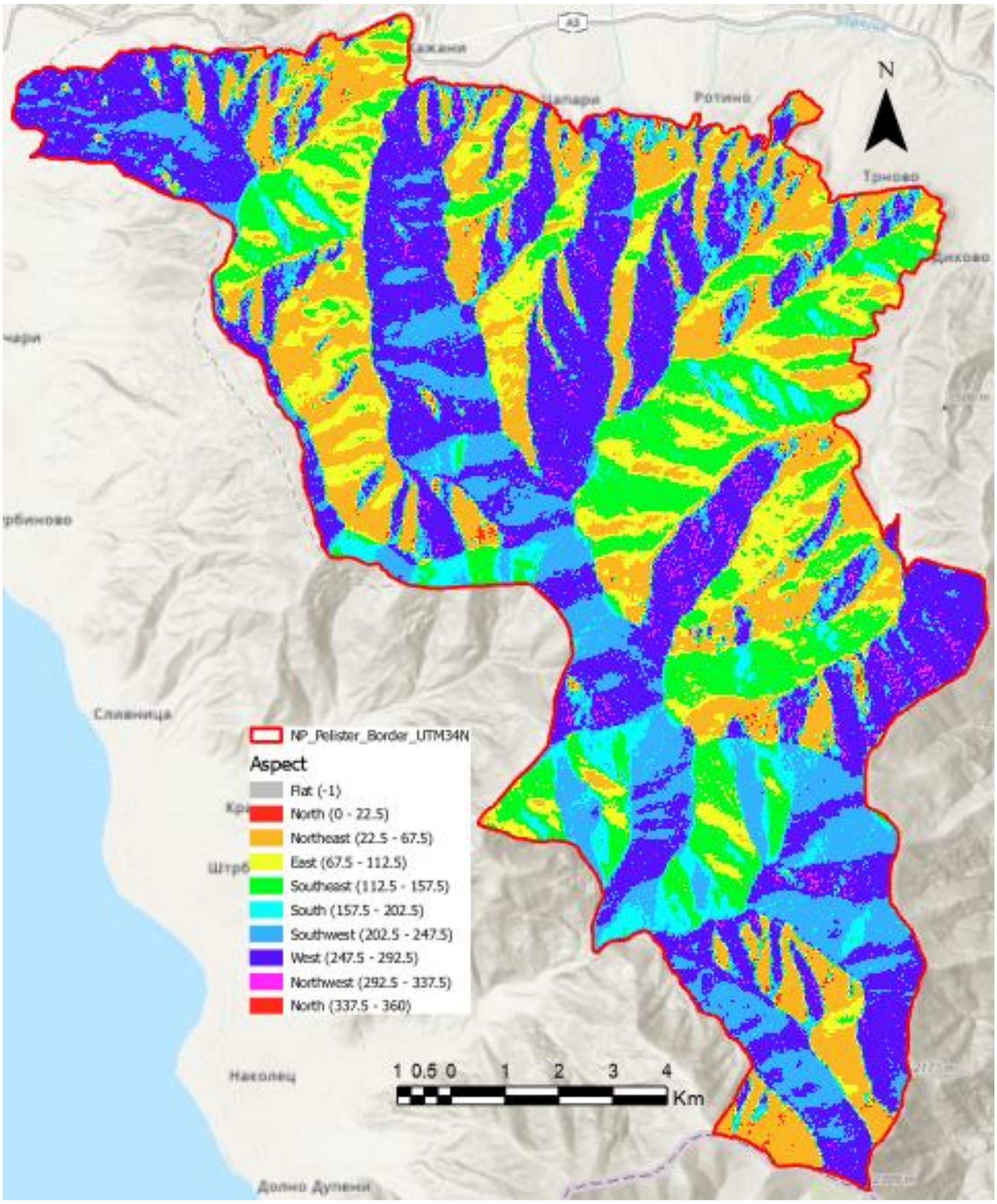

Figure 11. Digital Aspects Model of Pelister National Park.

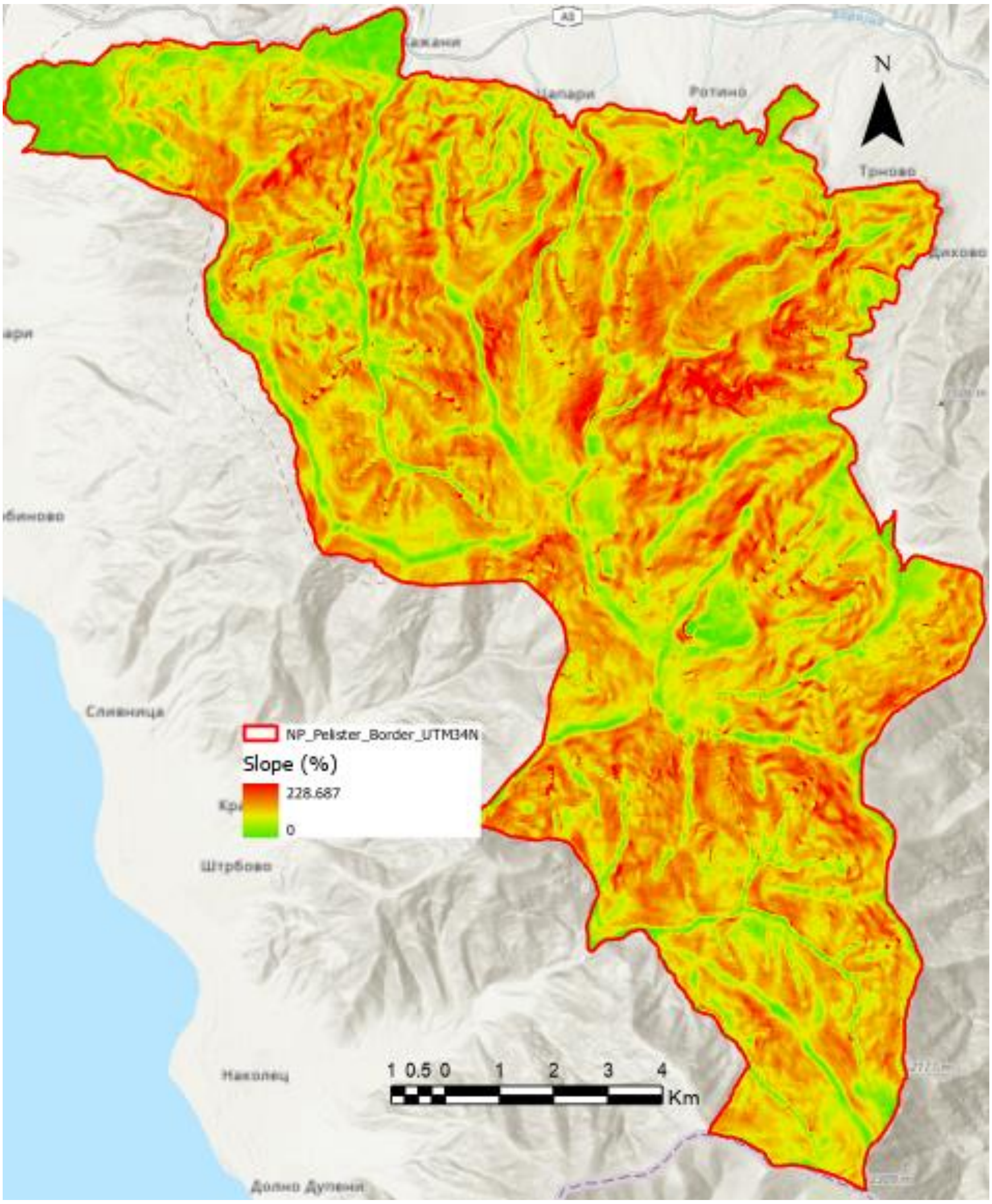

Figure 12. Digital Slopes Model of Pelister National Park.

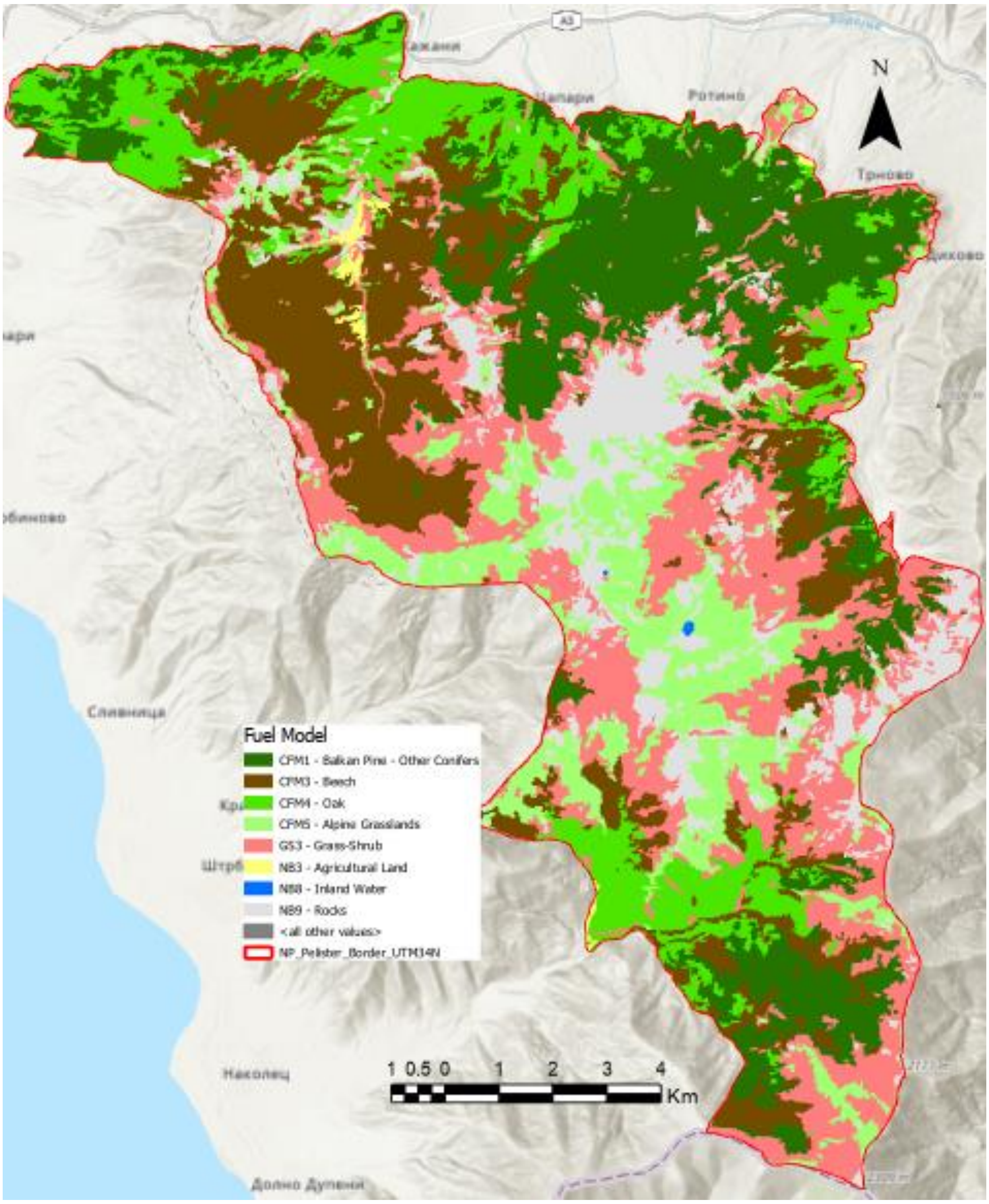

Figure 13. Fuel Models of Pelister National Park

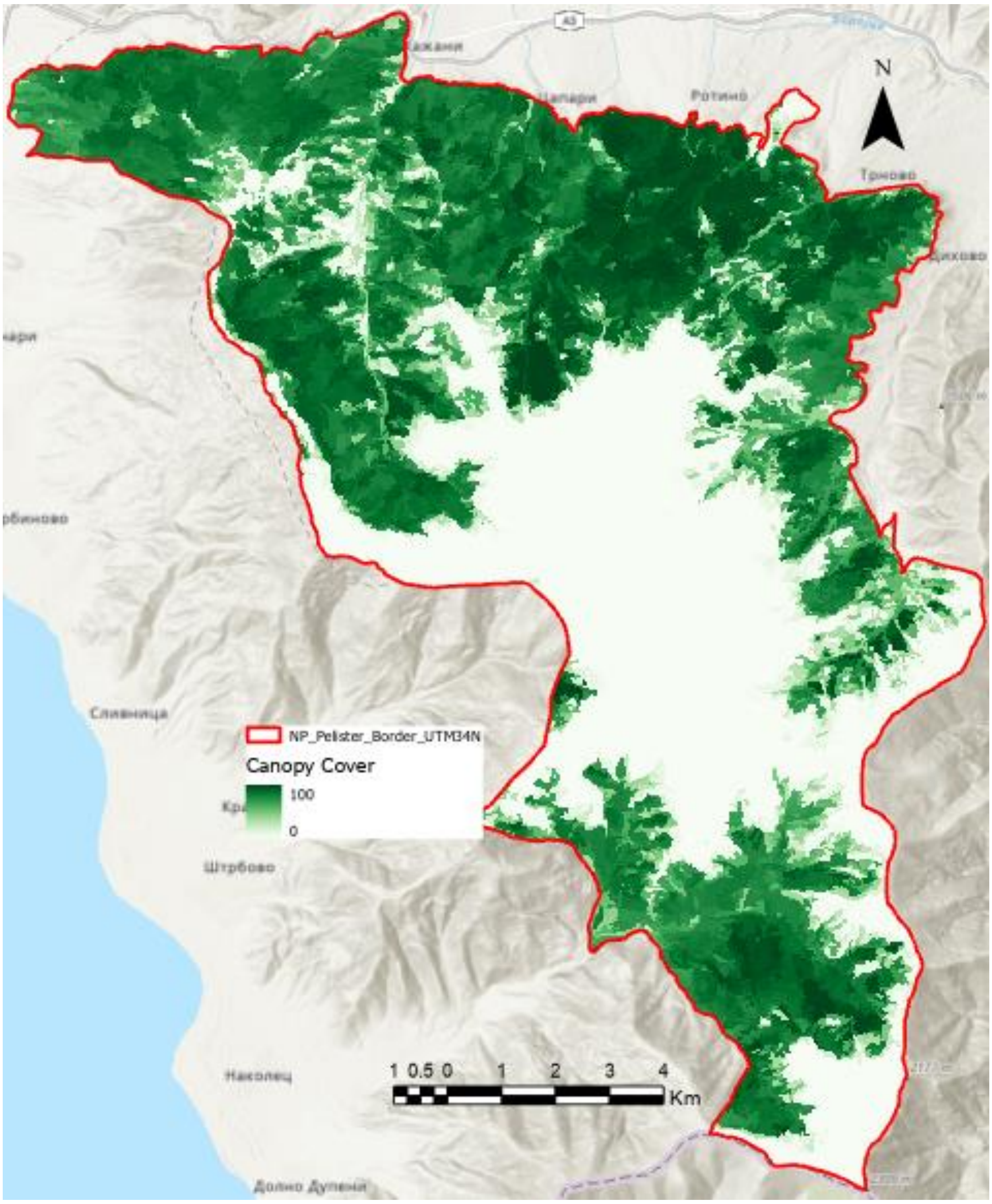

Figure 14. Canopy Cover of Pelister National Park

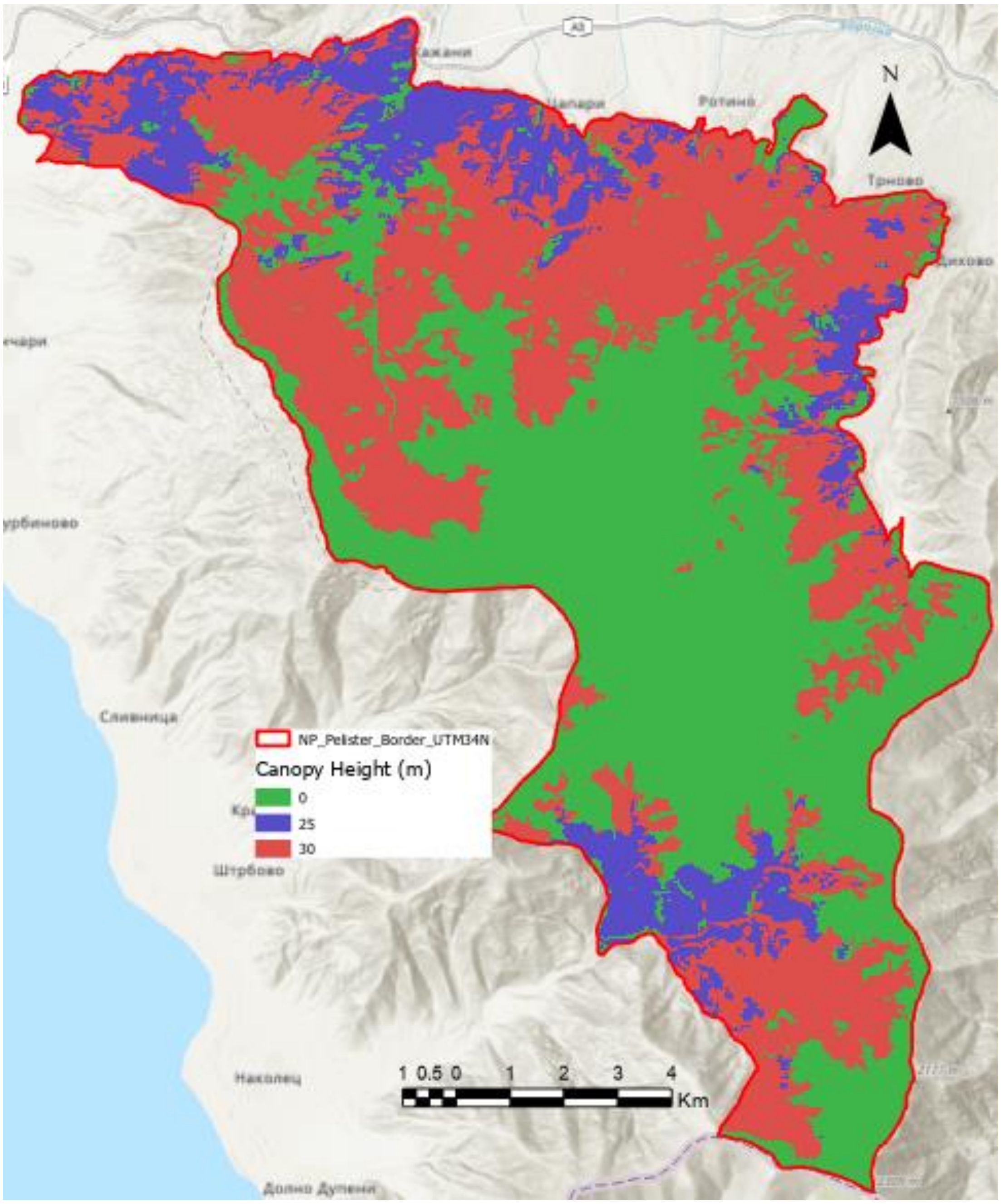

Figure 15. Canopy Height of Pelister National Park

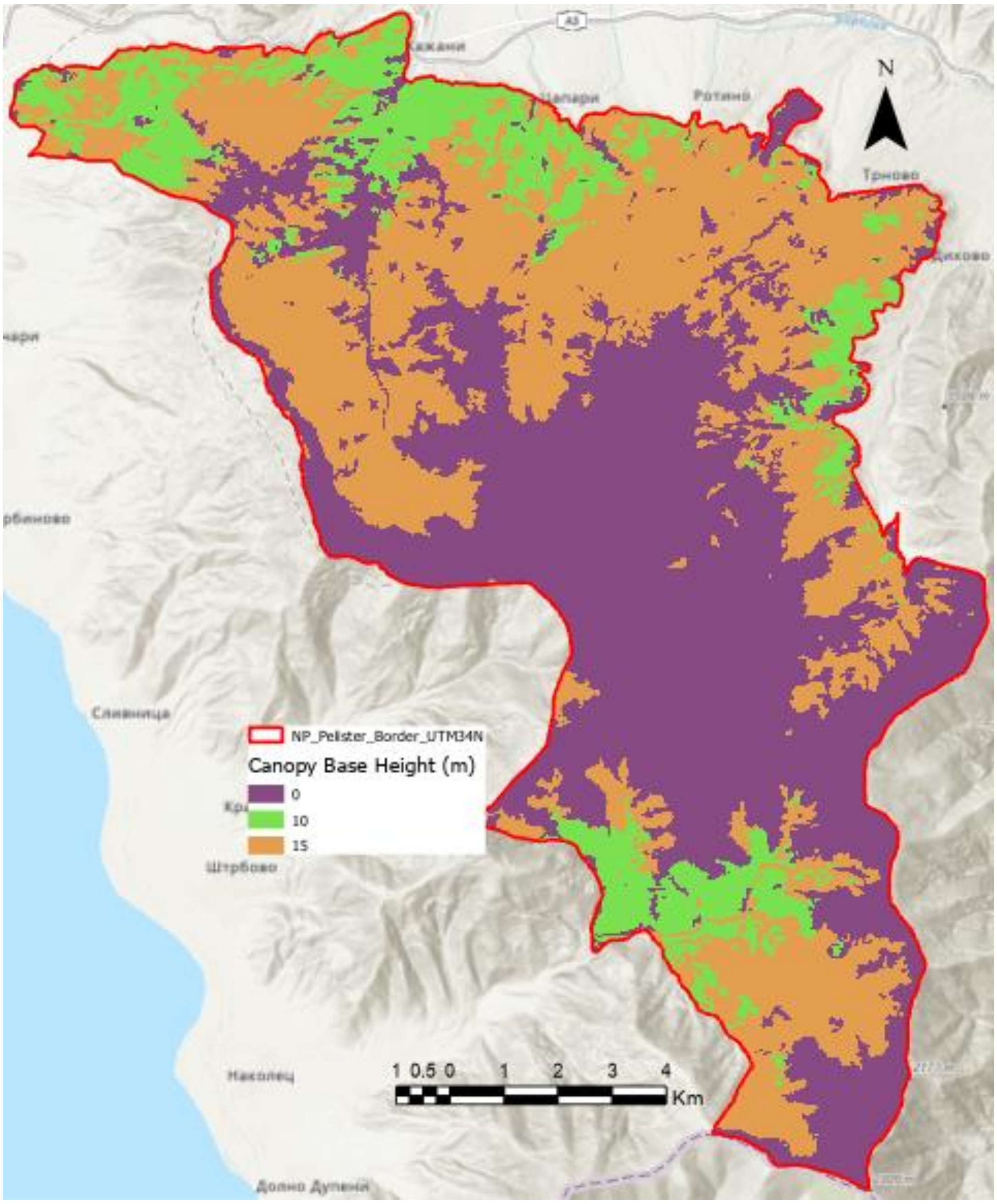

Figure 16. Canopy Base Height of Pelister National Park under the regular scenario

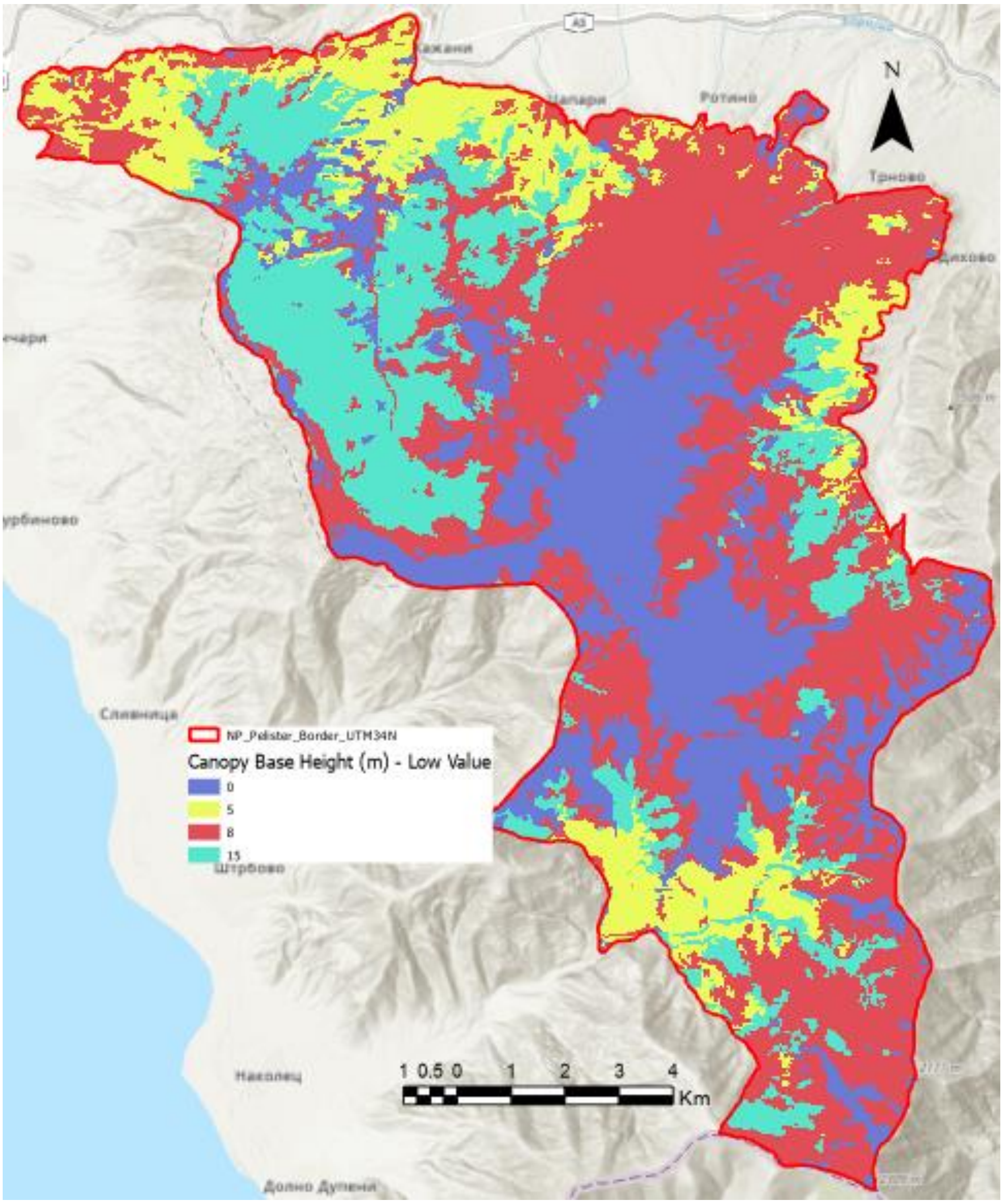

Figure 17. Canopy Base Height of Pelister National Park under the scenario of a low CBH

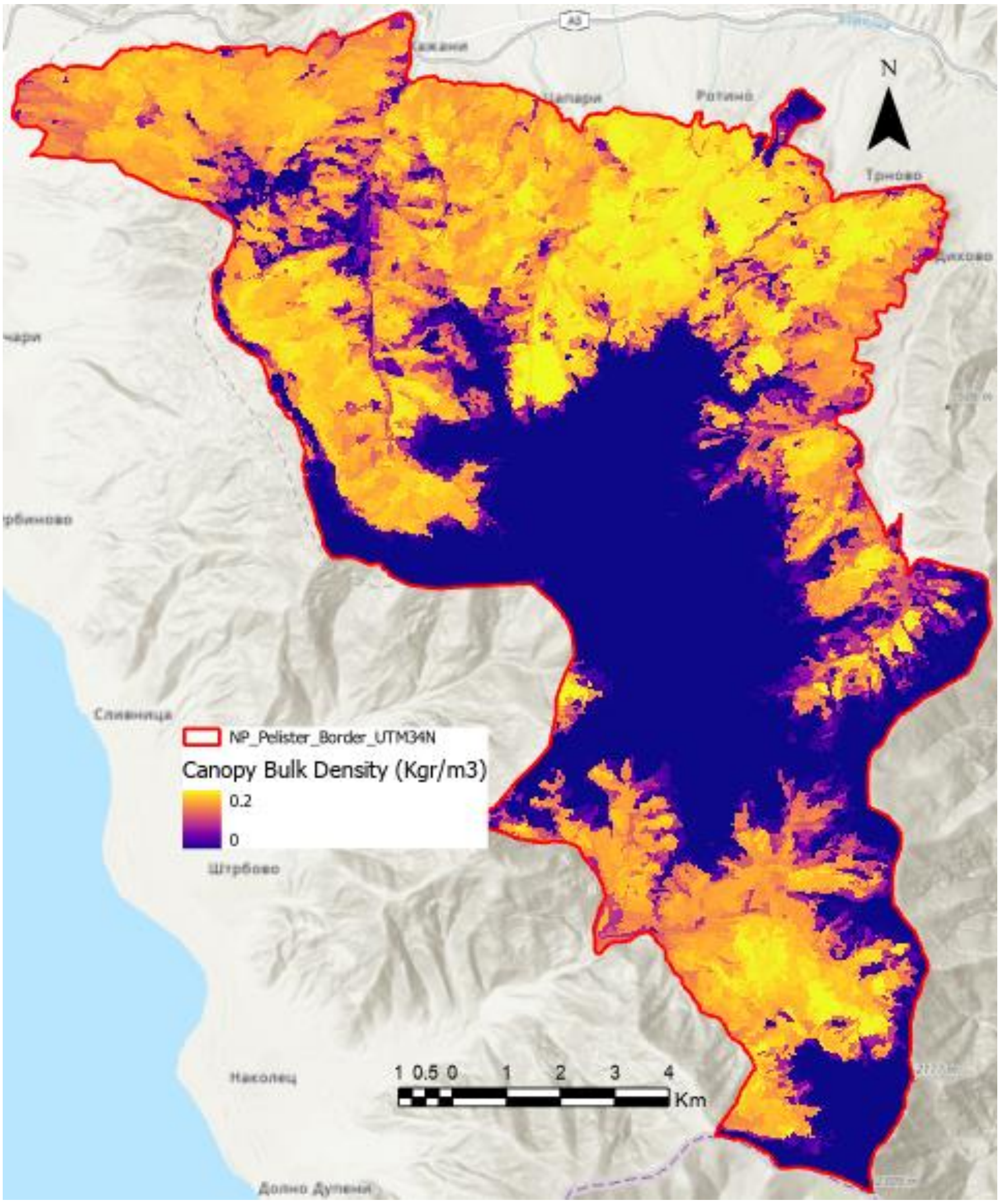

Figure 18. Canopy Bulk Density of Pelister National Park under the regular scenario

3 Results

3.1. Results on long term Vegetation trends

The tested vegetation indices show all statistically significant relationships with time and statistically significant positive or negative trends during the study period (Table 6). The results clearly indicate that during the study period the vegetation cover of the study area has increased significantly.

Table 6. Results of the linear regression between time and vegetation indices

Vegetation Indices	Linear Regression		
	b	Adj-R^2	p
NDVI	0.0021	0.56	<0.001
SAVI	0.0032	0.55	<0.001
EVI2	0.0042	0.55	<0.001
NDWI	0.0018	0.66	<0.001
BSI	-0.0014	0.60	<0.001

All indices which are sensitive to the existence of vegetation exhibit a positive trend during the study period (Figures 19-22), while the BSI, which is sensitive to bare ground exhibit a negative trend (Figure 23). BSI is an index which constitutes a combination between a vegetation index and a bare soil index and tends to obtain higher values in the least vegetated areas. Both these results demonstrate that vegetation has increased its density significantly during the study period, as a result of several factors that will be discussed later.

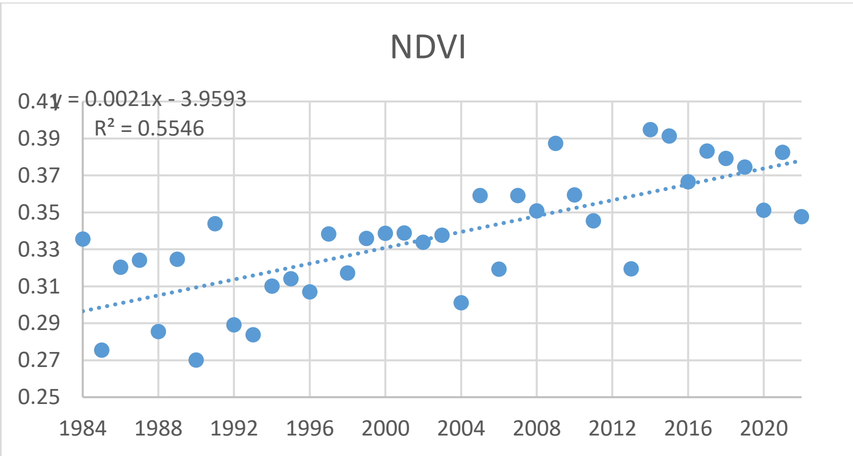

Figure 19. NDVI dynamics and trend during the study period. The graph is built based on the 1000 randomly located points, corresponding to 1000 pixels.

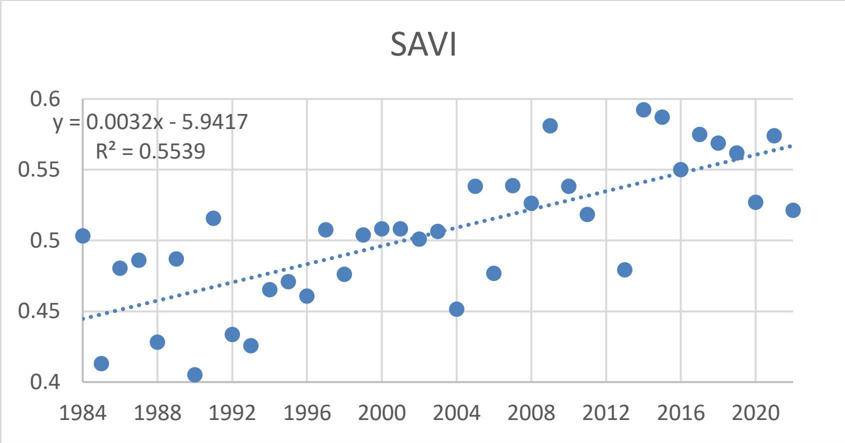

Figure 20. SAVI dynamics and trend during the study period. The graph is built based on the 1000 randomly located points, corresponding to 1000 pixels.

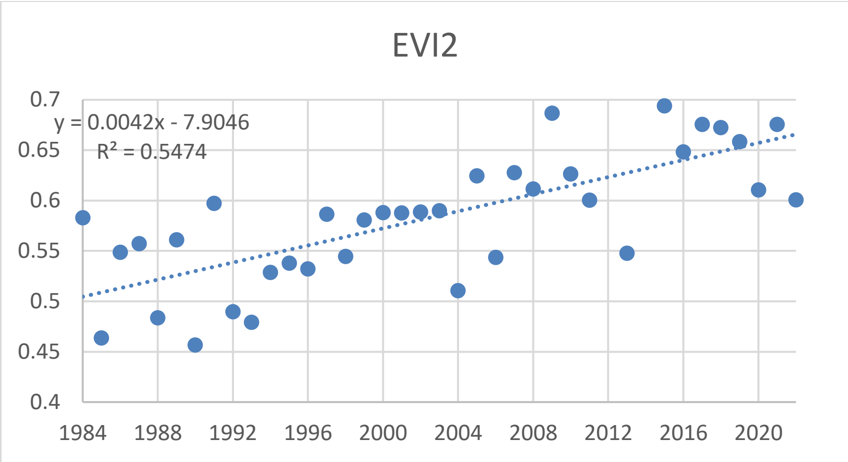

Figure 21. EVI dynamics and trend during the study period. The graph is built based on the 1000 randomly located points, corresponding to 1000 pixels.

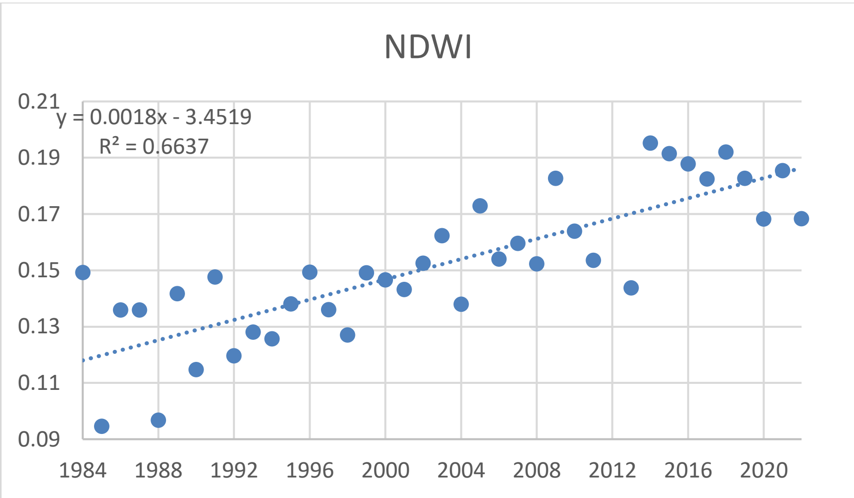

Figure 22. NDWI dynamics and trend during the study period. The graph is built based on the 1000 randomly located points, corresponding to 1000 pixels.

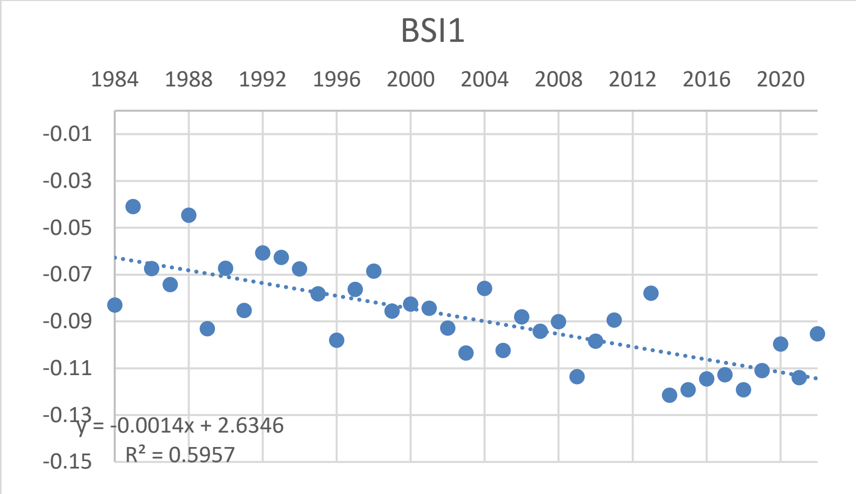

Figure 23. BSI dynamics and trend during the study period. The graph is built based on the 1000 randomly located points, corresponding to 1000 pixels.

Figures 6 shows a visual representation of the of the NDVI trend over the study period and it clear show that areas with high NDVI value are increasing while those with low are decreasing.

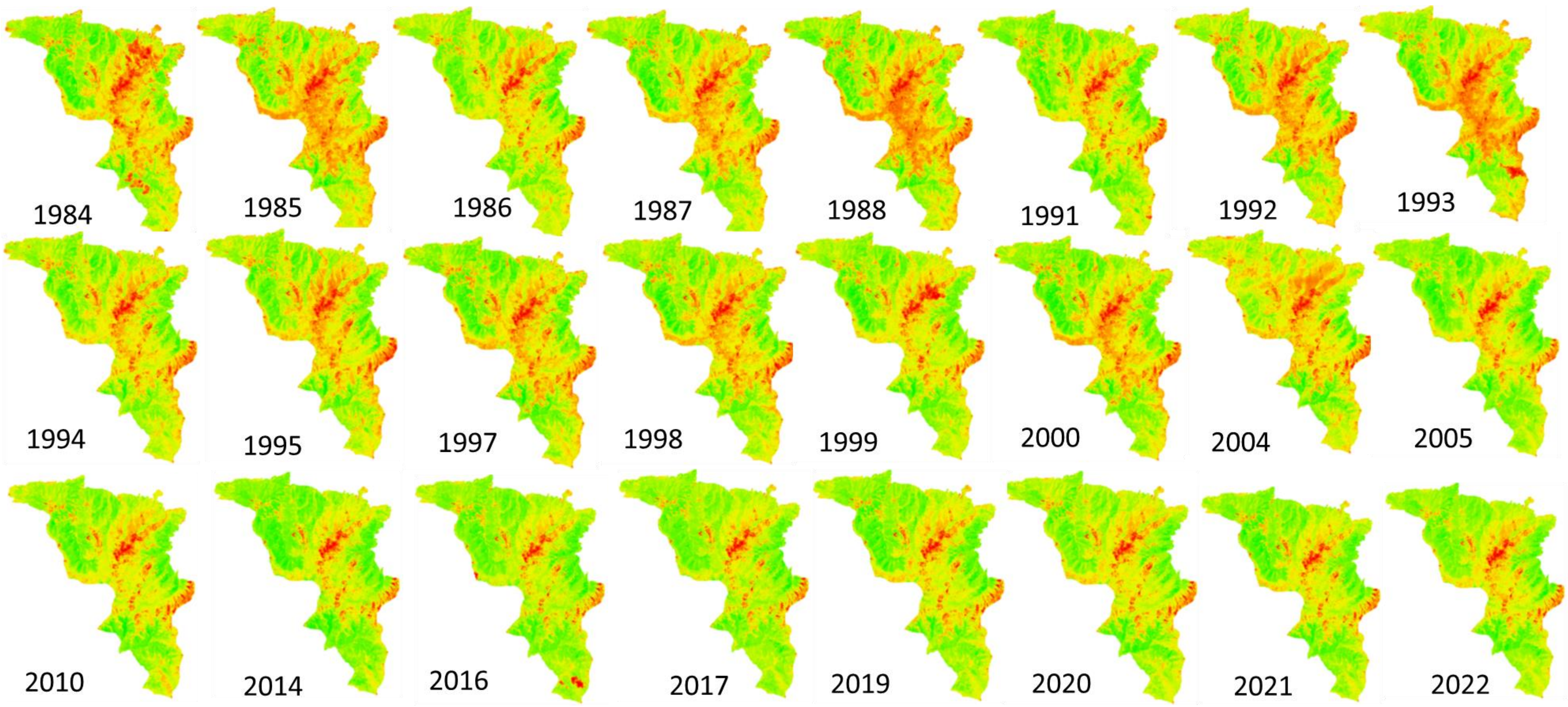

Figure 24. NDVI trend over the study period.

3.2 Results on long term Vegetation trends

The results obtained from the fire simulations are pretty revealing regarding the risk of fire in the region. As shown in figures 25 to 28 the risk of high intensity crown fire depends primarily on the vertical distribution of fuel. Under dry conditions with low fuel moisture content the risk of fire for molika pine is high and under favourable conditions it will affect a large part of the forest (Figure 29). The results show that canopy base height is a crucial factor in determining fire risk in forested landscapes such as the one in the study area. It refers to the vertical distance from the ground to the lowest branches and leaves of trees and other vegetation. This height can vary widely depending on the type of vegetation, tree species, and environmental conditions. The significance of canopy base height for fire risk lies in its influence on the ability of a fire to spread and its potential for severity. Canopy base height plays a significant role in determining fuel continuity. Low canopy base heights mean that vegetation, such as shrubs and low-hanging branches, extends closer to the ground. This creates a continuous ladder of fuel that can allow a ground fire to easily transition into a crown fire, which is much more difficult to control and can spread rapidly. A low canopy base height increases the risk of crown fires, where the flames spread through the upper canopy of trees. Crown fires are typically more intense and destructive than ground fires and can lead to rapid fire spread and increased fire severity.

Canopy base height influences fire behavior by affecting fire intensity, rate of spread, and flame length. In areas with low canopy base heights, fires are more likely to burn with greater intensity, making them more challenging to contain. Understanding canopy base height is essential for wildfire management and prevention efforts. It helps fire managers assess the potential for fires to transition into crown fires and make informed decisions about strategies to mitigate fire risk, such as controlled burns, thinning, or prescribed fires.

In summary, canopy base height is a crucial factor in assessing fire risk because it influences fuel continuity, crown fire potential, and overall fire behavior. It helps fire managers and researchers understand the potential for wildfires to become more severe and difficult to control, allowing for more effective fire management and prevention efforts in at-risk areas.

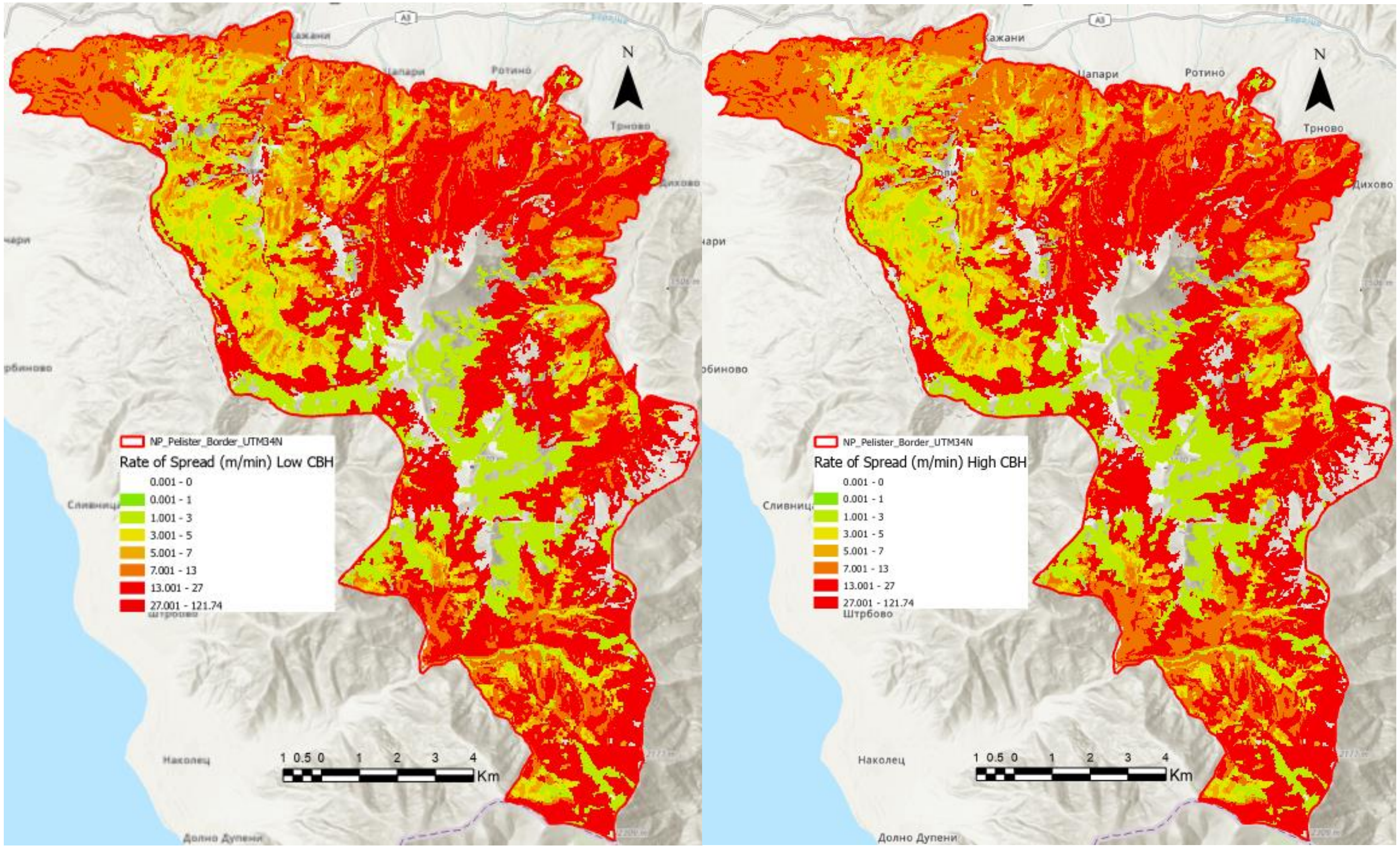

Figure 25. Fire rate of Spread under two scenarios of Low CBH and High CBH

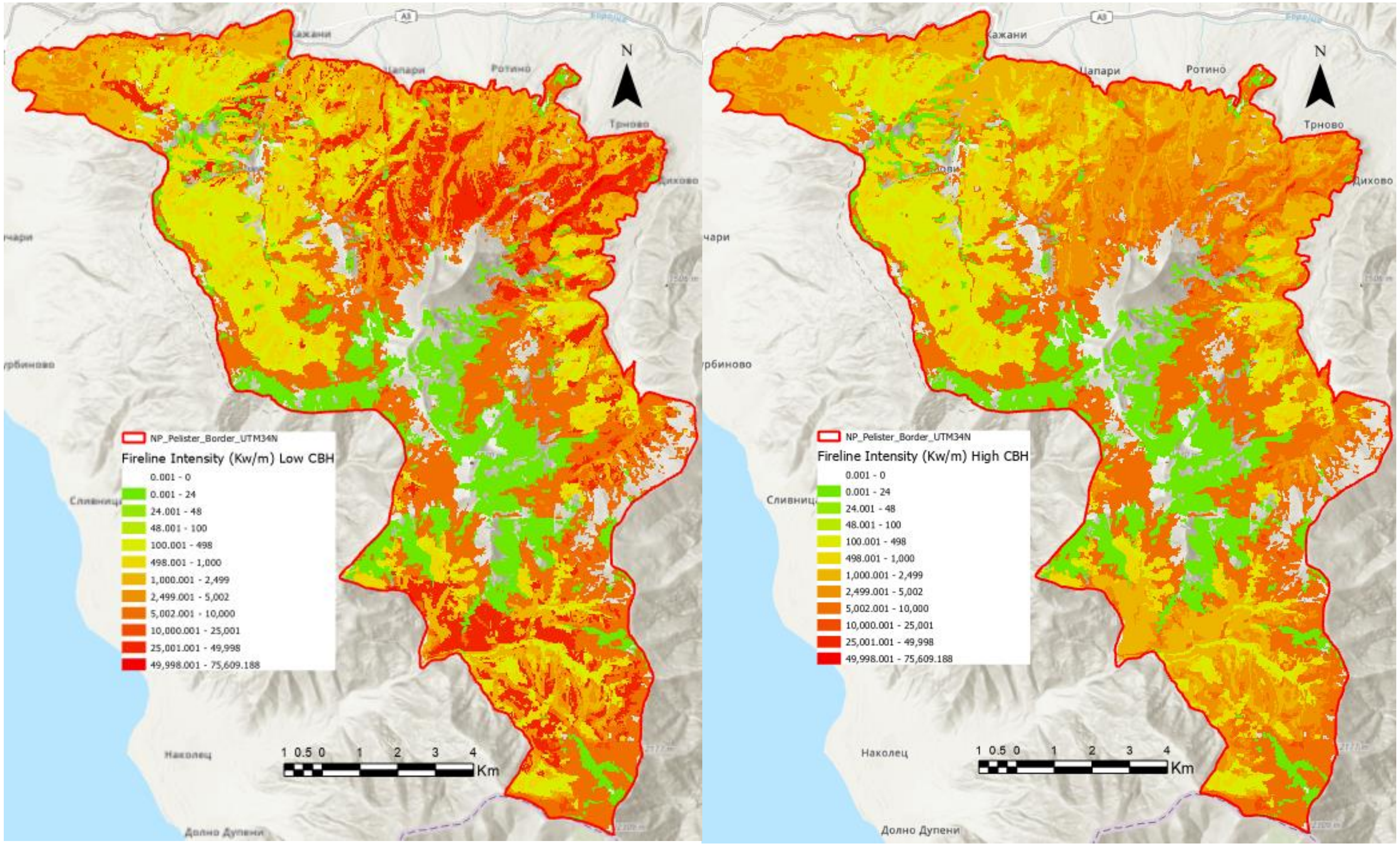

Figure 26. Fireline intensity under two scenarios of Low CBH and High CBH

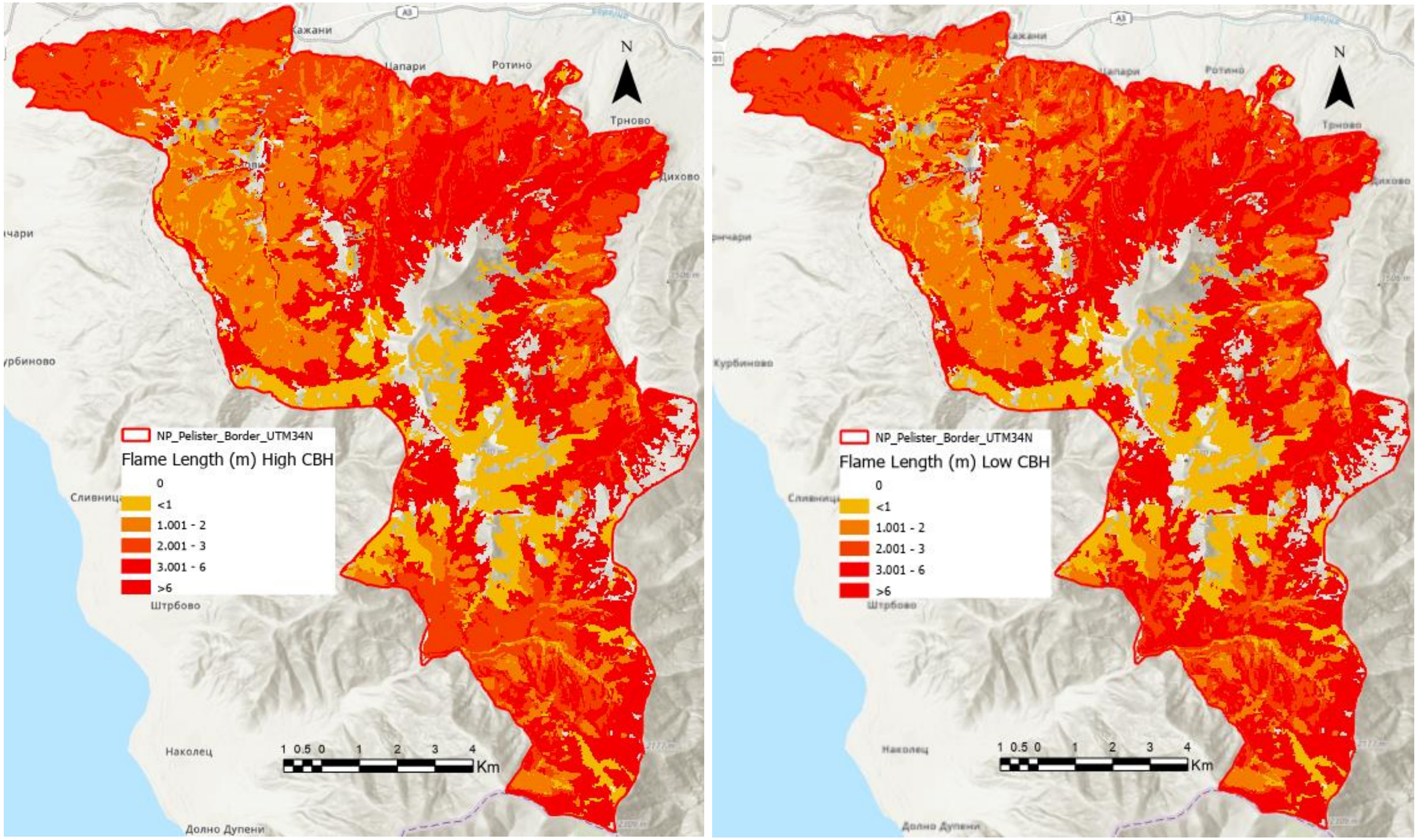

Figure 27. Flame length under two scenarios of Low CBH and High CBH

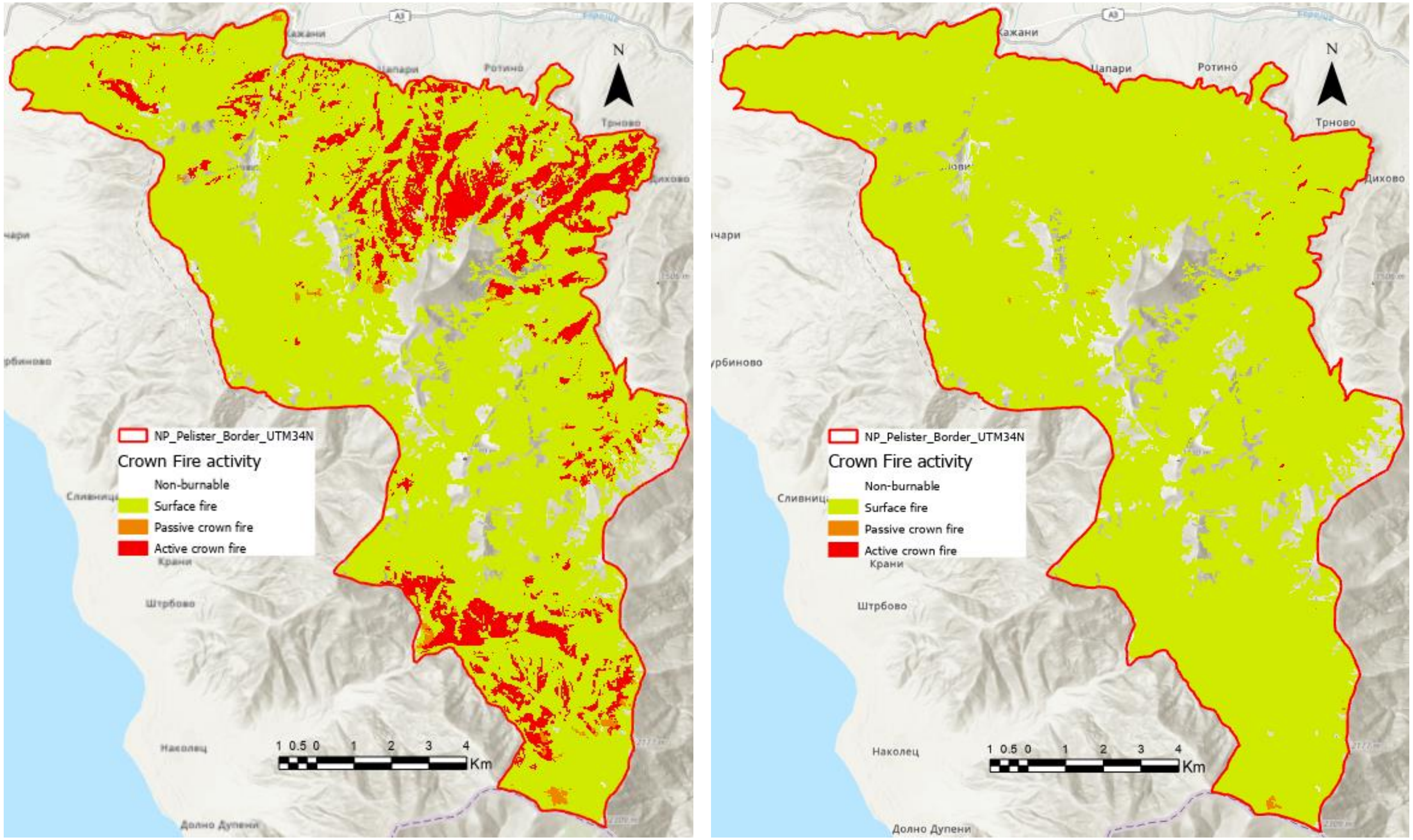

Figure 28. Crown fire activity under two scenarios of Low CBH (left) and High CBH (right)

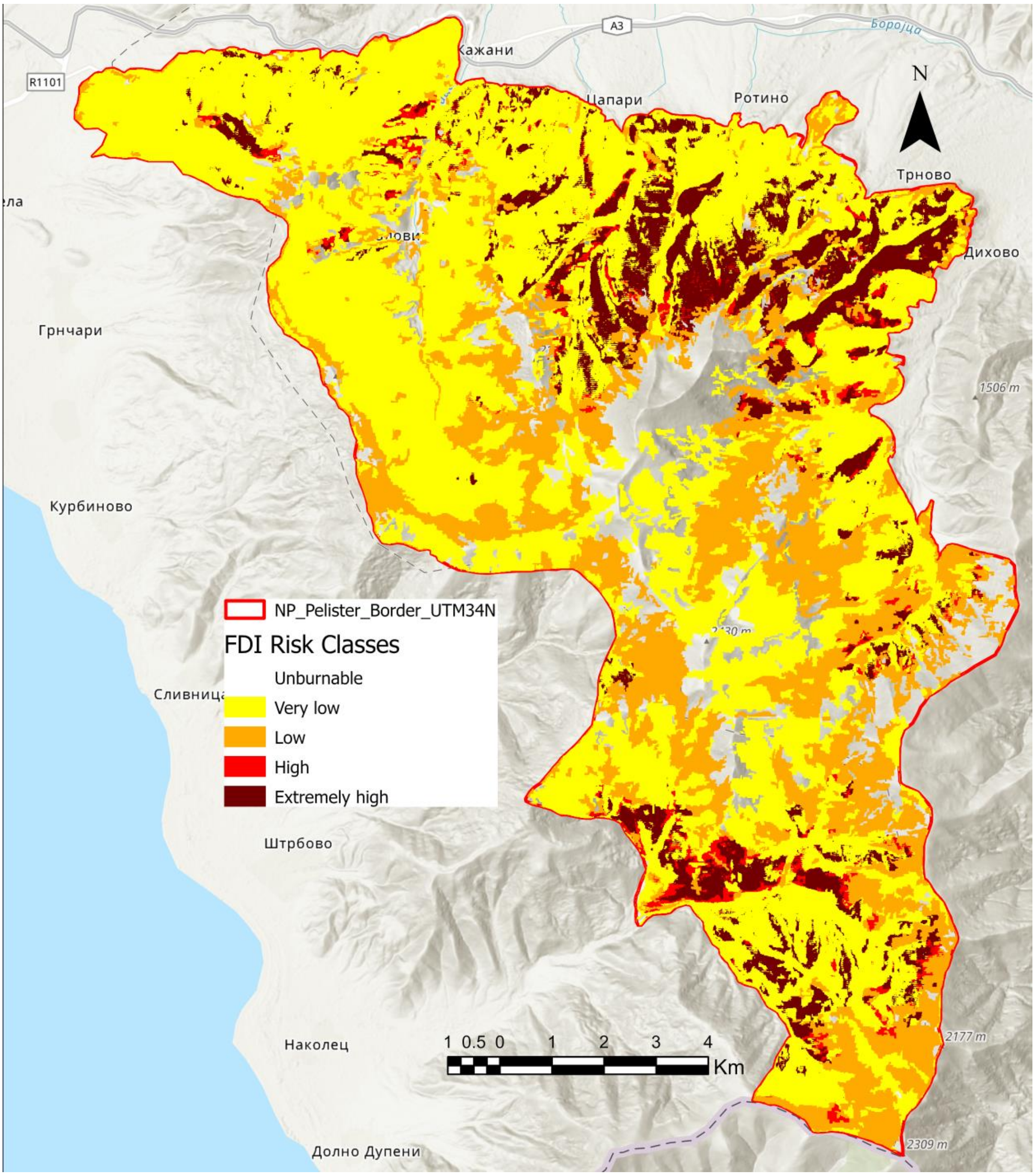

Figure 29. Fire Danger Index classis of risk for Pelister National Park

4 Conclusions and recommendations

Pelister National Park appear to represent a dynamic landscape with significant vegetation transitions occurring during the recent decades, probably as a result of land abandonment, reduction of livestock breeding and climate change. This transition is likely to altitudinally increase the tree line allowing the Balkan pine to advance in higher altitudes and reduce the area currently cover by sub-alpine grasslands (Figure 30). At the same time the same drivers are likely restrict in the future the area covered currently by Balkan pine due to encroachment by the more competitive species *Abies alba* which is already present in various parts of the study area.

Figure 30. Expansion of Balkan pine into higher altitudes and subalpine grasslands

An important consequence of land abandonment and forest recovery is the increase of biomass, which on one hand is a positive service, due to higher concentration of carbon, but on the other hand it increases the amount and continuity of fuel (Morreira et al. 2011). This trend has been observed in several other areas with similar vegetation dynamics and as a result the relative importance of weather patterns and fuel in determining fire regime and behavior has shifted in recent years in favor of the former and fires have turned from “fuel-driven” to “weather-driven” (Dimitrakopoulos et al. 2011; Pausas & Fernandez-Munoz, 2012; Koutsias et al. 2013; Turco et al. 2016). This simply means that when whether conditions are suitable for a wildfire to start and progress then it is likely to turn into an intensive fire because fuel availability is ensured. Furthermore Konoes et al. (2013) reported an increase in the altitudinal range that fires occur in recent years demonstrating the increased risk of forest fires in non-fire prone environments where species are not adapted to frequent fires. Similar observation was made by Xofis & Poirazidis (2018) for another protected area in Norhern Greece which indicates the increased susceptibility of mountainous areas to wildfires.

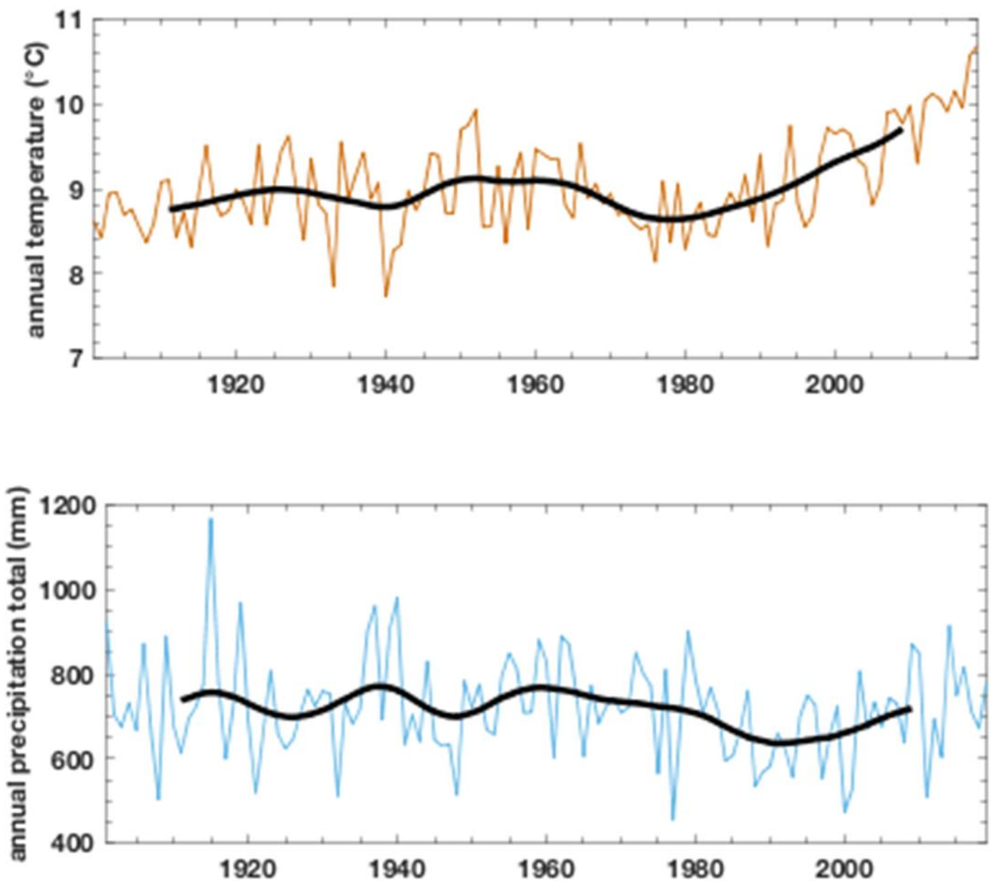

Figure 31. Mean annual temperature and precipitation trend in the study area (Harris et al. 2020)

The climatic trends of the study area are also a reason for concern regarding the fire dynamics. Although the data presented in figures 31 are the result of spatial interpolation of the weather observations made in meteorogical stations within a radius of the study area and they have to be treated with care, it is pretty obvious that there is a trend of increased mean annual temperature in the last 40 years. This observation in combination with the reported above increase in the biomass concentration may lead to the conclusion that wild fires are likely to increase in frequency in Pelister NP which makes the adoption of fire prevention measures increasingly necessary.

The Canopy base height was found to have a significant impact in fire behaviour and the potential risk of a high intensity and stand replacing fire. At the same time this parameter of fire behaviour can be altered with appropriate management measures. Maintaining a closed canopy can be important for ensuring a high canopy base height in pine forest ecosystems, particularly on those where fire management strategies prioritize reducing fire risk. A closed canopy often results in a higher canopy base height because the lower branches and vegetation are shaded and less likely to extend close to the ground. This can help prevent the formation of ladder fuels that can carry fire from the ground into the tree canopy. Maintaining a closed canopy is a common strategy for reducing the risk of catastrophic wildfires, especially in areas where human communities interface with wildland areas. By reducing the potential for crown fires and high-intensity ground fires, a closed canopy can make it safer for both people and property. In some forest ecosystems, maintaining a closed canopy is important for overall ecosystem health. The canopy provides habitat for various species, regulates microclimates, and supports nutrient cycling. Altering the canopy structure too dramatically can have ecological consequences. However, it's important to note that maintaining a closed canopy is not a one-size-fits-all solution. The approach to managing canopy closure and canopy base height may vary depending on factors such as forest type, ecological goals, and local fire management objectives. Balancing the need for a closed canopy with other ecological considerations and fire management strategies is essential to achieve a holistic approach to forest and land management. Collaboration between ecologists, land managers, and fire experts is often necessary to make informed decisions that address fire risk while preserving ecosystem health and resilience.

Another important issue observed in the study is the dynamic of forest in terms of competiotion between the priority species, which is the Balkan (Molika) pine and other species such as *Abies alba* and *Fagus silvatica*. *Abies alba* appears to be encroaching in Molika pine ecosystems in many occasions and so dies to a certain degree the beech. Both these species due to their ability to survive under shadow are much more competitive than any pine species, including Balkan pine. So it appears that in the furure Bakab pine will probably be suppressed and the other two species may increase dramatically their cover. Although Balkan pine appears to be advancing to higher altitudes, its dominance in the area is likely to be reduced. Perhaps fire is the only mechanism that can control competition and allow Balkan pine to maintain its dominance in the study area. Pine species due to their small seed size and easier distribution tend to dominate in these altitudes compared to Abies or Fagus species. Therefore, this dual role of fire, both as a destructive factor and as a molika pine conservation factor needs to be considered in a holistic management plan of the study area.

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