

# Multicriteria Analysis of Fire Risk in the Split-Dalmatia County

Antonija NETOLICKI, Tomislav BLAŽEVIĆ, Andrija ANTOLLOVIĆ

National Protection and Rescue Directorate, Državni centar 112, Nehajska 5, 10000 Zagreb, Croatia  
andrija.antolovic@duzs.hr

**Abstract:** Considering the fact that, in the Split-Dalmatia County, forest fires occur very frequently during the tourist season, causing catastrophic damage to the environment, affecting tourism and other industries, this paper will demonstrate how the use of GIS tools can analyse existing data to assess levels of vulnerability to fire in the county. The data collected that affect the outbreak of open fire include: climate (temperature and relative humidity), topography (aspect, slope of the terrain), vegetation (CORINE Land Cover, NDVI) and anthropogenic factors (e.g. roads, railways and settlements). The article shows how ArcInfo GIS software may be used in order to improve preventive measures and operative procedures. These are necessary due to the large numbers of fires that occur in this area during the summer months.

**Keywords:** Split-Dalmatia County, open fire, reclassification of data, fire cause factors, GIS, multicriteria analysis

## 1. Introduction and Methodological Notes

Fire is the uncontrolled movement of flames over the surface of the ground. It varies in type, origin and degree of damage. For fire to occur, a certain temperature, flammable mass and oxygen are required. If one of these is eliminated, the fire is quenched. Fires are a major global problem; over ten million hectares of forests are lost globally every year (Mladineo, 2001).

In the summer months, the Split-Dalmatia County is highly exposed to the risk of fire. In addition to the damage caused by fire and the cost of dealing with it, is a particular concern when people are directly or indirectly endangered. We need to know the dangerous circumstances which lead to open fire, and what security measures should be taken to reduce the risk as far as possible. In addition to fire prevention measures, the only effective way to reduce the damage caused by fire is to detect potential outbreaks and respond with rapid, appropriate intervention.

The degree of fire hazard depends on how well equipped fire-fighting groups are to respond, the intensity of the flames, the terrain, vegetation, weather

and other conditions. In this paper, we will show that it is possible to analyze future fire risk situations, based on past data.

The aim of this paper is to create an analysis of the fire risk for 2011 based on data from previous fire seasons in the Split-Dalmatia County. GIS has proved to be the most appropriate tool for analyzing process overlap, and the results are presented cartographically. This analysis has been created entirely in ArcInfo. It was carried out according to the following steps:

1. After reviewing the literature and previous research on this topic, the most important factors in the outbreak of fire were selected. The availability of data was taken into account. Analyzed data on temperature and humidity were obtained from the MHI (Meteorological and Hydrological Institute). Data on vegetation were taken from the EPA (Environmental Protection Agency) and downloaded from satellite images from NASA Terra satellite MODIS, data on relief were obtained from the SGA (State Geodetic Administration), while anthropological data were obtained from the NPRD (National Protection and Rescue Directorate), and are based on CRSU (Central

# Višekriterijska analiza rizika od požara u Splitsko-dalmatinskoj županiji

Antonija NETOLICKI, Tomislav BLAŽEVIĆ, Andrija ANTOLLOVIĆ

Državna uprava za zaštitu i spašavanje, Državni centar 112, Nehajska 5, 10000 Zagreb  
andrija.antolovic@duzs.hr

**Sažetak:** Polazeći od činjenice da na području Splitsko-dalmatinske županije u vrijeme turističke sezone izbijaju česti požari sa znatnim posljedicama za okoliš i štetama turizmu i drugim djelatnostima, u ovom radu bit će pokazano kako se uz pomoć GIS alata može napraviti analiza postojećih podataka u svrhu procjene ugroženosti od požara u toj županiji. Tijekom rada prikupljeni su podaci koji utječu na nastajanje požara otvorenog tipa: klimatski (temperatura i relativna vlažnost zraka), topografski (ekspozicija, nagib padine), vegetacijski (CORINE Land Cover, NDVI) i antropogeni (ceste, željeznička pruga, naselja) čimbenici. U radu je pokazan način korištenja ArcInfo GIS softvera u svrhu poboljšanja preventivnih mjera i operativnih postupaka. One su nužne s obzirom na veliku količinu požara koji pogode ove prostore za vrijeme ljetnih mjeseci.

**Glavne riječi:** Splitsko-dalmatinska županija, požari otvorenog tipa, reklasifikacija podataka, čimbenici uzroka požara, GIS, višekriterijska analiza

## 1. Uvod i metodološke napomene

Požar je nekontrolirano, stihijsko kretanje vatre po površini. Razlikuje se po vrsti, načinu postanka i šteta. Za nastanak požara potrebna je određena temperatura, goriva masa i kisik; ako se jedno od toga ukloni, požar prestaje. Požari su veliki svjetski problem, jer se u njima godišnje u svijetu izgubi više od deset milijuna hektara šuma (Mladineo, 2001).

Područje Splitsko-dalmatinske županije u ljetnim mjesecima izrazito je izloženo velikim opasnostima od izbijanja požara. Osim šteta i troškova posebno je zabrinjavajuće što stradavaju ljudi bilo oni izravno angažirani u gašenje požara ili oni koji su stjecajem okolnosti bili ugroženi. U svakom pogledu treba imati znanja o opasnim okolnostima u požaru otvorenog tipa, odnosno koje mjere sigurnosti treba poduzeti kako bi se opasnost svela na što manju mjeru. Osim preventivnih protupožarnih mjera, jedini efikasan način smanjenja štete koju uzrokuju požari otvorenog prostora je pravovremeno uočavanje požara u nastajanju, te brza i odgovarajuća intervencija.

Stupanj ili razina opasnosti prilikom požara ovisi o snazi vatrogasne grupe, intenzitetu gorenja, reljefnom izgledu terena, sastavu raslinja, meteorološkim i drugim uvjetima. Zato će se u ovom radu pokazati kako se može na temelju dosadašnjih podataka napraviti analiza rizika od požara za buduće situacije.

Svrha je ovog rada da se uz pomoć dosadašnjih podataka o prostoru Splitsko-dalmatinske županije napravi analiza rizika od požara. GIS se pokazao kao najprimjereniji alat za analizu postupcima preklapanja, te su rezultati prikazani kartografski. Analiza je u potpunosti napravljena u ArcInfo. Analiza je provedena u sljedećim koracima:

1. Nakon uvida u literaturu i dosadašnja istraživanja na tu temu, određeni su čimbenici koji su najvažniji pri izbijanju požara. Trebalo je voditi računa i o dostupnosti podataka. Analizirani su podaci o temperaturi i vlažnosti zraka dobiveni od DHMZ-a (Državni hidrometeorološki zavod), podaci o vegetaciji dobiveni od AZO-a (Agencija za zaštitu okoliša) i preuzeti sa satelitskih snimaka NASA-inog satelita Modis Terra, podaci o reljefu dobiveni su od DGU-a (Državna

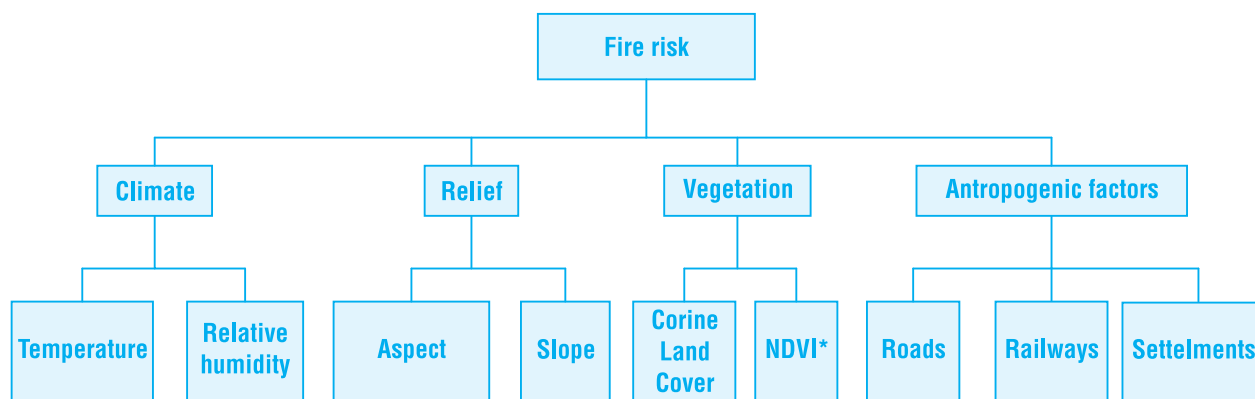


Fig. 1. Most important factors in the outbreak of fire (\*Normalized Difference Vegetation Index)

Register of Spatial Units) and CBS (Central Bureau of Statistics) data.

- Using the DC-log (National Centre) web application, we analyzed data from the fire season between June 1 and October 1 2010. The data were georeferenced. Fire threat categories were created (in which 1 corresponded to a very low risk and 5 a very high risk of fire).
- Finally, these data were synthesised to create a final map of the risk of fire in the Split-Dalmatia County. The importance of each factor in the outbreak of fire was weighted. How the procedure for processing each of the elements included in the analysis differed will be explained in detail later.

## 2. The Area Studied

In geographical terms, the Split-Dalmatia County includes a group of large islands (Brač, Hvar, Vis, and Šolta) and some smaller ones, the coastal flysch zone and the hinterland.

*Coastal flysch zone* is the most appropriate area for agricultural activities is the coastal flysch zone, therefore the earliest villages developed here, rather than by the sea, in elevated situations, where the flysch meets the limestone slopes of the coastal mountains. Since most of the population is focussed in the coastal area, and in the summer months a large number of tourists arrive, there is an increased risk of fire.

*Sub-Mediterranean Hinterland* is a predominantly mountainous and sparse Karst area, where small-scale animal husbandry is common. The main agricultural activities take place in well cultivated inhabited areas – viticulture, growing maize, vegetables and tobacco. The greatest risk to this region in terms of the outbreak of

fire is represented by abandoned agricultural land which is no longer worked.

*Central Dalmatian Islands* includes a group of large islands (Brač, Hvar, Vis and Šolta) and some smaller ones. The islands of Central Dalmatia are more densely populated than the Kvarner islands. Agricultural production and small-scale animal husbandry are predominant. There is a greater risk of fire during the summer months, due to the large number of tourists visiting the islands.

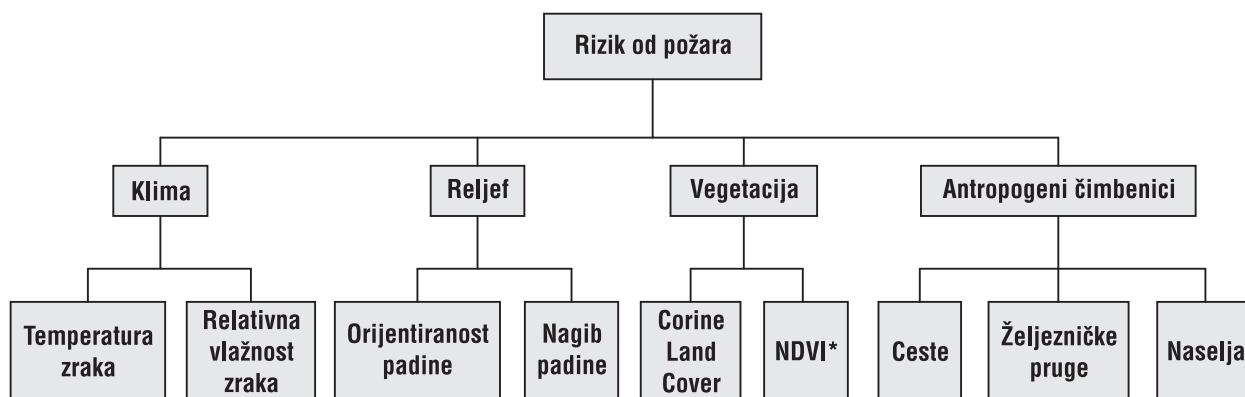
## 3. Important Factors in the Outbreak of Fire

When analyzing the risk of fire, 9 factors were selected as being the most important in the outbreak of fire (Fig. 1).

### 3.1. Climate factors

The most important climate indicators to take into consideration are temperature and relative humidity. Dry and wet periods of the year are of special importance for fire prevention and the recovery of burned areas. The Split-Dalmatia County climate is moderately warm and humid with hot summers (Cfa), while the coastal area and islands have a Mediterranean climate with hot, dry summers (Csa). Hot summers are the result of the intense daily warming of the low relief, which is mostly bare, while the soil is mostly porous and dry (Šegota, 1996).

In order to create a fire threat map, temperature and relative humidity data from the MHI (Meteorological and Hydrological Institute) was collected from measuring stations in Šibenik, Split and Makarska and on Hvar and Vis and processed, With the help of *Analysis tool*



**Slika 1.** Najvažniji čimbenici pri izbijanju požara (\*normirani indeks razlike u vegetaciji - Normalized Difference Vegetation Index)

geodetska uprava), dok su antropološki podaci dobiveni od DUZS-a (Državna uprava za zaštitu i spašavanje), a bazirani su na SRPJ-u (Središnji registar prostornih jedinica) i podacima DZS-a (Državni zavod za statistiku).

2. Korištenjem web aplikacije dnevnik DC-a (Državnog centra) obrađeni su podaci iz požarne sezone od 1. lipnja do 1. listopada 2010. Podaci su georeferencirani. Napravljene su kategorije ugroženosti od izbijanja požara (tako da je 1- vrlo niska opasnost, 5- vrlo visoka opasnost od izbijanja požara).
3. Na samom kraju, ti podaci su preklapljeni radi izrade konačne karte rizika od požara na području Splitsko-dalmatinske županije. Važnost svakog čimbenika pri izbijanju požara je ponderirana. Kako je postupak obrade podataka drugačiji za svaki od elemenata uključenih u analizu, oni će se posebno objasniti dalje u tekstu.

## 2. Istraživano područje

Splitsko-dalmatinska županija prirodno-geografski obuhvaća skupinu velikih (Brač, Hvar, Vis, Šolta) i manjih otoka, obalnu flišnu zonu i Zagoru.

Za poljoprivredno iskorištavanje najpogodnija je *obalna flišna zona* pa su se najstarija seoska naselja razvila u toj zoni, ne uz more, nego na višem položaju, na kontaktu fliša i vapnenačkih padina primorskih planina. Kako je u obalnoj zoni težište naseljenosti, te u ljetnim mjesecima dolazi velik broj turista, povećava se rizik od požara.

*Submediteranska zagora* je pretežno brdovit i siromašan krški kraj s tradicionalnim sitnim stočarstvom; glavne su ratarske djelatnosti u dobro obrađenim i naseljenim poljima – vinogradarstvo, uzgoj kukuruza i

povrća te duhana. Najveću opasnost u toj regiji od izbijanja požara predstavljaju napuštena poljoprivredna zemljišta koja se više ne obrađuju.

*Srednjodalmatinski otoci* obuhvaćaju skupinu velikih (Brač, Hvar, Vis, Šolta) i manjih otoka. Otoci srednje Dalmacije gušće su naseljeni od kvarnerskih otoka. Na srednjodalmatinskim otocima prevladava poljoprivredna proizvodnja te sitno stočarstvo. Ljetni mjeseci su najugroženiji zbog velikog broja turista koji dolaze na otoke.

## 3. Najvažniji čimbenici pri izbijanju požara

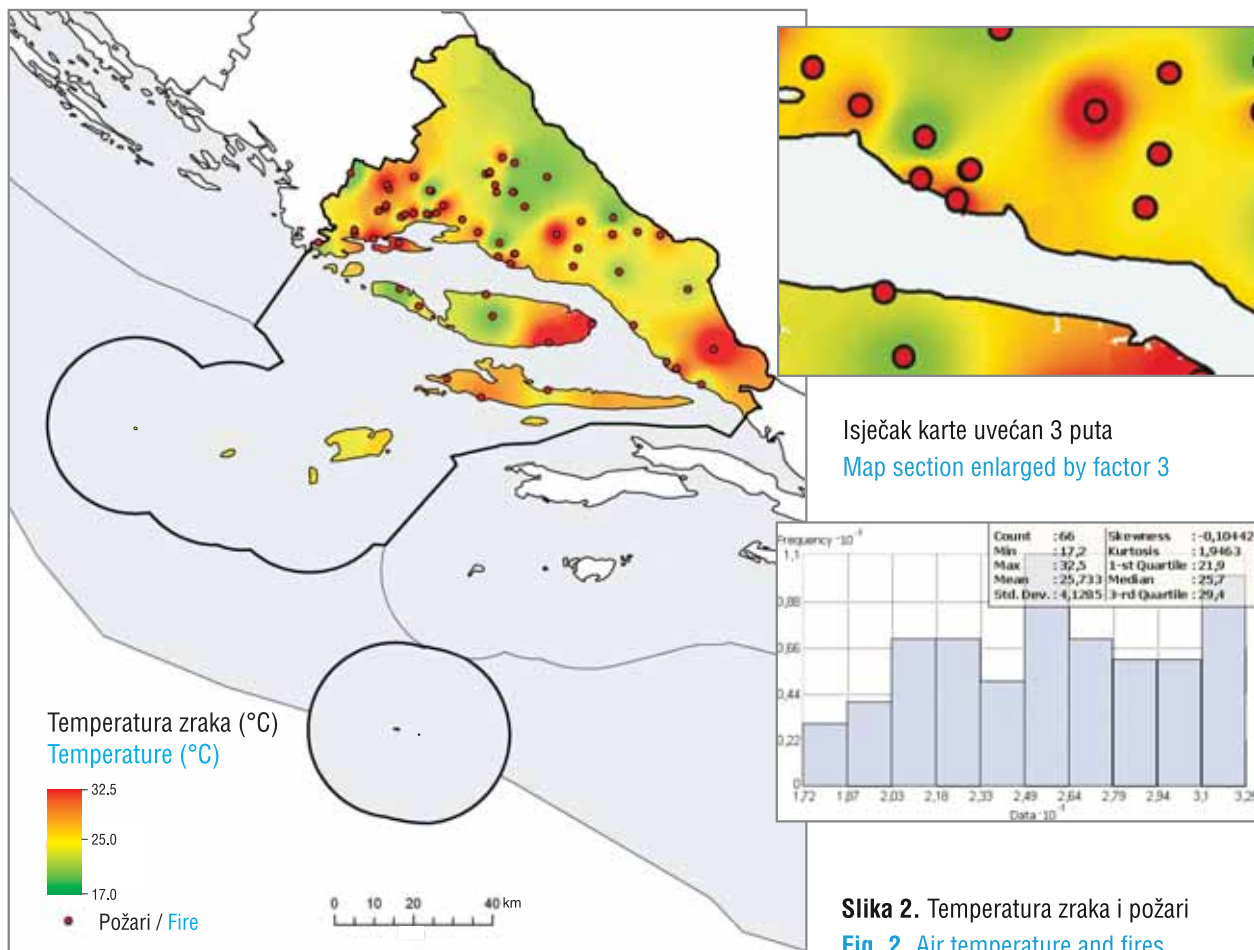
Pri analizi rizika od požara odabrano je 9 čimbenika koji su najvažniji pri izbijanju požara otvorenog tipa (slika 1).

### 3.1. Klimatski čimbenici

Najvažniji klimatski pokazatelji koji se uzimaju u razmatranje su temperatura i relativna vlažnost zraka. Sušna i vlažna razdoblja u godini posebno su važna za vatrogasnu preventivu i sanaciju izgorjele površine.

Klima Splitsko-dalmatinske županije umjereno je topla i vlažna s vrućim ljetom (Cfa), dok priobalni dio i otoci imaju sredozemnu klimu sa suhim vrućim ljetom (Csa). Vruća ljeta uvjetovana su jakim dnevnim zagrijavanjem reljefno niskoga kraja, koji je uz to još i ogolio, a tlo je najčešće propusno i suho (Šegota, 1996).

Za izradu karte ugroženosti obrađeni su podaci od DHMZ-a za temperaturu i relativnu vlažnost zraka s mjernih postaja Šibenik, Split, Makarska, Hvar, Komiža. Uz pomoć *Analysis toola (proximity; point distance)* izračunata je udaljenost svakog požara do najbliže mjerne postaje. S obzirom na to da se zna točno vrijeme izbijanja

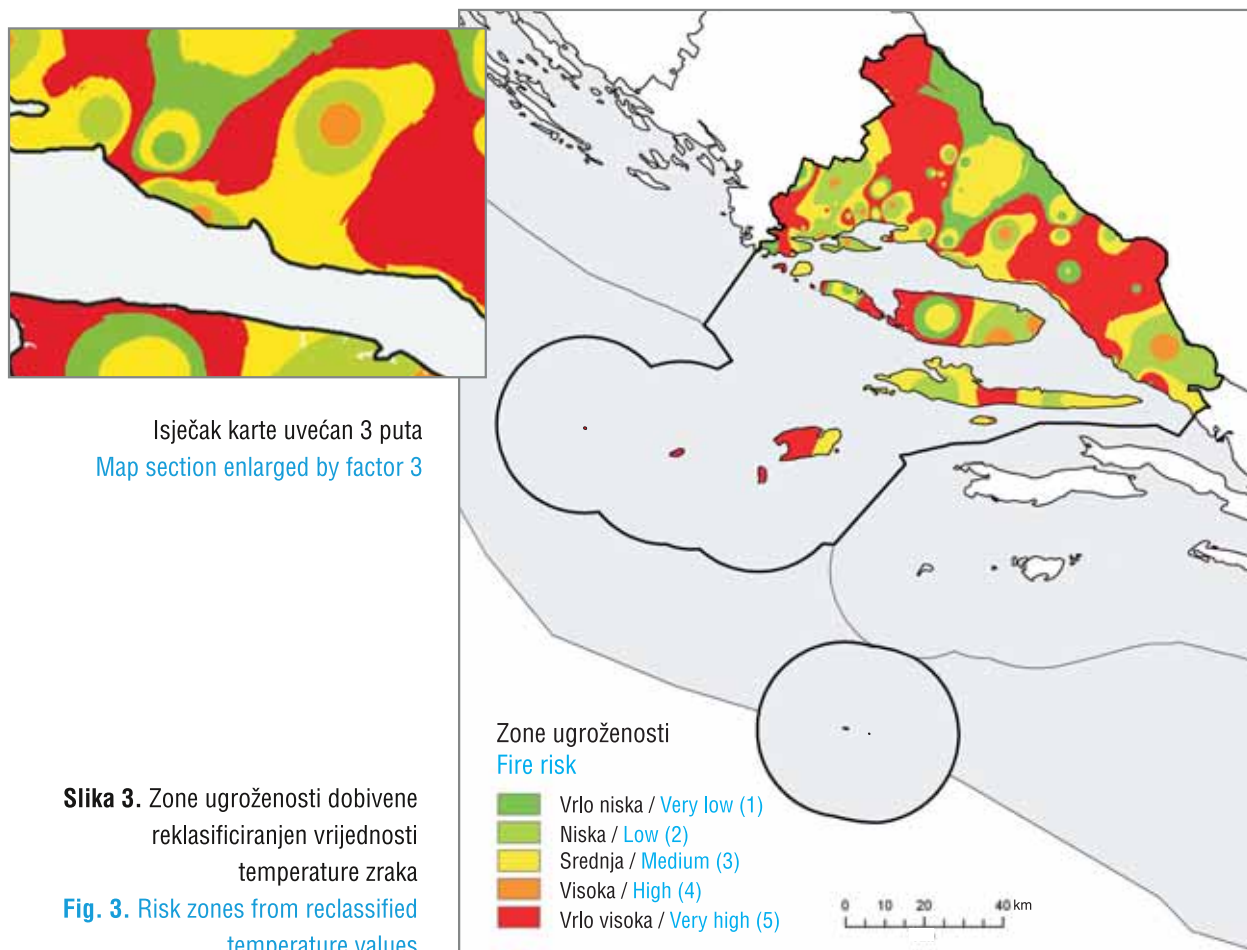


(proximity; point distance) the distance of each fire from the nearest measurement station was calculated. Thus, since we knew the time of each fire, we could assign it a temperature and relative humidity value (for the exact time and the nearest measurement station). This was done because there were not enough monitoring stations for a more precise analysis. In this way, we obtained the exact values for each fire location, and transferred them from a *point feature* to a *polygon feature* using the Kriging method (using existing data to approximate an unknown value at a particular location).

### 3.1.1. Air Temperature

Air temperature is one of the most important climate elements. Air temperature is the degree to which air is heated. Air temperature is lowest just after sunrise, and highest just after its zenith. In Croatia, this is between 13.00 and 14.00. In the Split-Dalmatia County, high summer temperatures are predominant. High temperatures dry out the soil and vegetation, so that the area is more at risk.

Using the Kriging method, we produced a map of the average temperatures for the Split-Dalmatia County. The data were transferred to a raster in order to continue the analysis (Fig. 2.). How each fire was georeferenced is shown in the histogram (Fig. 2), which shows the temperatures at which most fires break out. This information was important because it allowed us to identify risk zones for each element. Even fires were recorded at a temperature of 25°C, and 10 fires at a temperature of 32°C. We noted that fires were recorded at several different temperatures, indicating that fires occur independently of temperature; nonetheless their number is dependent on temperature increases. Once temperatures had been divided into classes, the reclassification of data and addition of new values was possible (histogram – Fig. 2). These values were reclassified using 3D Analyst tools (raster reclass; reclassify) so that the class in which the most fires were recorded was given the highest value (5), and the class in which the least fires were recorded the lowest value (1) (Fig. 3).



požara, mogli smo svakom požaru pridodati vrijednost temperature i relativne vlažnosti zraka za točno to vrijeme i za najbližu mjernu postaju. To je napravljeno zbog toga jer je premalo mjernih postaja za bilo kakvu kvalitetniju analizu. Na taj način dobili smo egzaktnu vrijednost za svaku lokaciju požara, a te vrijednosti prebačene su iz *point feature* u *polygon feature* metodom krigiranja (koja uz pomoć postojećih podataka aproksimira nepoznate vrijednosti na nekoj lokaciji).

### 3.1.1. Temperatura zraka

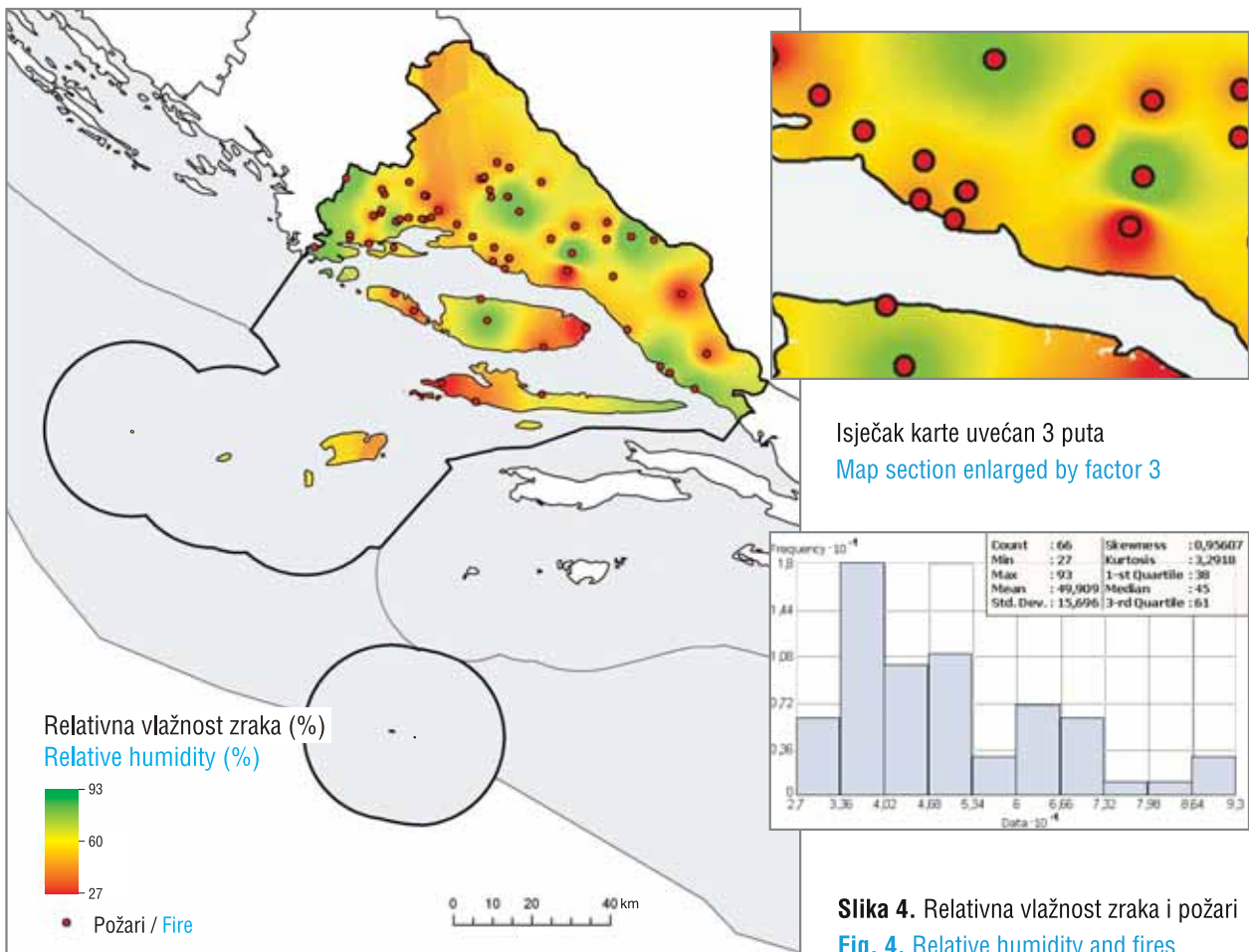
Temperatura zraka jedan je od najvažnijih klimatskih elemenata. Može se reći da je temperatura zraka stupanj njegove zagrijanosti. Temperatura je najniža nešto nakon izlaza sunca, a najviša nešto nakon njegova najvišeg položaja. Kod nas je to između 13 i 14 sati. Na području Splitsko-dalmatinske županije prevladavaju visoke ljetne temperature, koje isušuju tlo i vegetaciju tako da je prostor više izložen riziku.

Metodom krigiranja dobili smo kartu prosječne temperature za Splitsko-dalmatinsku županiju. Te smo podatke prebacili u raster da bismo dalje mogli

raditi analizu (slika 2). Kako je svaki požar georeferenciran, iz histograma (slika 2) se može vidjeti pri kojim temperaturama zraka je izbilo najviše požara. Taj podatak nam je bitan zato što će se na temelju toga napraviti zone ugroženosti za svaki od elemenata. Čak 11 požara je zabilježeno pri temperaturi od 25°C, te 10 požara pri temperaturi od 32°C. Vidimo da su požari zabilježeni pri svakoj temperaturi, što znači da se javljaju neovisno o temperaturi, ali da njihov broj ipak ovisi o porastu temperature. Nakon što je napravljena podjela temperature u razrede, može se obaviti reklasifikacija podataka i pridodavanje novih vrijednosti (histogram – slika 2). Te vrijednosti reklasificirane su s alatima 3D Analysta (*raster reclass; reclassify*) tako da onaj razred u kojem je zabilježeno najviše požara ima vrijednost 5, a onaj razred u kojem je najmanje požara ima vrijednost 1 (slika 3).

### 3.1.2. Relativna vlažnost zraka

Relativna vlažnost zraka je broj koji u postocima pokazuje odnos između količine vodene pare koja stvarno postoji u zraku (u određenom trenutku) i



**Slika 4.** Relativna vlažnost zraka i požari  
**Fig. 4.** Relative humidity and fires

### 3.1.2. Relative humidity

Relative humidity is a number expressed as a percentage that indicates the relationship between the amount of water vapour actually present in the air (at a given time) and the maximum amount of water vapour that the air at that temperature could absorb before becoming saturated. If the relative humidity is near 0%, the air is dry, and if it is close to 100%, the air is humid. Relative humidity is greater in winter than in summer, and greater on islands than on the coast.

Relative humidity is an important factor in affecting the occurrence and spread of fire, and it manifests itself in the form of air humidity, ground moistness and the moistness of combustible materials. If combustible materials are dry, they will burn faster and reach a temperature of 200°C swiftly. If air humidity is low, the dry air absorbs more easily water vapours from combustible material and the ground where the fire is burning.

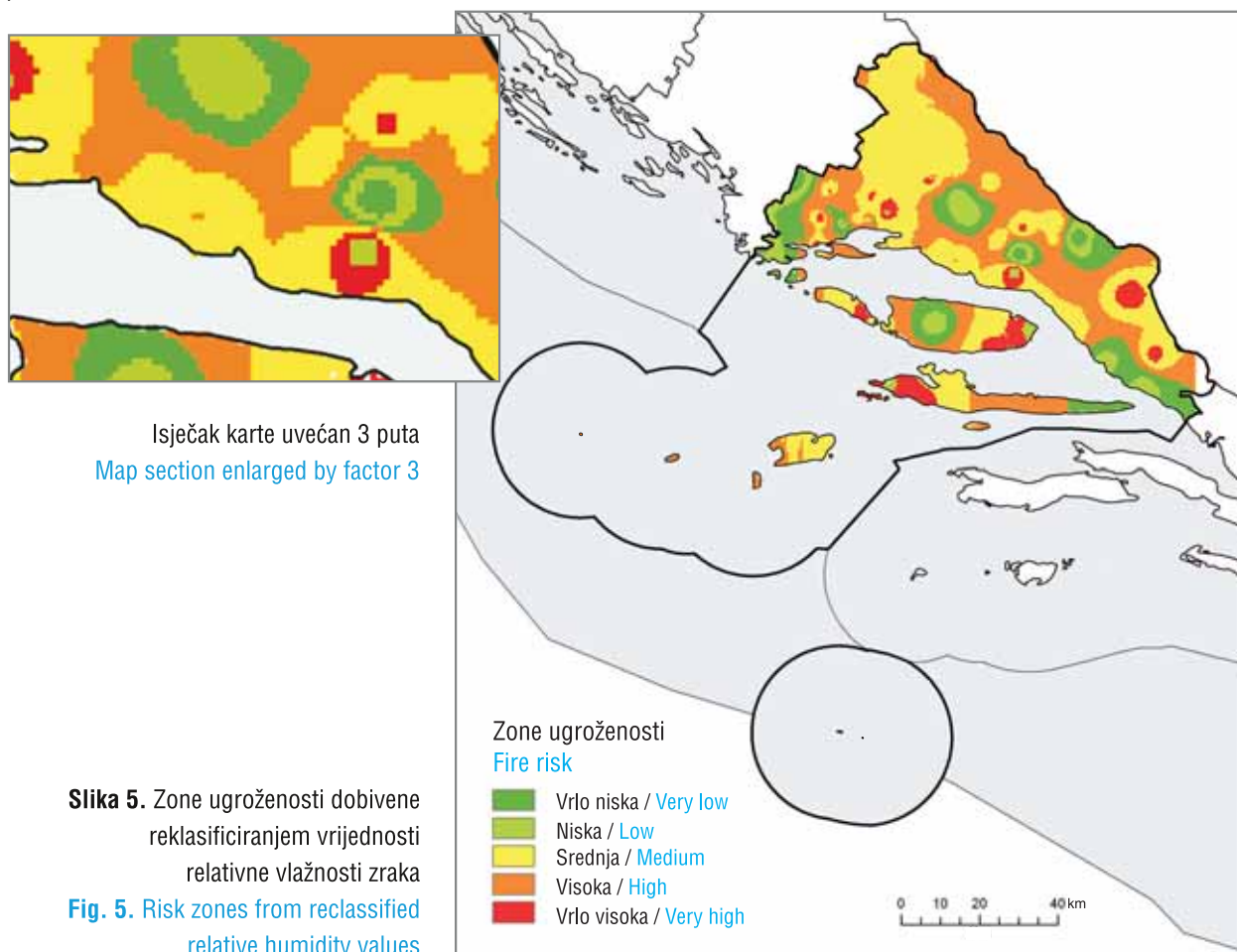
The process of making maps is the same as for air temperatures. The histogram shows that when the relative humidity is low, there are more reported fires (Fig. 4). These data were also reclassified (Fig. 5).

### 3.2. Relief as a risk factor

Analysis of the relief was based on a digital height model (x, y, z). Given the large number of points, the classic production of TIN (Triangulated Irregular Network) models was not possible. Instead, a model was built using 3D Analyst tools; Terrain (create terrain, add the feature class to terrain, build terrain). Subsequently, these data were transferred to raster (3D Analyst tool; conversion; from terrain, terrain to raster). From that format, we created aspect and slope in 3D Analyst.

#### 3.2.1. Aspect

Aspect has a significant influence on the occurrence of fire because microclimate and vegetation elements are determined by the points of the compass. North-facing slopes are much less exposed to sunlight. South- and southwest-facing slopes are exposed to sunlight for longer periods, and xerophyte plants thrive on such slopes. It is known that dry habitats and the plant structure in such environments favours the occurrence of fire, and it should be emphasised out that the sun's heat



**Slika 5.** Zone ugroženosti dobivene reklasificiranjem vrijednosti relativne vlažnosti zraka  
**Fig. 5.** Risk zones from reclassified relative humidity values

maksimalne količine vodene pare koju bi zrak na toj temperaturi mogao primiti da bi bio zasićen. Što je relativna vlažnost zraka bliže 0% to znači da je zrak suši, a ako je bliže 100% znači da je zrak vlažniji. Relativna vlažnost zraka veća je zimi nego ljeti, veća je na otocima nego na obali.

Relativna vlažnost zraka je bitan čimbenik koji odlučuje o mogućnosti nastanka i širenja požara, a javlja se u obliku zračne vlage, vlažnosti staništa i vlažnosti gorivog materijala. Ako je gorivi materijal suh, gori brže i brže se postiže temperatura od 200°C. Ako je zračna vlažnost manja, suhi zrak lakše upija oslobađajuću vodenu paru iz gorivog materijala i iz tla na kojemu traje proces gorenja.

Proces izrade karte isti je kao i kod temperature zraka. Iz histograma je vidljivo da što je relativna vlažnost zraka manja, više je zabilježenih požara (slika 4). Ti podaci su također reklasificirani (slika 5).

### 3.2. Reljef kao čimbenik ugroženosti

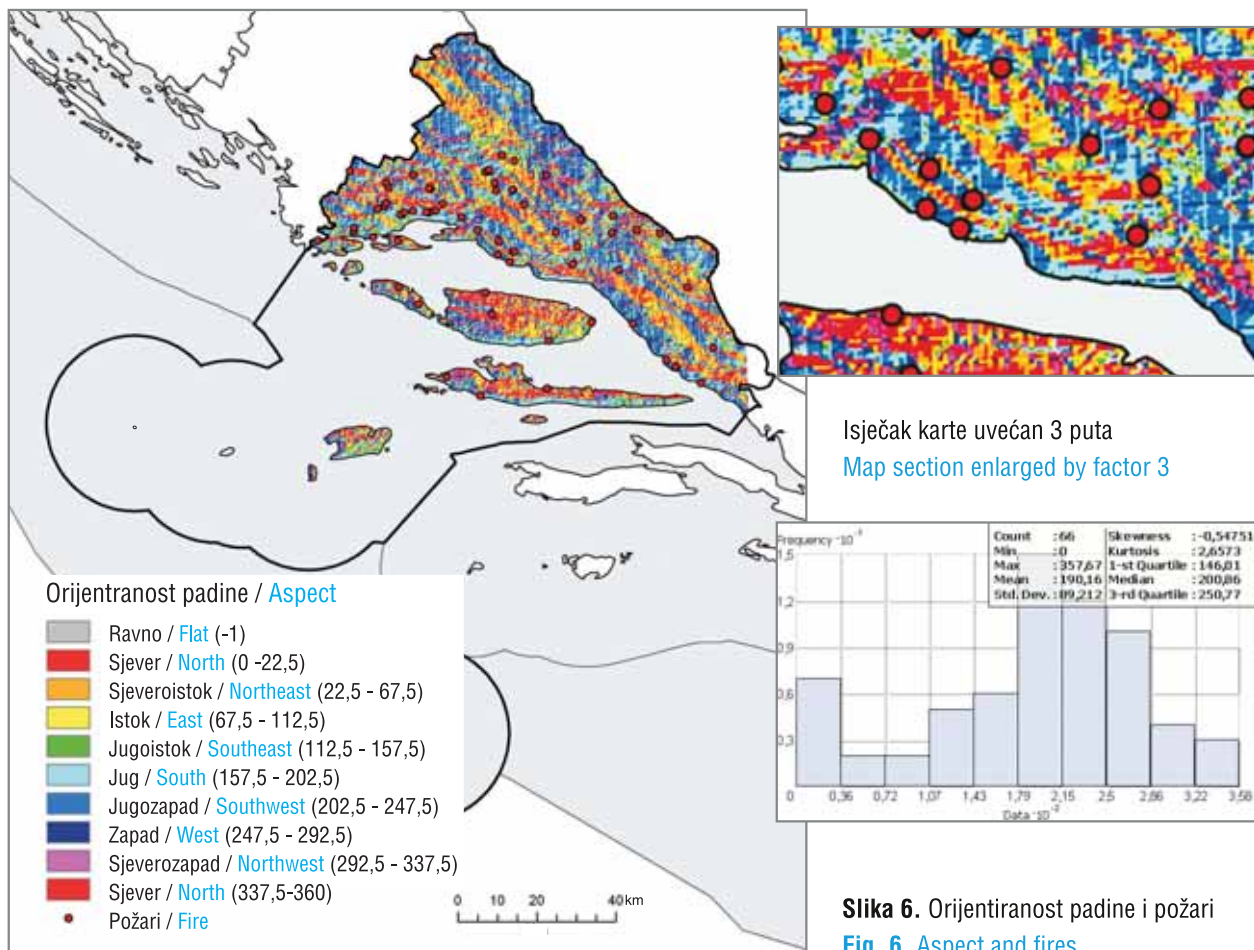
Analiza reljefa bazirana je na digitalnome modelu visina ( $x, y, z$ ). S obzirom na veliki broj točaka, klasična

izrada TIN (nepravilna mreža trokuta) modela nije bila moguća. Umjesto toga napravljen je model s alatom 3D Analysta Terrain (*create terrain; add feature class to terrain; build terrain*). Nakon toga, ti podaci su prebačeni u raster (3D Analyst tool; conversion; from terrain; terrain to raster). Iz tog formata dalje se izrađuju u 3D Analystu orijentiranost i nagib padine.

#### 3.2.1. Orijentiranost padine

Orijentiranost padine znatno utječe na pojavu požara jer su mikroklimatski i vegetacijski elementi određeni stranama svijeta. Sjeverne padine puno su manje izložene sunčevu zračenju. Južne i jugozapadne padine duže su vremena izložene sunčevu zračenju, pa se na tim ekspozicijama razvijaju kserofitne biljke. Poznato je da suha staništa i biljna struktura na takvim tlama pogoduje pojavi požara, a uz to treba naglasiti da sunčeva toplina tijekom dana utječe na pojavu vjetrova koji puše iz doline prema vrhu. Kao što je vidljivo iz slike 6, najviše požara zabilježeno je na jugoistočnim, južnim i jugozapadnim padinama zato što su te padine pod jačim utjecajem sunčeva





during the day causes winds to arise, blowing from the lower towards the higher ground. As shown in Fig. 6, most fires were recorded on southeastern, southern and western slopes. These slopes are under the strong influence of solar radiation, as well as having different vegetation, and the direction they face makes them dryer than others. With reclassification, we obtained fire risk zones (Fig. 7).

### 3.2.2. Slope

Hills with steep slopes facilitate the faster spread of fire. On steeper ground, fire rapidly progresses up a slope, because warm air rises, drying combustible material as it goes. It is rare for fire to spread down a slope (in such cases, it must be fuelled by a strong, downward wind). A fire that breaks out at the foot of a slope, when there is no wind, causes currents of warm and cold air and the fire spreads by advancing up the slope. Although slope plays a more important part in the actual spread of fire, rather than its outbreak, according to the histogram results it is still included in the analysis because of the interesting data (Fig. 8) recorded. We can

see from the results obtained in the histogram that a number of fires occur in areas of less inclination, and as the angle of inclination increases, the number of fires rapidly decreases. An estimated 40% of fires were recorded on slopes between 0–4°. This can be linked to the fact that a large number of fires broke out on agricultural land, i.e. on flat surfaces. They were probably the result of burning weeds in the afternoon.

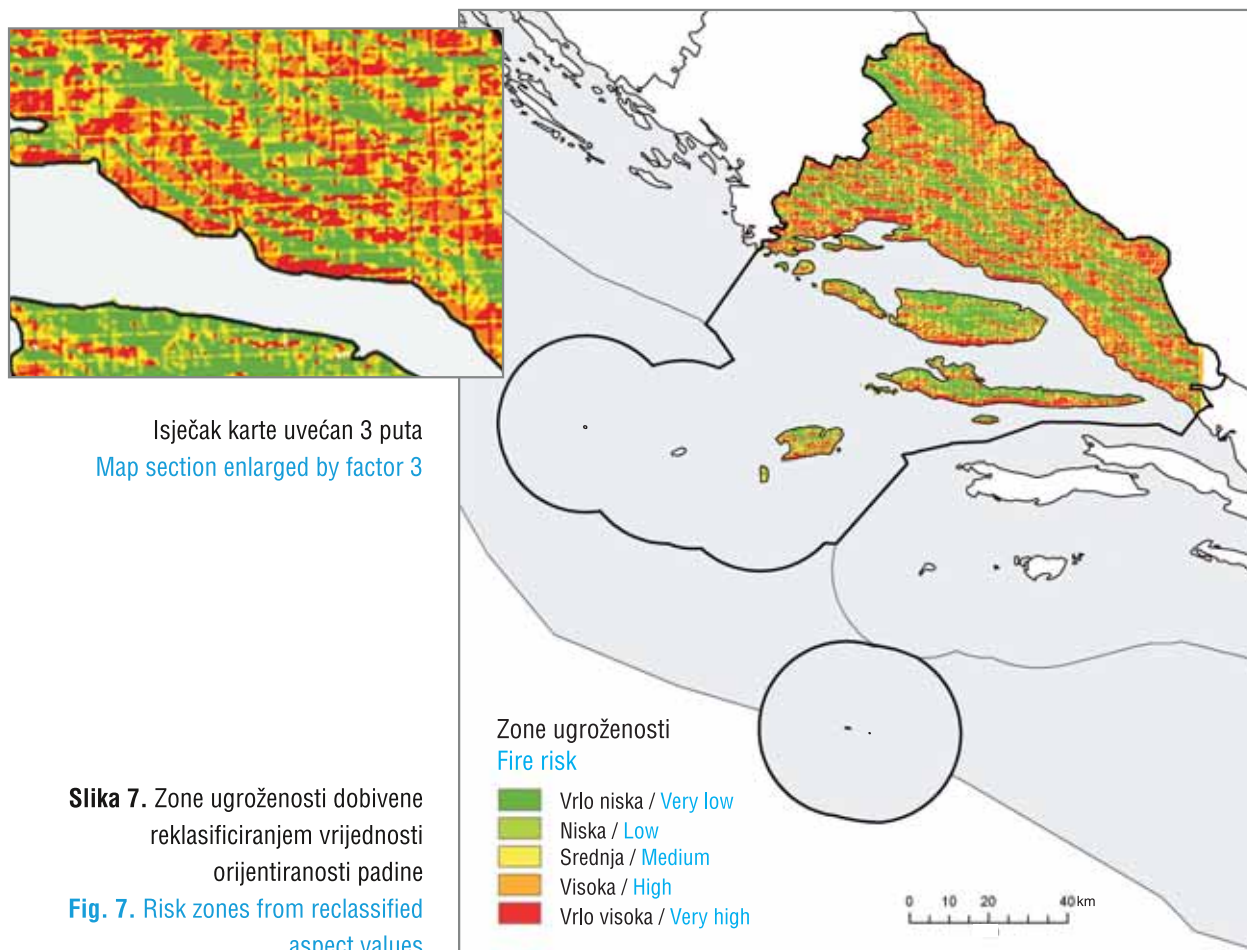
With reclassification we obtained risk zones (Fig. 9).

### 3.3. Vegetation

The most important vegetative parameters used were the CORINE (Coordination of Information on the Environment) Land Cover and Normalized Difference Vegetation Index (hereinafter: NDVI).

#### 3.3.1. CORINE Land Cover (CLC)

CORINE is a programme for the coordination of information about the environment and natural resources, launched by the European Community. CLC is the identification and meaningful categorization of land



zračenja. Uz razliku u vegetaciji, također je bitno da je ta strana padine suša od ostalih jer je duži dio dana osunčana. Reklasifikacijom smo dobili zone ugroženosti od požara (slika 7).

### 3.2.2. Nagib padine

Strmi nagib padine pogoduje bržem širenju požara. Na nagnutom terenu vatra brže napreduje uz padinu, jer se topli zrak penje i pred sobom isušuje gorivi materijal. Rijetka je pojava da se požar širi niz padinu (tada je požar potpomognut jakim vjetrom koji puše niz padinu). Požar koji izbije u podnožju padine i u vrijeme bez vjetra, gorenjem izaziva strujanje toplog i hladnog zraka pa širenje požara napreduje uz padinu.

Iako je nagib važniji pri samom širenju požara, prema rezultatima histograma ipak je uključen u analizu radi zanimljivih podataka (slika 8). Iz dobivenih rezultata u histogramu vidimo da se broj požara javlja na prostorima manjeg nagiba, te da se povećanjem tog nagiba broj požara brzo smanjuje. Čak 40% požara zabilježeno je na nagibu između  $0^\circ$  i  $4^\circ$ . To možemo

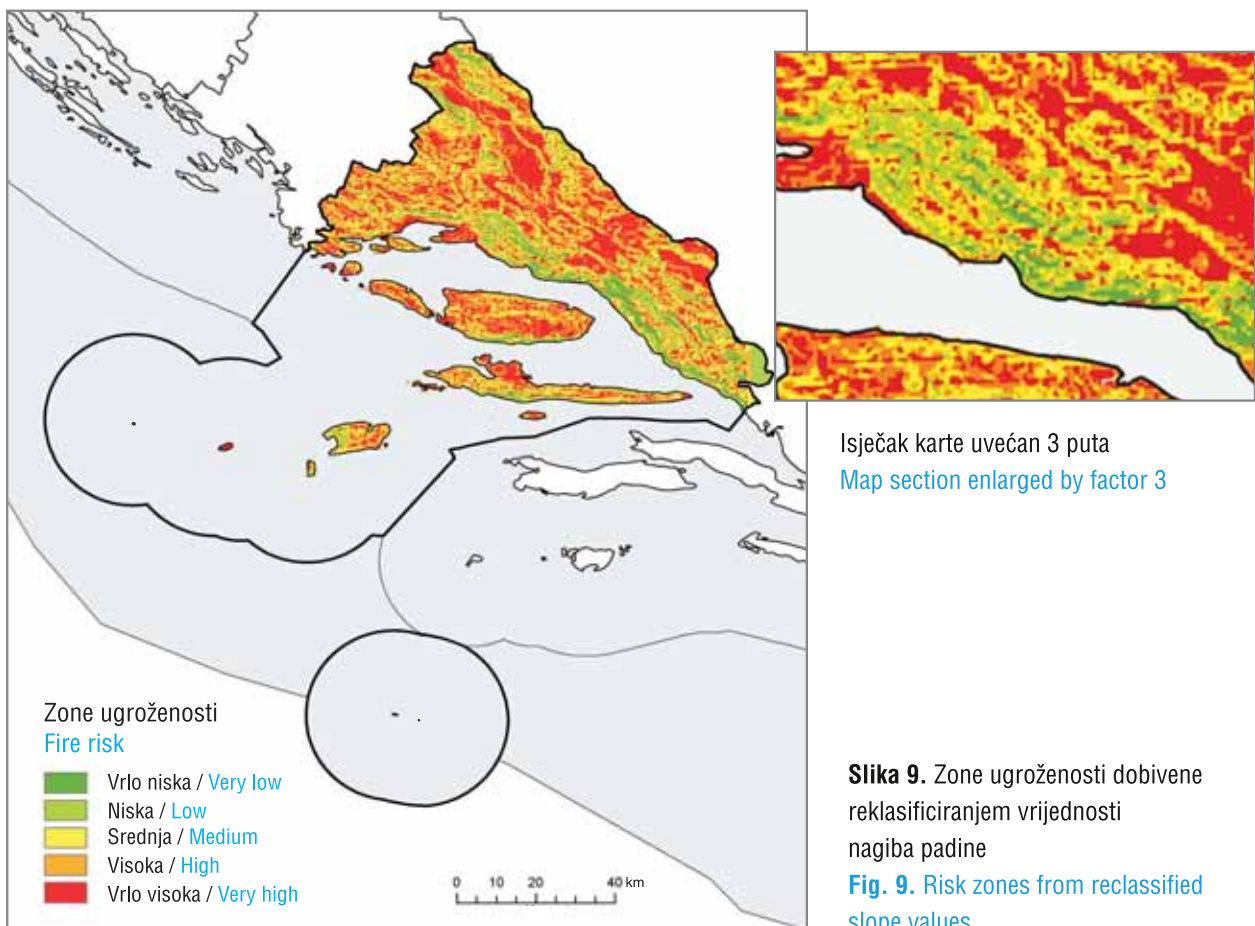
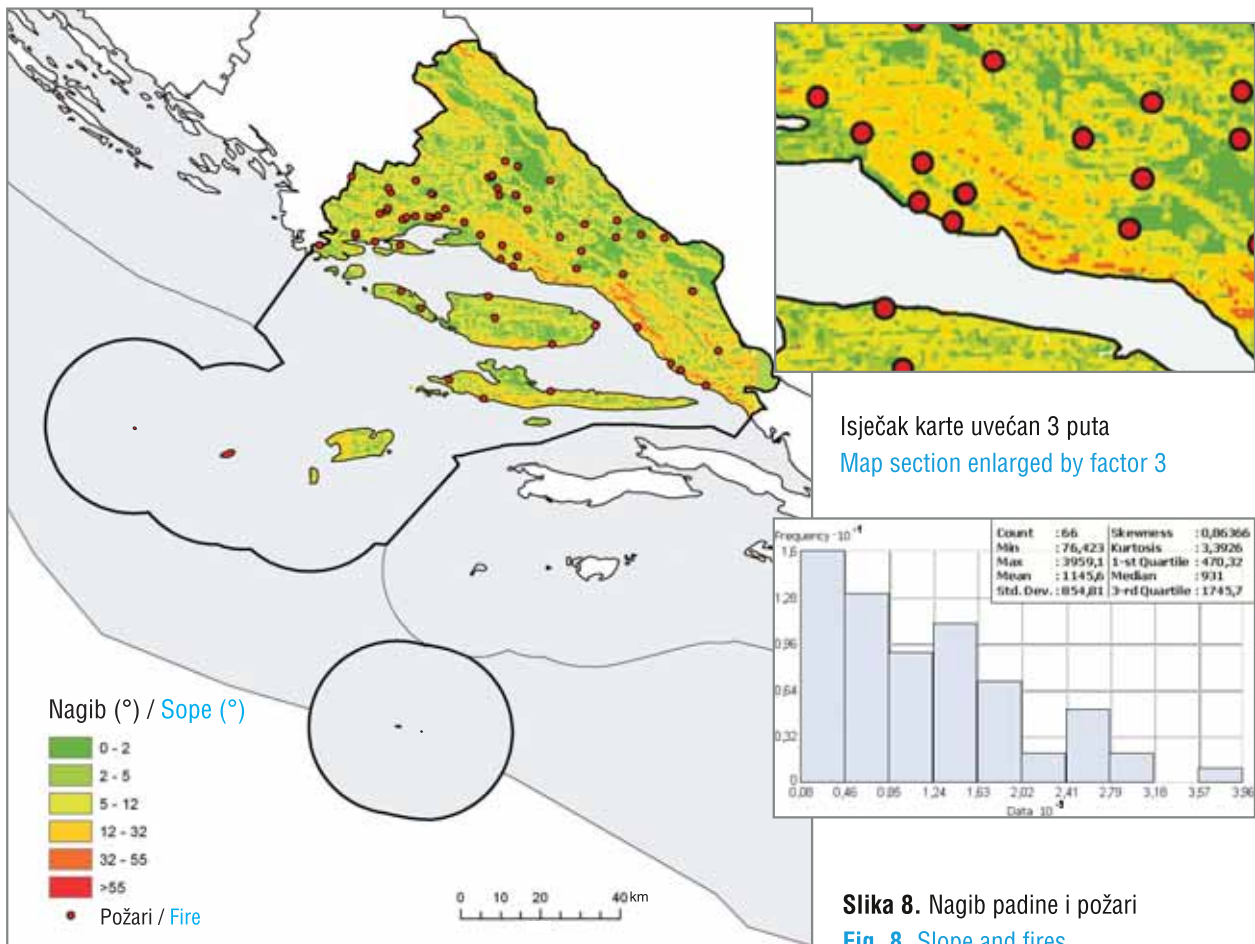
povezati s time da je veliki broj požara izbio na poljoprivrednim zemljištima koja su na zaravnjenim površinama, vjerojatno kao posljedica potpaljivanja koroza u poslijepodnevnim satima. Reklasifikacijom su dobivene zone ugroženosti (slika 9).

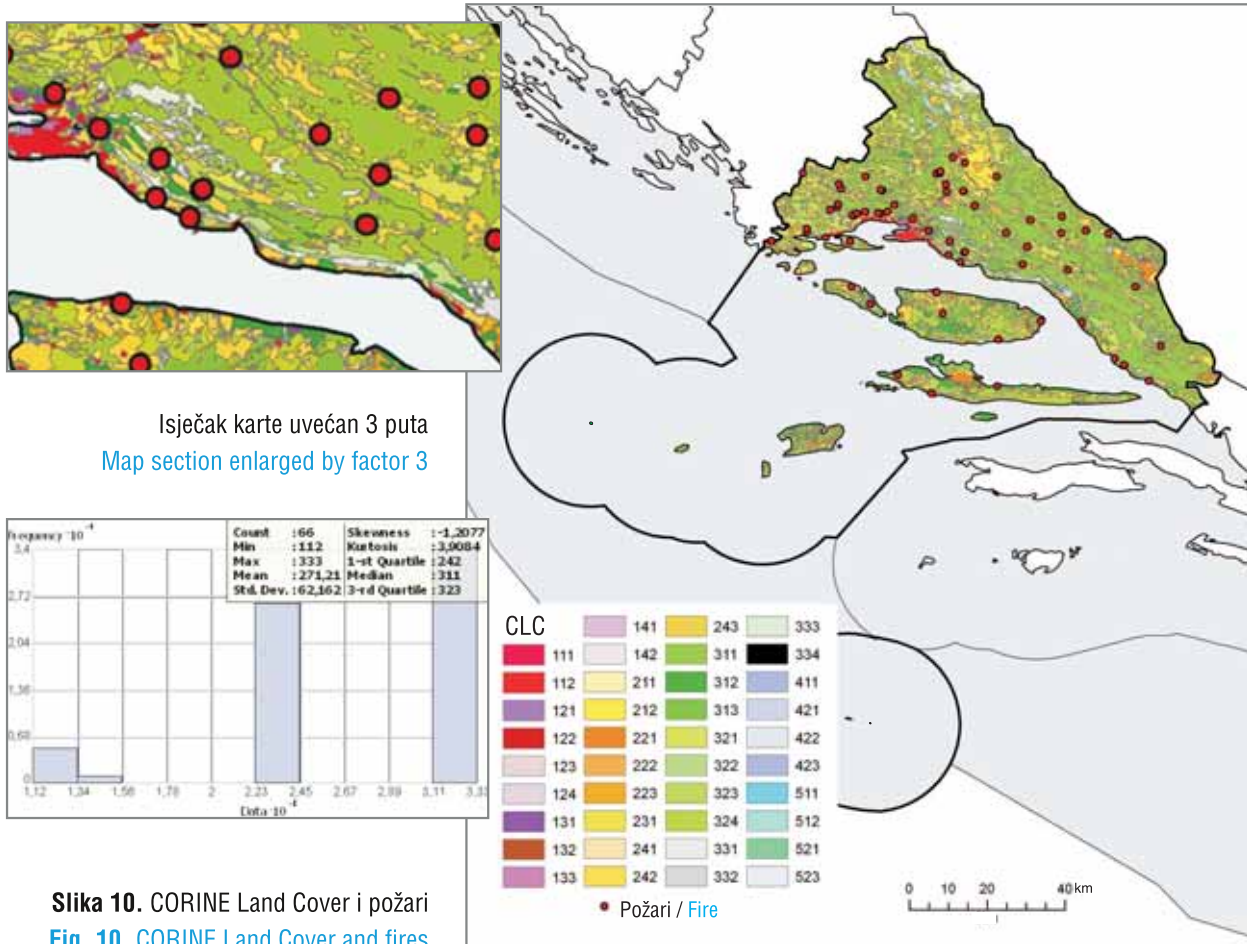
### 3.3. Vegetacija

Najvažniji vegetacijski pokazatelji kojima smo se koristili su CORINE (COoRdination of INformation on the Environment) Land Cover i Normalized Difference Vegetation Index – normirani indeks razlike u vegetaciji (dalje u tekstu NDVI).

#### 3.3.1. CORINE Land Cover (CLC)

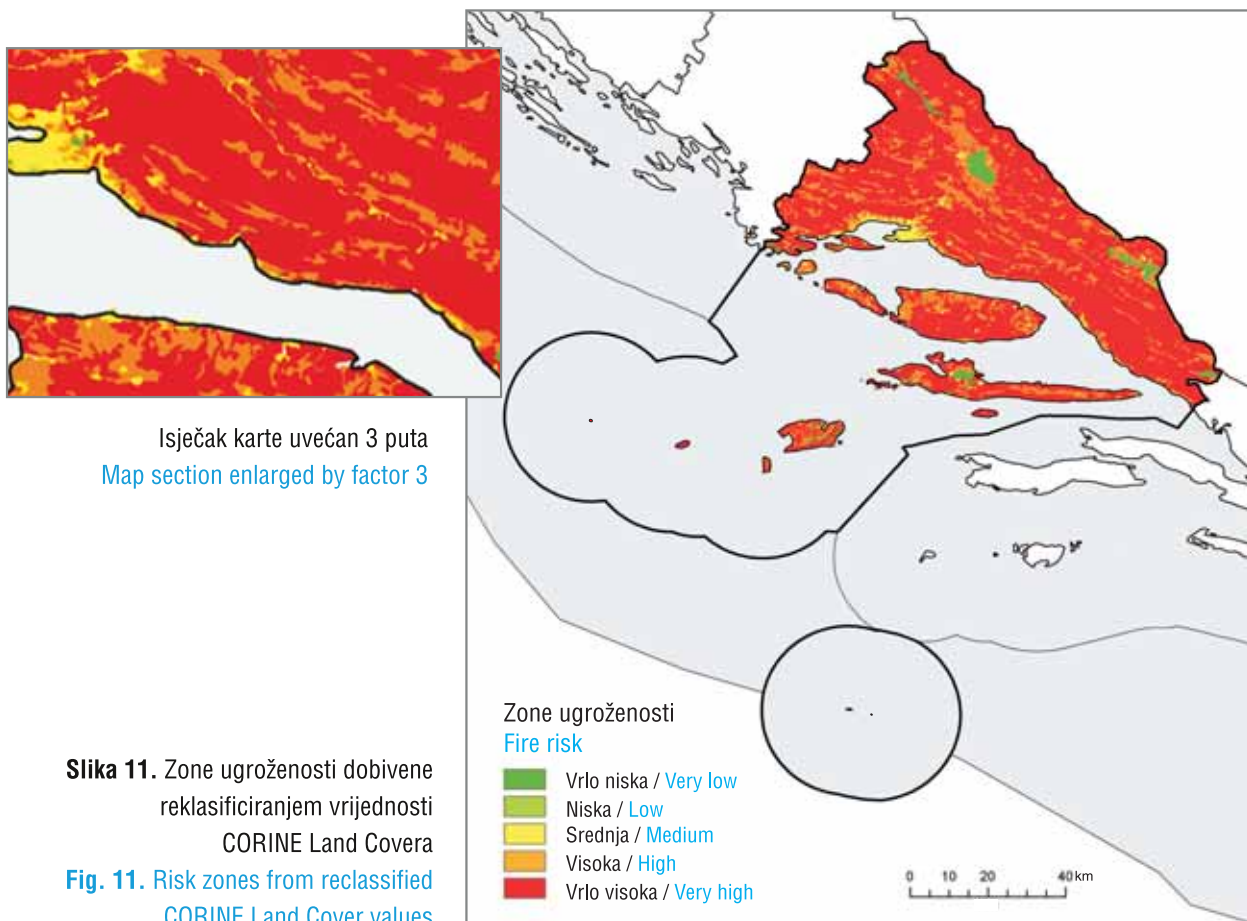
CORINE je program za koordinaciju informacija o okolišu i prirodnim resursima pokrenut od Europske zajednice. CLC je identifikacija i smisljena kategorizacija pokrova zemljišta, koja uključuje definiranu nomenklaturu kodiranja i stvaranja kvalitetne baze podataka, potrebne za nadgledanje prirodnih resursa, njihovo organiziranje i upravljanje njima na





Isječak karte uvećan 3 puta  
Map section enlarged by factor 3

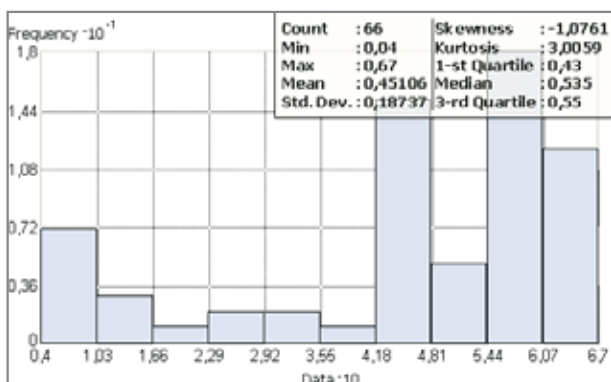
Slika 10. CORINE Land Cover i požari  
Fig. 10. CORINE Land Cover and fires



Isječak karte uvećan 3 puta  
Map section enlarged by factor 3

Slika 11. Zone ugroženosti dobivene  
reklasificiranjem vrijednosti  
CORINE Land Covera  
Fig. 11. Risk zones from reclassified  
CORINE Land Cover values

cover, which includes defined nomenclature and coding, to create a high-quality database for monitoring, organizing and managing natural resources at the regional and national levels. Data on the status of land cover provide new insights into changes in natural resources in different fields, such as agriculture, forestry, regional spatial planning, the inventorisation of natural resources and environmental monitoring. With the creation of CORINE Land Cover, data on the actual land cover for Croatia, based on standards applied in Europe, was obtained.



**Slika 12.** Broj požara i vrijednost NDVI-a  
**Fig. 12.** Number of fires and value of NDVI

It is evident from the histograms (Fig. 10) that most fires recorded broke out on agricultural land, growing plots, meadows, transitional forest areas, undergrowth and garrigue. Through reclassification into threatened areas, it is evident that the Split-Dalmatia County is a very large area, highly compromised in terms of vegetation (up to 73%) (Fig. 11).

**3.3.2. NDVI (Normalized Difference Vegetation Index)**

NDVI is based on the reflection properties of vegetated areas in comparison to clouds, water and snow on the one hand, and rocks and barren land on the other. Vegetated areas have relatively high reflectance in the near-infrared section of the spectrum, and low reflectance in the visible section. Clouds, water and snow have a higher reflectance in the visible section than in the near-infrared section of the spectrum. Rock and bare land have an equal degree of reflectance in both sections of the spectrum. NDVI can be used to determine the presence of vegetation and its condition (wet or dry). In this analysis, NDVI was used only for determining the presence of vegetation.

NDVI was calculated using the formula:

$$NDVI = (NIR - VS) / (NIR + VS),$$

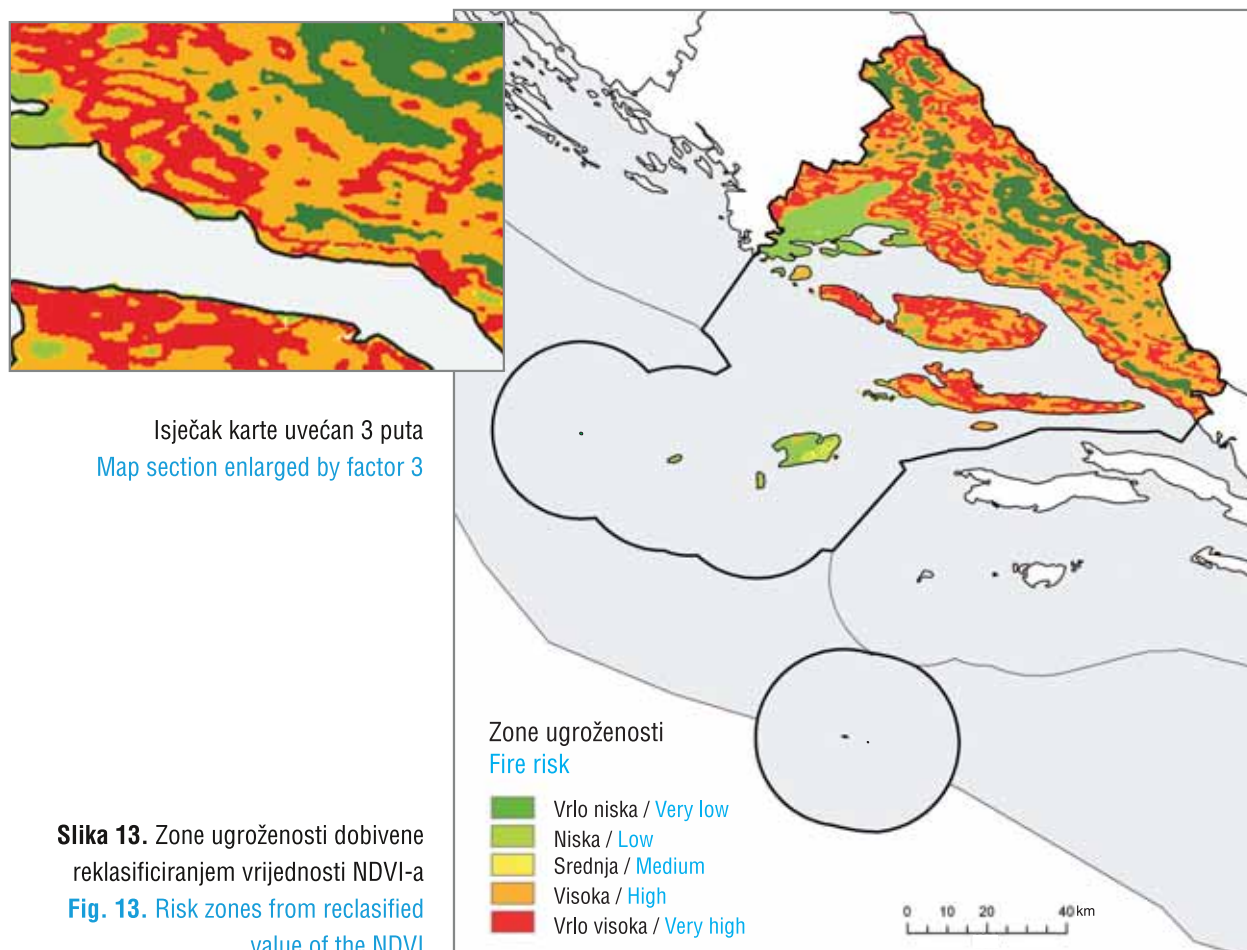
in which NIR is the value of reflectance in the near-infrared section of the spectrum, and VS the value of reflectance in the visible part of the spectrum. The calculation of NDVI for a pixel is always in the range of values from -1 to +1, however, green plants do not give a value of 0. Zero means no vegetation, and as the value +1 is approached, the area is greener and richer in vegetation, indicating a high density in the tree canopy.

For our analysis, we used a photograph taken by the Modis Terra satellite of the Rome tor Vergeta zone, resolution 250 m, in GeoTiff format. Since it was impossible to conduct the analysis throughout 36 days, because we did not have the personnel or computing power, the analysis was conducted as follows. The date chosen was that on which we recorded the highest number of fires during the season. This date was 22 August, when there were five fires in the Split-Dalmatia County. Since footage comes in 3 bands (RGB), we first needed to transfer values to NDVI values. This was done by exporting each band separately in grid format, and then reloading and reclassifying RGB values according to Table 1. In this way, we obtained the value of NDVI for the Split-Dalmatia County and could proceed to the analysis of histograms (Fig. 12).

**Table 1.** RGB values for the NDVI  
 (Source: <http://rapidfire.sci.gsfc.nasa.gov/faq/>)

Red	Green	Blue	NDVI
153	204	255	≤0.0
225	175	100	0.05
255	225	150	0.15
225	255	175	0.25
152	255	152	0.35
102	255	102	0.45
51	204	51	0.55
0	153	0	0.65
0	102	0	>0.75
255	255	255	No data

As expected, when the NDVI value was high, the number of fires in the area was larger. A high NDVI value indicates more vegetation, so it was clear that in areas with lower NDVI values, there could also be fires, in these cases consuming undergrowth and garrigue. Reclassification of the data was calculated and the fire risk was calculated according to NDVI values (Fig. 13).



regionalnoj i nacionalnoj razini. Podaci o stanju pokriva zemljišta daju novi uvid u stanje i promjene prirodnih resursa na različitim poljima poput poljoprivrede, šumarstva, lokalnog prostornog planiranja, inventarizacije prirodnih resursa i praćenja okoliša.

Izradom CORINE Land Covera dobiveni su podaci o stanju stvarnog pokriva zemljišta za Hrvatsku koji se temelje na standardima primijenjenim u Europi. Iz histograma (slika 10) je vidljivo da je najviše požara zabilježeno na poljoprivrednim zemljištima, uzgojnim parcelama, travnjacima, prijelaznim šumskim područjima, makiji i garigu. Reklasifikacijom u zone ugroženosti vidljivo je da je Splitsko-dalmatinska županija jako velik prostor koji je vrlo ugrožen što se tiče vegetacije (čak 73%) (slika 11).

### 3.3.2. NDVI (Normalized Difference Vegetation Index)

NDVI se temelji na svojstvima refleksije područja te njegove krajnje vrijednosti ukazuju na prisutnost oblaka, vode i snijega s jedne strane, te stijena i golog zemljišta s druge strane. Područja pod vegetacijom imaju relativno visoku refleksiju u bliskom infracrve-

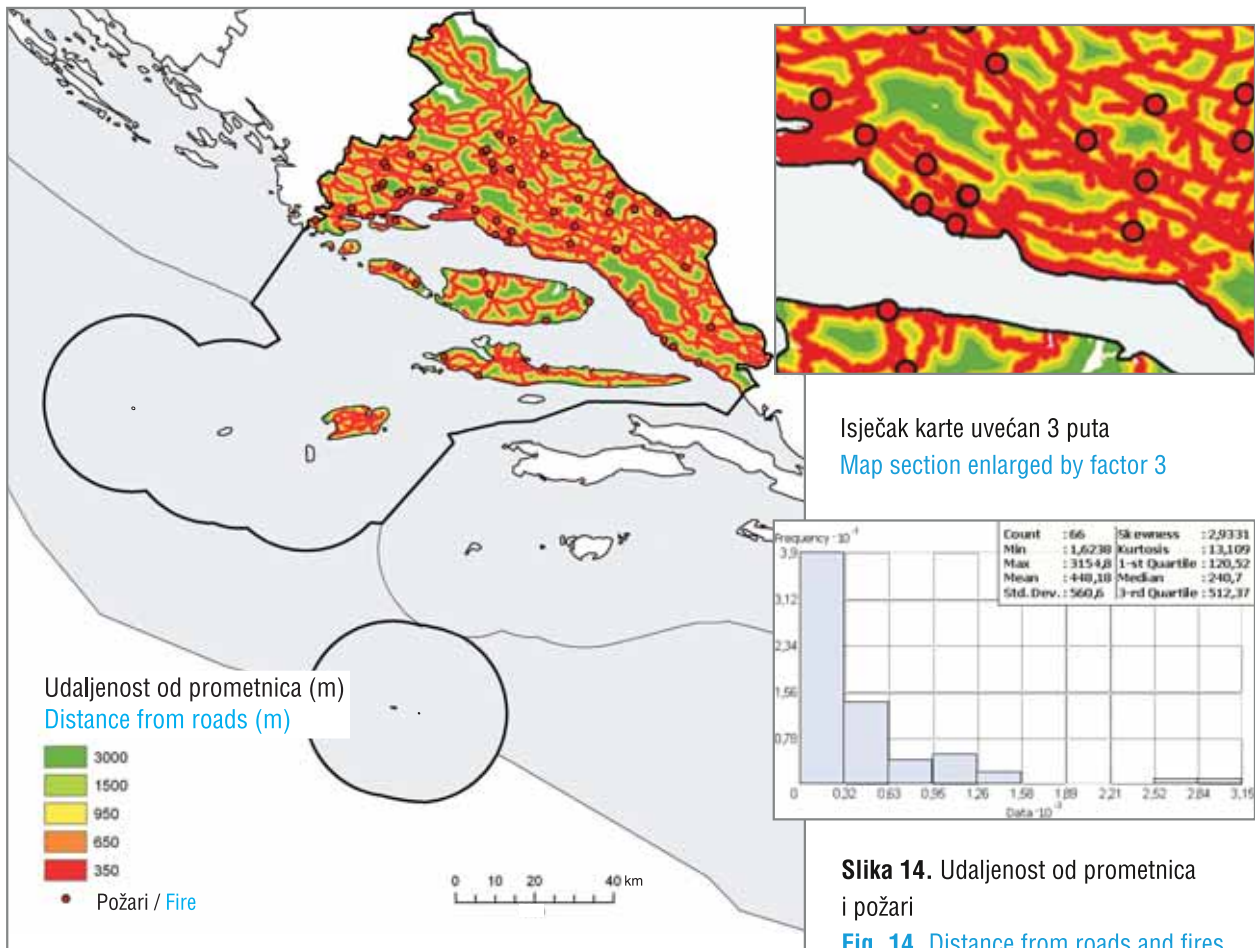
nom dijelu spektra, a nisku u vidljivom. Oblaci, vode i snijeg imaju višu refleksiju u vizualnom nego u bliskom infracrvenom dijelu spektra. Stijene i gola zemljišta imaju podjednaki stupanj refleksije u oba dijela spektra. NDVI se može koristiti da se utvrdi prisutnost vegetacije i njezino stanje (vlažna/suha). Pri ovoj analizi korišten je samo za utvrđivanje prisutnosti vegetacije.

NDVI se računa po formuli:

$$NDVI = (BIC - VID) / (BIC + VID),$$

gdje je BIC vrijednost refleksije u bliskom infracrvenom dijelu spektra, a VID vrijednost refleksije u vidljivom dijelu spektra. Proračun za NDVI za određeni piksel uvijek je u rasponu vrijednosti od -1 do +1, međutim zelene biljke ne daju vrijednost 0. Nula znači da nema vegetacije, i što se više približava vrijednosti +1 to je površina zelenija i bogatija vegetacijom, te pokazuje veliku gustoću lišća u krošnjama.

Za potrebe analize preuzeli smo snimku sa satelita Modis Terra, iz Rome tor Vergeta zone, rezolucije 250 m, u formatu GeoTiff. S obzirom na to da je bilo



**Slika 14.** Udaljenost od prometnica i požari

**Fig. 14.** Distance from roads and fires

### 3.4. Anthropogenic factors

Fires are closely linked to the proximity of roads, railways and towns. Deliberate or accidental, the human factor is to blame in most cases of outbreaks of fire (Nodilo, 2003). In creating these zones, Analysis Tools (Proximity, Buffer) were used.

#### 3.4.1. Distance from roads

Roads are an important factor in the analysis, because the transport network is extremely dense, which in the case of fire is unfavourable. The human factor is the most important in the outbreak of fire (Nodilo, 2003), and the dense network of roads means that, during their daily travels, people sometimes throw cigarette ends from their vehicles, and this often causes fires. Looking at the histogram (Fig. 14) we see that more than 50% of fires broke out within 350m of a road.

Before developing risk zones, it was necessary to create a union of all values in a buffer (using an editor), and then clip it to get a compact polygon with zones for reclassification. First, however, it was transferred from

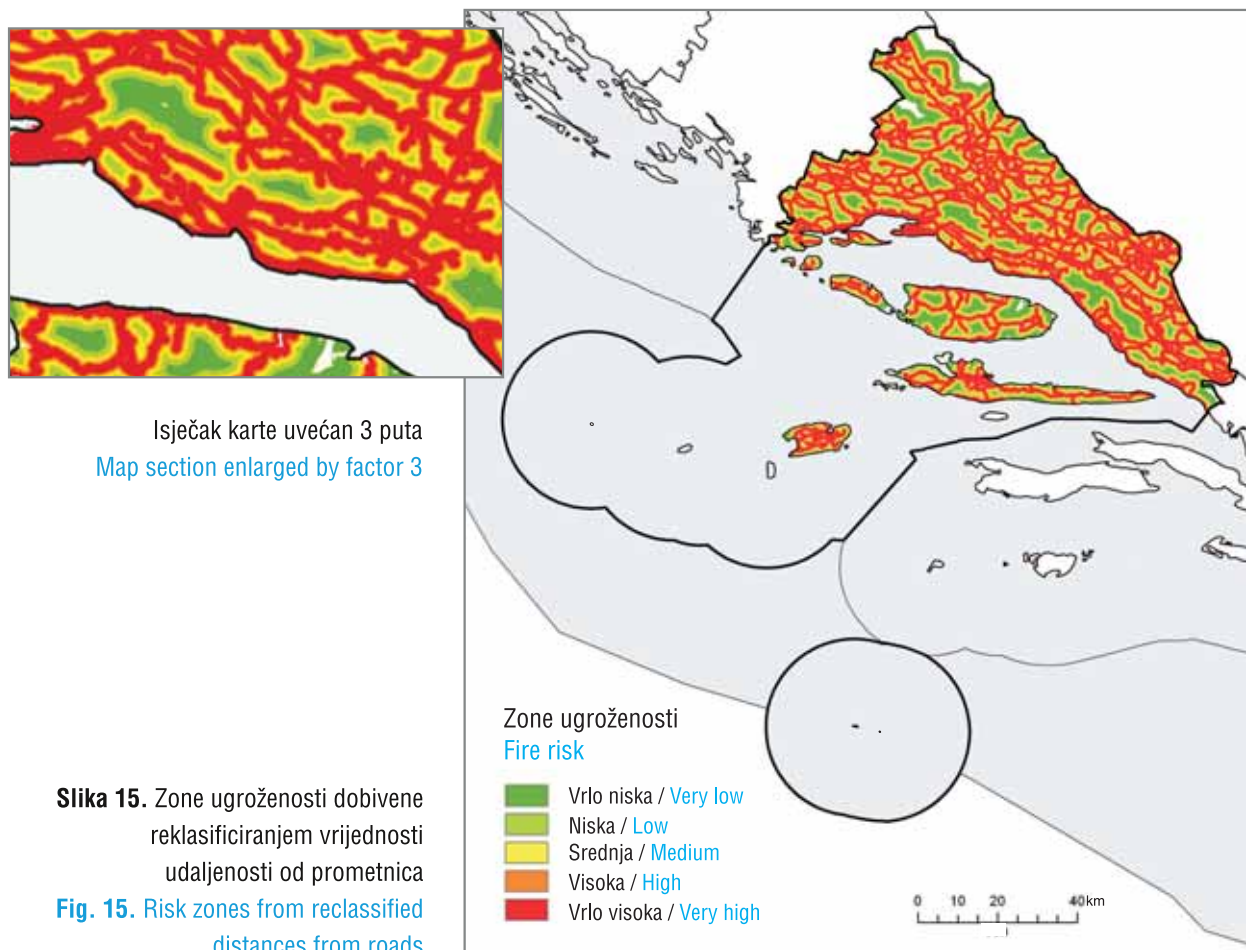
the vector into raster (conversion tools; to raster, polygon to raster).

#### 3.4.2. Distance from railways

Given the fact that the railroad in the Split-Dalmatia County crosses only a small part of the terrain, it did not make sense to analyze the influence of railways on all fires. With the help of a histogram, it was determined that the analysis would include fires within 10 km of the railway line (Fig. 16). In the next step, we created a 10 km radius buffer and showed the results in the histogram (Fig. 17). From this histogram we can see that in the immediate vicinity of the railway, six fires broke out. These data were transferred to raster and reclassified into 5 fire risk zones (Fig. 18).

#### 3.4.3. Distance from settlements

As a final factor in creating the fire risk map, the distance from settlements was considered. It is evident from the histograms (Fig. 19) that the number of fires decreases as the distance from settlements increases. It



nemoguće provesti analizu za svih 36 dana jer nismo imali ni ljudstvo, ni računalnu snagu, analizu smo proveli na sljedeći način. Datum je odabran po tome što je na taj dan zabilježeno najviše požara u sezoni. Dana 22. kolovoza zabilježeno je 5 požara u Splitsko-dalmatinskoj županiji. Kako snimka dolazi u 3 pojasa (RGB), prvo je trebalo prebaciti te vrijednosti u vrijednosti NDVI-a, i to tako da se prvo svaki pojas posebno eksportirao u format grid, te ih se učitalo i reklasificiralo po vrijednostima RGB-a prema tablici 1. Na taj način dobivena je vrijednost NDVI-a za Splitsko-dalmatinsku županiju i moglo se krenuti u analizu histograma (slika 12).

Kao što se očekivalo, što je vrijednost NDVI-a viša, to je broj požara na tom prostoru veći. Visoke vrijednosti NDVI-a znače obilatu vegetaciju, tako da je jasno da i na mjestima s nižom vrijednošću NDVI-a može biti požara, jer to znači da gori makija i garig. Reklasifikacijom podataka izračunata je zona rizika od požara za vrijednosti NDVI-a (slika 13).

**Tablica 1.** Vrijednosti RGB-a za NDVI

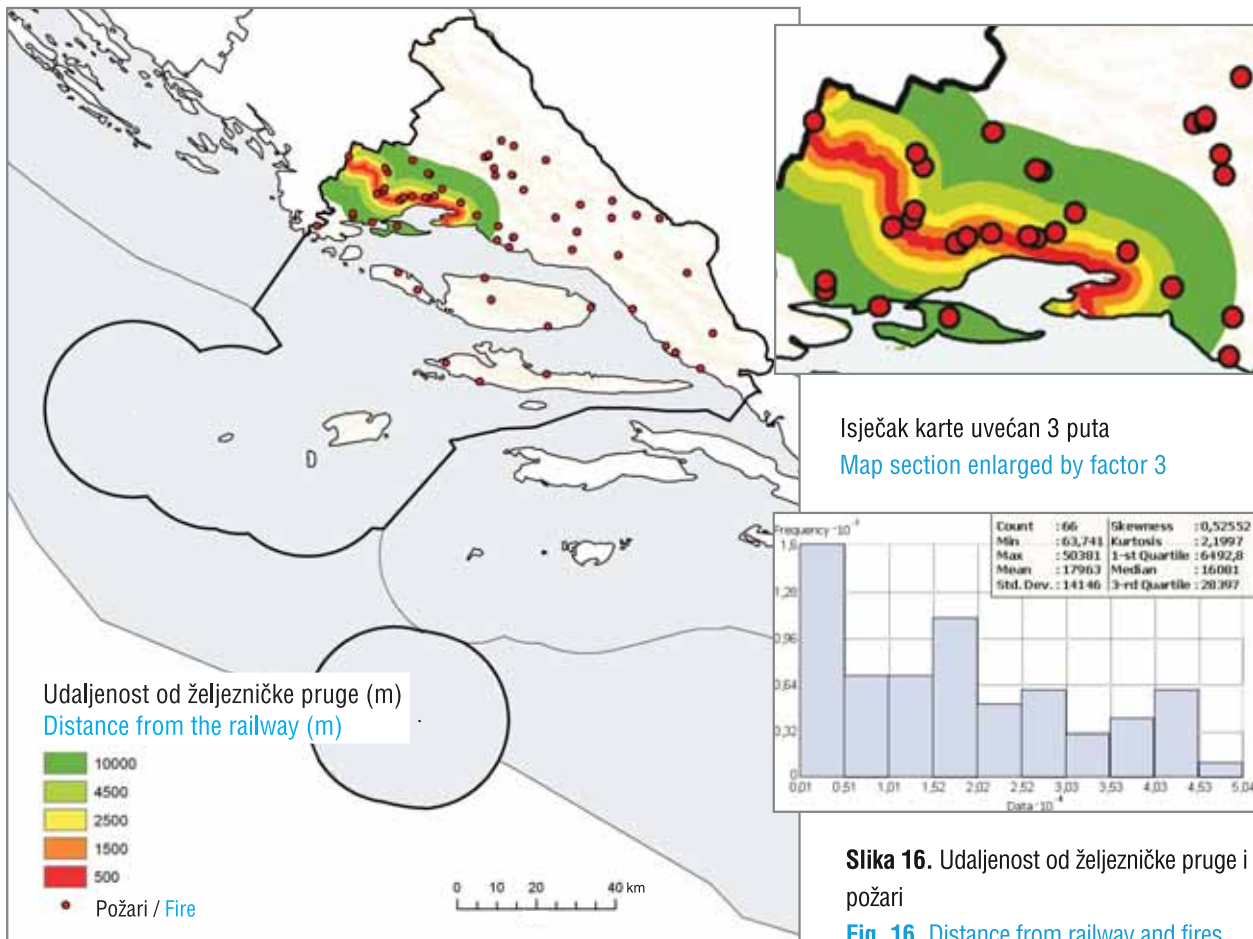
(Izvor: <http://rapidfire.sci.gsfc.nasa.gov/faq/>)

Red	Green	Blue	NDVI
153	204	255	≤0,0
225	175	100	0,05
255	225	150	0,15
225	255	175	0,25
152	255	152	0,35
102	255	102	0,45
51	204	51	0,55
0	153	0	0,65
0	102	0	>0,75
255	255	255	Bez podataka

### 3.4. Antropogeni čimbenici

Požari otvorenog prostora usko su povezani s blizinom cesta, željezničkih pruga i naselja. Svjesno ili nesvjesno ljudi su najveći uzročnici izbijanja požara (Nodilo, 2003). Pri izradi ovih zona korišten je *Analysis tools (proximity; buffer)*.

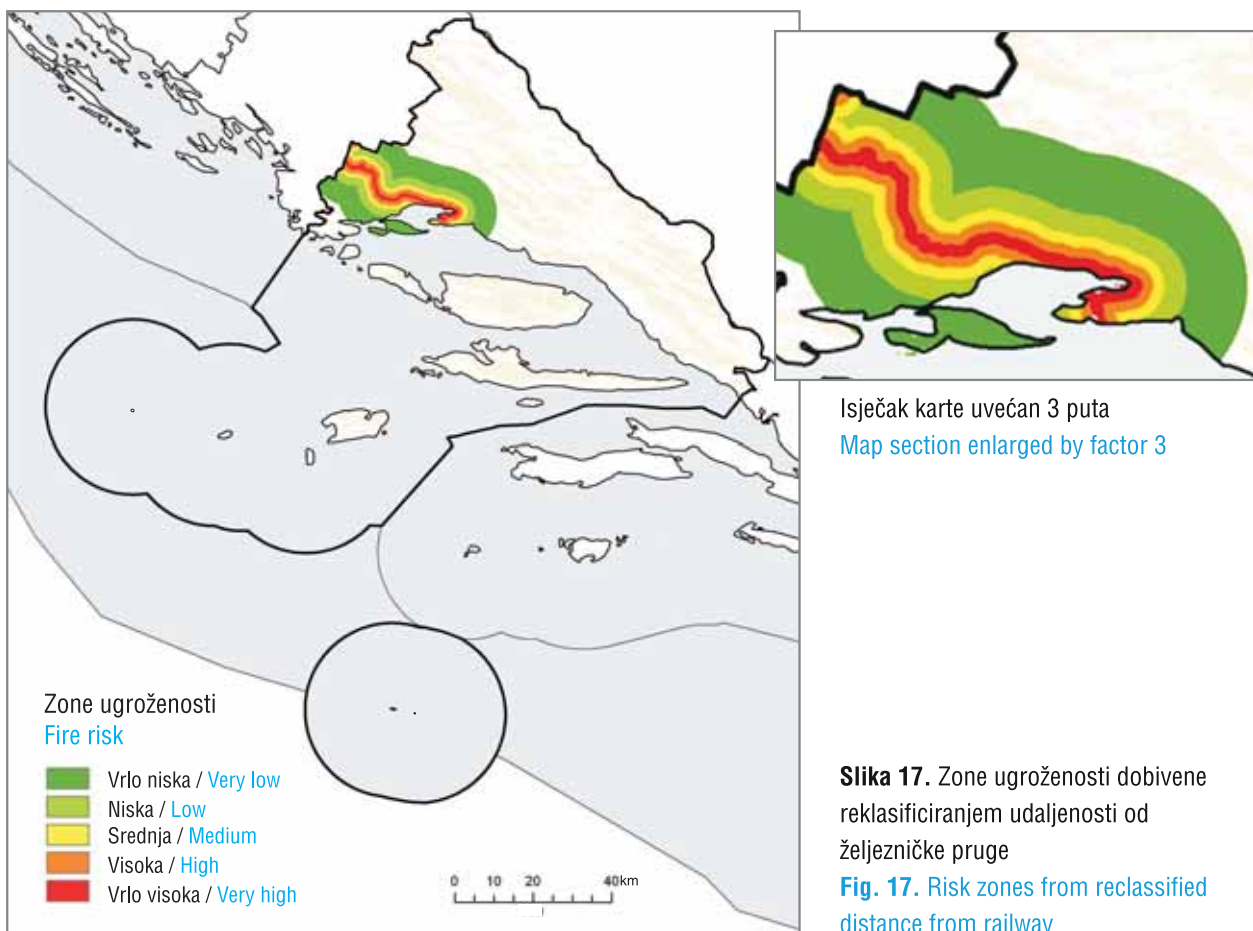




Isječak karte uvećan 3 puta  
Map section enlarged by factor 3

Slika 16. Udaljenost od željezničke pruge i požari

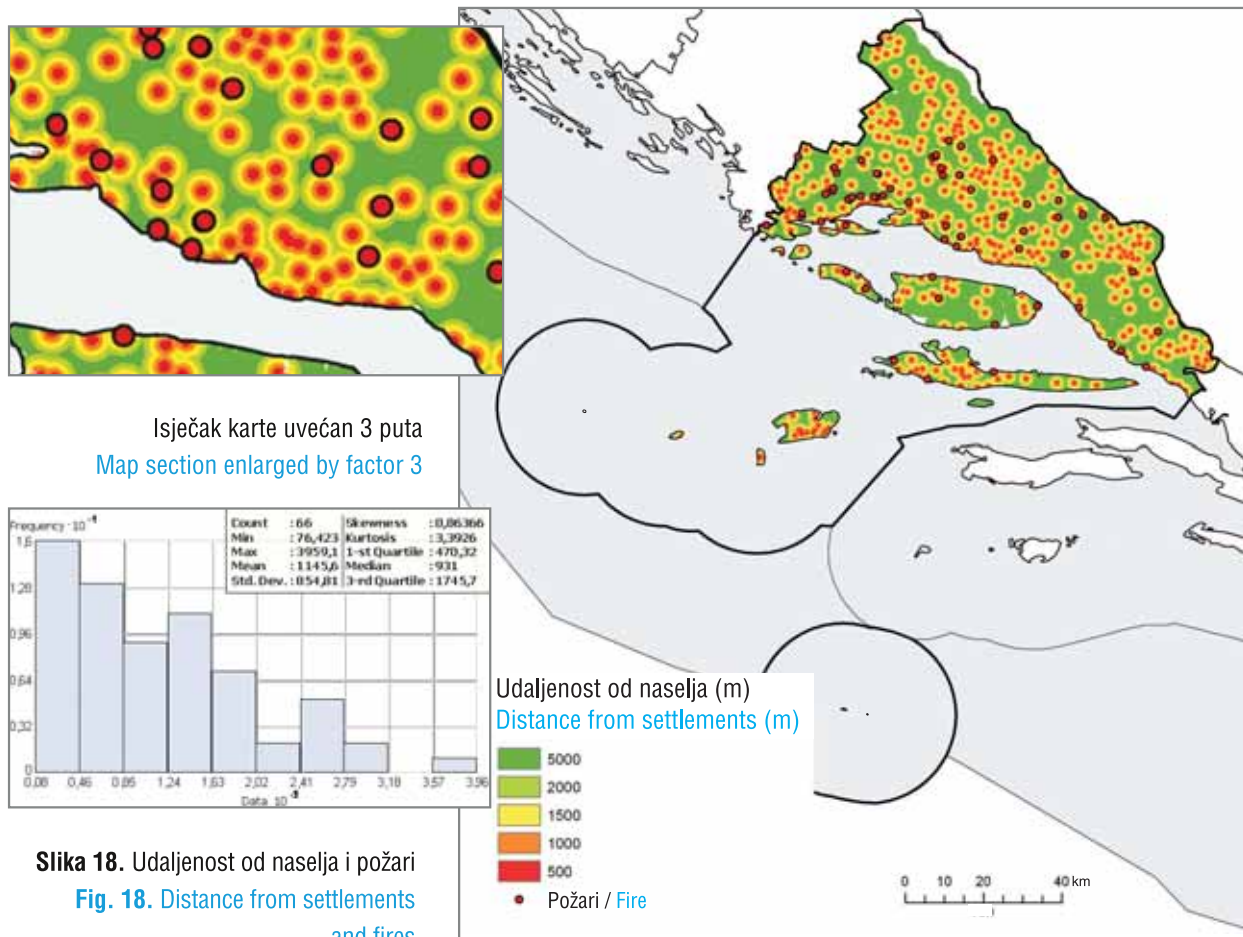
Fig. 16. Distance from railway and fires



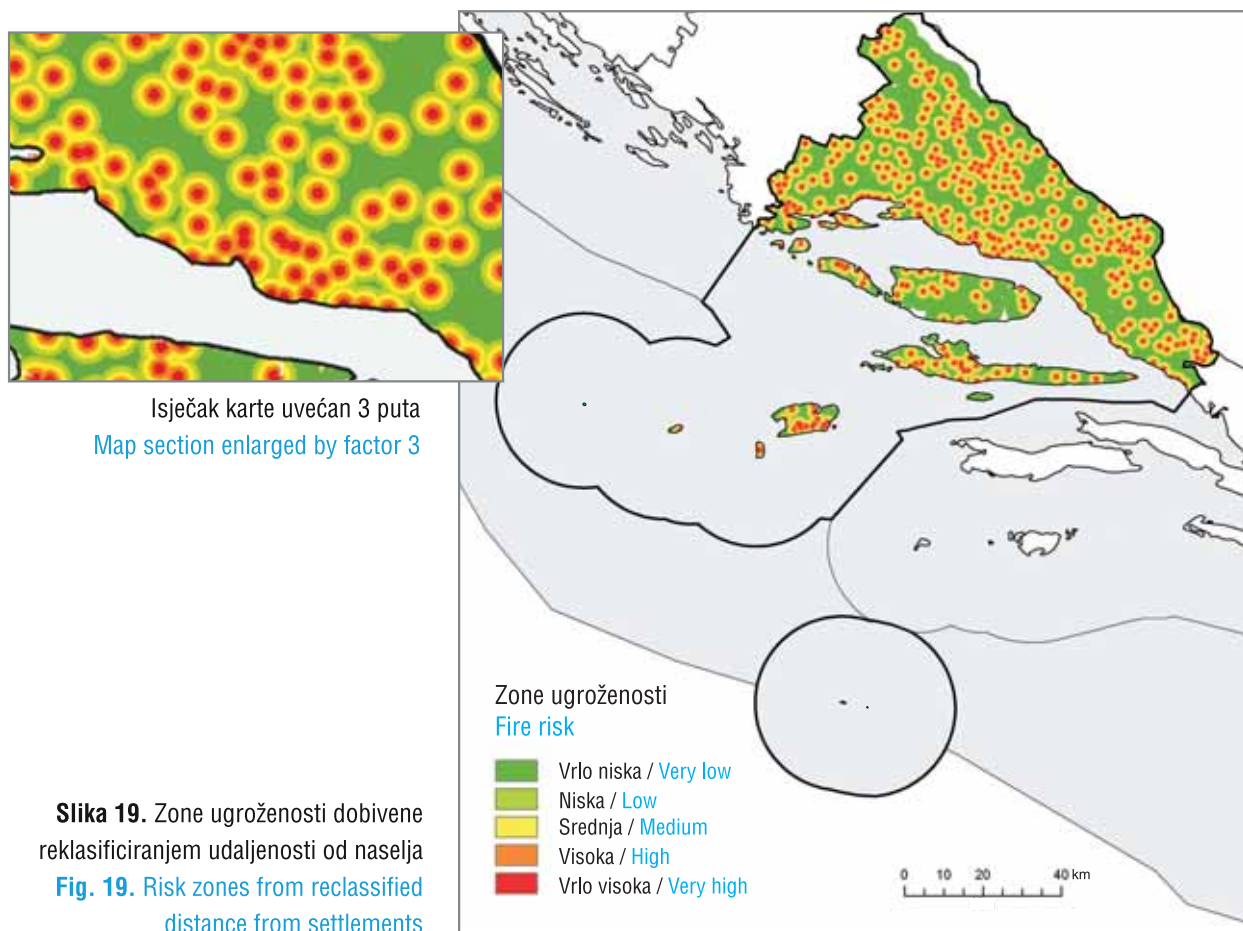
Isječak karte uvećan 3 puta  
Map section enlarged by factor 3

Slika 17. Zone ugroženosti dobivene reklasificiranjem udaljenosti od željezničke pruge

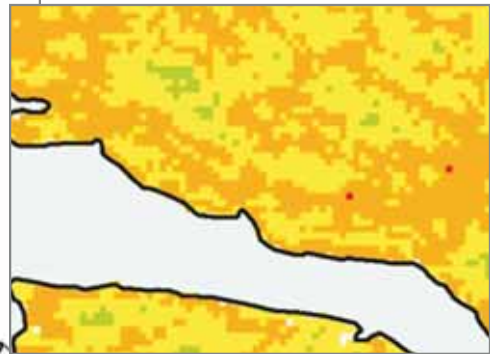
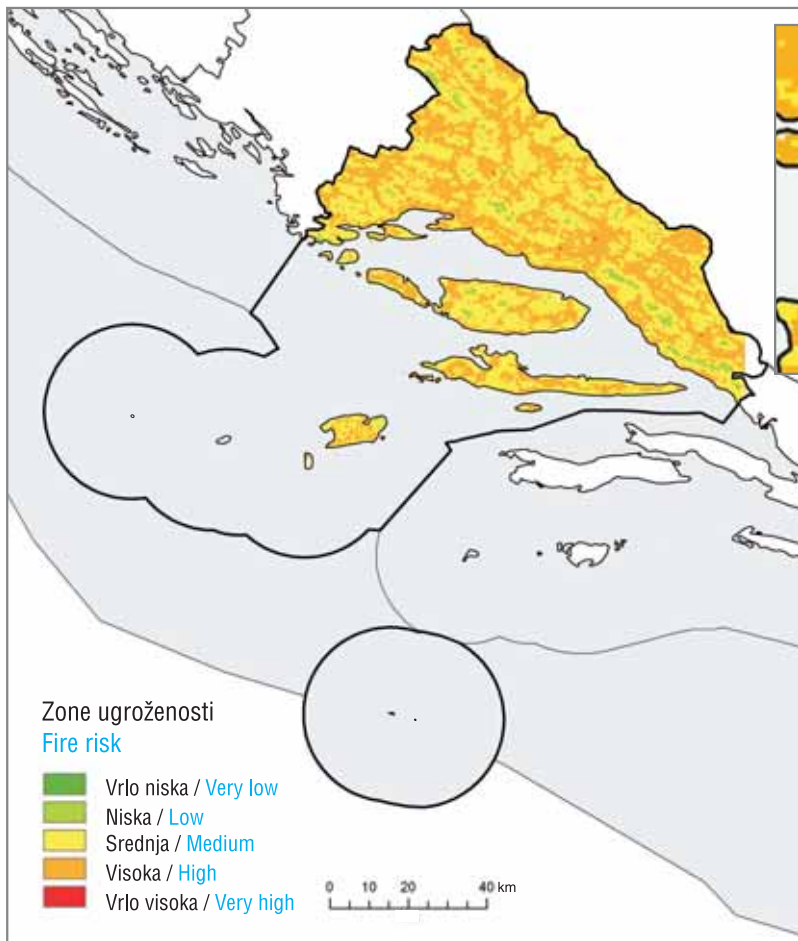
Fig. 17. Risk zones from reclassified distance from railway



Slika 18. Udaljenost od naselja i požari  
Fig. 18. Distance from settlements and fires

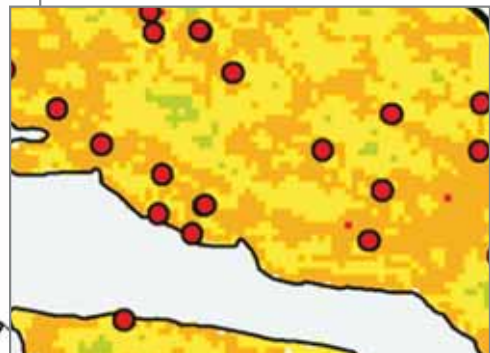
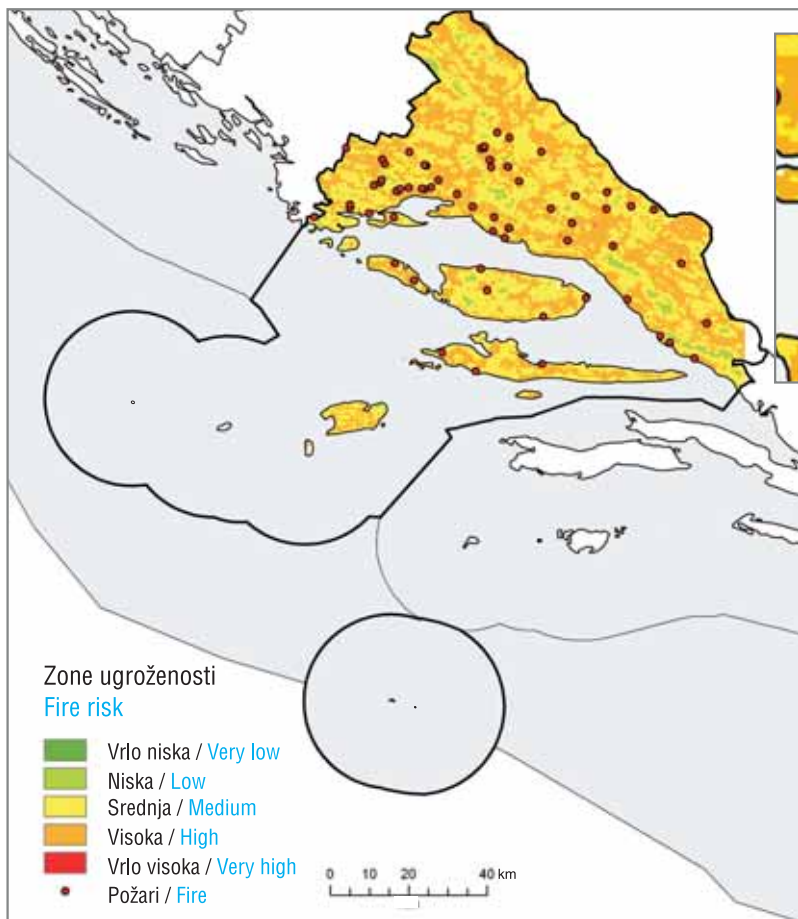


Slika 19. Zone ugroženosti dobivene reklasificiranjem udaljenosti od naselja  
Fig. 19. Risk zones from reclassified distance from settlements



Isječak karte uvećan 3 puta  
Map section enlarged by factor 3

**Slika 20.** Zone ugroženosti od požara u Splitsko-dalmatinskoj županiji  
**Fig. 20.** Fire risk zone in Split-Dalmatia County



Isječak karte uvećan 3 puta  
Map section enlarged by factor 3

**Slika 21.** Usporedba dosadašnjih požara s procjenom za požarnu sezonu  
**Fig. 21.** Comparison of previous fires with a prediction for the fire season

### 3.4.1. Udaljenost od cesta

Ceste su bitan faktor pri analizi zato što je prometna mreža iznimno gusta, što u ovom slučaju nije poželjno. Kako su ljudi najvažniji čimbenik pri izbijanju požara (Nodilo, 2003), gusta mreža prometnica znači da pri svojim dnevnim migracijama ljudi bacanjem opušaka iz vozila često uzrokuju požare. Na histogramu (slika 14) možemo vidjeti da je više od 50% požara izbilo unutar 350 m od prometnice.

Prije izrade zona ugroženosti, bilo je potrebno uređivanjem spojiti (*union*) sve vrijednosti *buffera* u jedan, te nakon toga izrezivanjem dobiti jedan kompaktan poligon sa zonama koje će se zatim reklasificirati. No prije toga podaci su promijenjeni iz vektora u raster (*conversion tools; to raster; polygon to raster*).

### 3.4.2. Udaljenost od željezničke pruge

S obzirom na to da željeznička pruga Splitsko-dalmatinskom županijom prolazi samo malim dijelom, nije imalo smisla provoditi analizu utjecaja pruge na sve požare, nego na samo jedan dio. Uz pomoć histograma određeno je da se radi analiza unutar 10 km udaljenosti od željezničke pruge (slika 16). U idućem koraku napravljen je koridor (*buffer*) od pruge radijusa 10 km i prikazan je histogram (slika 17) iz kojega se može vidjeti da je u neposrednoj blizini željeznice izbio 6 požara. Ti podaci prebačeni su u raster i reklasificirani u 5 zona ugroženosti od izbijanja požara (slika 18).

### 3.4.3. Udaljenost od naselja

Kao posljednji čimbenik pri izradi karte zona rizika od požara uzeta je udaljenost od naselja. Vidljivo je iz histograma (slika 19) da se udaljavanjem od naselja smanjuje broj požara. Već je utvrđeno da je čovjek glavni uzročnik požara, tako da je logično da se udaljavanjem od njegova prebivališta broj požara smanjuje. Pri izradi te procjene izrađeni su koridori (*buffer*) oko naselja, i s obzirom na to da se na nekim mjestima preklapaju, uz pomoć uređivanja (*union, clip*) taj problem je riješen, kreiran je jedan poligon sa zonama. Nakon što je prebačen u rasterski format, vrijednosti su reklasificirane i prikazane su zone ugroženosti (slika 20).

## 4. Rezultati i zaključak

Kako bismo dobili zone ugroženosti od požara bilo je potrebno sve čimbenike koji su analizirani i rekla-

sificirani preklopiti. No prije toga trebalo ih je rangirati po važnosti pri samom izbijanju požara.

U tu svrhu opet su poslužili histogrami. Iz svakog histograma pročitano je najveći broj požara unutar nekog stupca. Sve vrijednosti svih čimbenika su zbrojene, te je svaka vrijednost podijeljena s decimalnom vrijednošću tog zbroja da bi se dobila važnost svakog čimbenika u postotnom udjelu (tablica 2).

**Tablica 2.** Čimbenici i njihova važnost pri izbijanju požara

Čimbenik	Broj požara	Rizik u %
Temperatura zraka	11	6
Relativna vlažnost zraka	18	10
Orijentiranost padine	15	8
Nagib padine	20	11
CORINE Land Cover	34	18
NDVI	18	10
Prometnice (ceste)	39	21
Željeznička pruga	16	8
Naselja	16	8
Ukupno	187	100

Na taj način minimalizirana je subjektivna procjena. U *Spatial analyst tools (overlay; weighted overlay)* pridodani su svi čimbenici (reklasificirani) te im se na temelju tablice 2 dodao postotni udio važnosti. To je bitno zato što svaki čimbenik nema jednaku važnost pri izbijanju požara.

**Tablica 3.** Rezultati dobiveni pri analizi

Zone ugroženosti	Broj požara	Površina (u %)
Zona 1 (vrlo niska opasnost)	0	0,0
Zona 2 (niska opasnost)	2	4,2
Zona 3 (srednja opasnost)	24	51,7
Zona 4 (visoka opasnost)	40	44,0
Zona 5 (vrlo visoka opasnost)	0	0,1

Dobiveni rezultati (slika 21) uspoređeni su s georeferenciranim požarima iz sezone 2010. na temelju kojih se i radila procjena, te se iz tablice 3 može vidjeti da je najviše požara (čak njih 40) unutar zone rizika 4 (velika opasnost od izbijanja požara). Na temelju toga možemo zaključiti da je takva analiza kvalitetna i da se na taj način može raditi procjena ugroženosti za svaki dan, s time da bi se vremenski čimbenici izmjenjivali za svaki dan. Time bi se dobila i preciznija procjena.

has already been established that the human factor is the main cause of outbreaks of fire, therefore it is only logical that the greater the distance from a settlement, the fewer the fires. In preparing these estimates, buffers were made around settlements, and since they overlapped in some places, this problem was solved using the editor (Union, Clip), by creating one polygon with zones. After being transferred to a raster format, values were been reclassified and vulnerability zones shown (Fig. 20).

#### 4. Results and Conclusions

In order to obtain fire damage zones, it was necessary to collate all the factors analyzed and reclassified. First, they needed to be ranked by importance in terms of fire outbreak.

For this purpose, histograms were again used. From each histogram, the largest number of fires within a column was extracted. The values for all factors were totalled, and each value was divided by the decimal value of the total to derive the importance of each factor expressed as a percentage (Table 2.).

In this way, we minimized subjective assessment. All the analyzed (reclassified) factors were incorporated in Spatial Analyst tools (overlay; weighted overlay) and, based on Table 2, we added a percentage of importance. This was important because not all elements were of equal significance in causing fires.

**Table 2.** Factors and their importance in the outbreak of fire

Factors	Number of fires	Risk %
Temperature	11	6
Relative humidity	18	10
Aspect	15	8
Slope	20	11
CORINE Land Cover	34	18
NDVI	18	10
Roads	39	21
Railways	16	8
Settlements	16	8
Total	187	100

**Table 3.** Results obtained during analysis

Risk zone	Number of fires	Area (%)
Zone 1 (very low risk)	0	0
Zone 2 (low risk)	2	4.2
Zone 3 (medium risk)	24	51.7
Zone 4 (high risk)	40	44
Zone 5 (very high risk)	0	0.1

The results obtained (Fig. 21) were compared with georeferenced fires from the fire season 2010, and from Table 3 it is clear that most fires (up to 40) fell within the high risk zone 4. Based on these results, we can conclude that the analysis was sound, and that it can be used for daily assessment, using alternate factors day by day. This would produce a more accurate estimate.

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