# Spatial patterns and drivers of fire occurrence in a Mediterranean environment: a case study of southern Croatia

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ABSTRACT: Wildfires are an important factor of landscape dynamics in fire-prone environments of the world. In the Mediterranean, one of the most fire-susceptible environments globally, between 45,000 and 50,000 wildfires are recorded every year, causing disturbances in forest and grassland ecosystems. As a Mediterranean country, Croatia faces these problems, averaging over 1000 registered wildfires annually, with the coastal areas dominated by forest fires and continental Croatia by fires on agricultural lands. This research combines various landscape and socioeconomic factors in the analysis of fire occurrence in Croatia's southernmost region of Dalmatia. Around 275 of the largest fires (encompassing 98% of the total burnt area) registered in 2013 were investigated using OLS, and different spatial indices were employed to analyse regional variability of fire distribution. The results revealed that areas more prone to fires are the northern inland areas of Dalmatia and its entire coastal zone. Altitude and vegetation type demonstrated a correlation with fire occurrence, but an increase in population in the study area was also correlated with wildfire occurrence. Regarding vegetation, the grasslands and Mediterranean shrubland (maquis) were found to be the most fire-prone vegetation types in the study region, the distribution of which can be linked to different socio-economic and demographic processes occurring in the Eastern Adriatic.

Keywords: fire occurrence, Mediterranean, vegetation, littoralization, OLS

## 1. Introduction

Wildfires are a global occurrence and are becoming an ever-growing issue due to their effect on people, soil and vegetation degradation, and material damage (Flannigan, Krawchuk, De Groot, Wotton, & Gowman, 2009; Moody & Martin, 2001; Thompson & Calkin, 2011). They are one of the most important factors responsible for disturbances in terrestrial ecosystems on a global scale, the impact of which is especially visible in forest and grassland ecosystems (Radeloff et al., 2005; van der Werf et al., 2010). The global annual area burned between 1997 and 2011 varied from 301 to 377 million hectares, with an average of 348 million hectares. Savannah fires comprised the largest proportion (71%) of area burned at the global scale, primarily in Africa, Australia, South Asia and South America. Grassland fires were the most prevalent in Central Asia, while forest fires accounted for the largest proportion of area burned in equatorial and boreal regions (Giglio, Randerson, & van der Werf, 2013). Seeing as forests are home to diverse plant and animal species, the preservation of forests is necessary to ensure the stability of the world's ecosystems. Moreover, forests are important for protection from erosion, flooding and torrential floods; in processes relating to water regimes and systems; for their impact on agriculture and climate; and for the development of activities such as tourism, hunting and defence (Costa, Thonicke, Poulter, & Badeck, 2011; Jurjević, Vuletić, Gračan, & Seletković, 2009; Martínez, Vega-Garcia, & Chuvieco, 2009). Apart from forests, agricultural areas are also at risk of large wildfires, affecting the part of the population whose lives depend solely on agriculture. In addition to their impact on the natural environment, wildfires can also have societal and economic consequences (Brenkert-Smith, Dickinson, Champ, & Flores, 2013; Jones, Ribbe, Cunningham, Weddle, & Langley, 2002; Shakesby, 2011; Syphard, Keeley, Massada, Brennan, & Radeloff, 2012). However, the ecological benefits of wildland fires sometimes outweigh their negative effects. A regular

occurrence of fires can reduce the amount of fuel build-up thereby lowering the likelihood of a potentially large wildland fire. Furthermore, fires work to eliminate dense foliage which allows sunlight to reach the forest floor, supporting the growth of young plants. The ashes that remain after a fire are rich in nutrients and minerals that make the soil more fertile (Keane & Karau, 2010).

Natural fires occur mostly due to lightning strikes and, sometimes, volcanic eruptions. However, fires more often occur due to human influence: anthropogenic fires make up between 95% and 99% of all recorded wildfires in the world (Costa et al., 2011; Oliveira, Ohler, San-Miguel-Ayanz, Camia, & Pereira, 2012). Globally, the areas which are most vulnerable to wildfires are the North American pine forests, the African savannas, and the Mediterranean (Konstantinidis, Tsiourlis, & Galatsidas, 2005; San-Miguel-Ayanz et al., 2009). The warm and arid summers, flammable resin-rich vegetation, the ageing population, depopulation, and consequent agricultural abandonment are some of the factors affecting the occurrence of wildfires and the size of burnt areas in the Mediterranean (Costa et al., 2011; Ganteaume & Jappiot, 2013; Sarris et al., 2014).

According to WWF data (2003) around 50,000 wildfires occur annually around the Mediterranean, burning between 600,000 and 800,000 ha of forest and totalling a 1.3% to 1.7% loss of Mediterranean forest cover. A study by Oliveira et al. (2012) estimates that the number of wildfires in Mediterranean Europe averages around 45,000 per year. According to Turco et al. (2016), the total annual burnt area and annual number of fires showed a general decreasing trend through the last 20 years, with the exception of Portugal. The negative trends can be explained, at least in part, by an increased effort in regards to fire management and prevention. However, other studies emphasize that fire seasons will become longer and more severe in the 21$^{st}$ century due

to global warming, which will increase fire risk and vulnerability (Flannigan et al., 2013; Lindner et al., 2010).

Changes occurring in areas affected by wildfires include, among others, forest and landscape degradation (Mouillot, Ratte, Joffre, Moreno, & Rambal, 2003; Sarris et al., 2014) which negatively influences tourism, an extremely important industry throughout the entire Mediterranean. Moreover, the lack of natural protection on slopes results in increased erosion and loss of arable land. In addition to the material damages, fires present a danger to human lives. On the other hand, the sudden growth of tourism coupled with processes of littoralization which are prevalent on the Croatian coast, as well as the coasts of other eastern Adriatic countries, (especially after the fall of communist and socialist systems at the beginning of 1990s) have initiated other changes such as agricultural abandonment and the abandonment of cattle herding, resulting in changes in vegetation cover connected to increased fire occurrence (Fernandes et al., 2014; Moreno, Conedera, Chuvieco, & Pezzatti, 2014; Pausas & Fernandez Muñoz, 2011). Despite all those problems, very little research has tackled the effect of socio-economic change on fire occurrence in this part of the Mediterranean. Previous research has mostly dealt with certain aspects of fires selectively, more often than not in (relatively) smaller areas, and with an emphasis on climatic or other bio-physical variables. One of the reasons for this noted lack of research could also be the scarcity of available data on both environmental and socio-geographical processes in this part of Europe. This has left important questions on how such changes have affected wildfire occurrence in these countries unanswered. It is therefore the aim of this paper to evaluate and analyse the different factors of fire occurrence in the southernmost province of Croatia – Dalmatia. To address this aim, we georeferenced 275 wildfires recorded in the study region in 2013 and tested several regression models. These models

included a number of socio-geographical and bio-physical variables we hypothesised to influence the fire occurrence in the region. The following research questions are raised and will be studied in this paper:

a) Do fires typically occur under different conditions and with different causes in different parts of Dalmatia?

b) What is the connection between littoralization and fire occurrence in Dalmatia?

c) Have socio-economic changes such as de-agrarisation, de-ruralisation and the development of tourism affected fire occurrence in Dalmatia?

d) Are areas undergoing depopulation and population ageing more fire susceptible?

e) What is the connection between physical-geographical elements and fire occurrence in Dalmatia?

## 2. Study area

This research covers the region of Dalmatia in Croatia (Figure 1). Dalmatia is a karst area in the Eastern Mediterranean, encompassing part of the eastern coast of the Adriatic with 416 islands and the central part of the Dinaric Alps with altitudes up to 1800 m above sea level. It is characterized by a typical Mediterranean climate, as well as a warm continental climate with hot summers in the northern parts. The majority of region is covered by grassland and shrubland (45%), while forests occupy one third of the territory. The interior is dominated by deciduous forests of Pubescent oak (*Quercus pubescens* Willd.) and Oriental hornbeam (*Carpinus orientalis* Mill.) while the coast is covered by coniferous forests of Aleppo pine (*Pinus halepensis* Mill.) and forests and maquis shrubland of Evergreen oak (*Quercus ilex* L.). Most of the region is less than 500 m above sea level, and is where the majority of the population is located.

Our study area is comprised of two administrative units – Šibenik-Knin County and Split-Dalmatia County – covering a total area of 7534 $km^2$ and with a population of around 565,000. The population increases to almost one million during the summer months, due to the influx of tourists to the coastal areas. The macro-regional centre is Split, the second largest city in Croatia. The hinterland is a mostly agricultural area which is sparsely populated, and economically underdeveloped. De-agrarisation and de-ruralisation are characteristic for the entire hinterland area, while the coast is highly urbanized and more economically developed, with tourism as an important branch of the economy. The islands are sparsely populated due to a long history of emigration.

Dalmatia, as part of Croatia and the Mediterranean, faces problems similar to those of other Mediterranean regions. In the 1998-2008 period, 91,705 fires occurred in Croatia, 31.7% of which occurred in Dalmatia with 38.9% of total burnt area recorded in the region. Although agricultural land holds the highest proportion in total burnt area on the national level, coastal Croatia is dominated by forest fires. Around 76% of forest fires and 93% of burnt forest areas are found in coastal parts of Croatia. There are two critical periods, during which most of the forest fires in Croatia occur. Between 1992 and 2007, the majority of fires occurred during the summer (July – August) in Croatian coastal areas, accounting for 30.8% of the total number of fires. The other critical period is early spring (February, March, April), when the majority of fires occurred in continental Croatia (Jurjević et al., 2009).

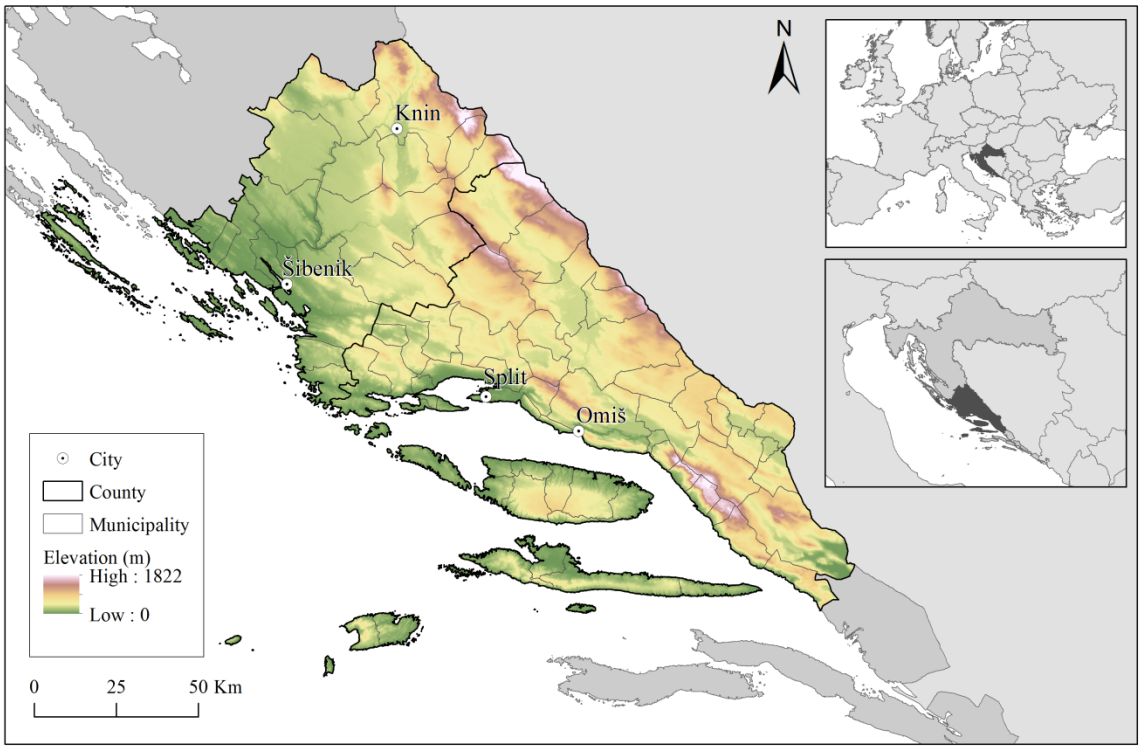


Figure 1. The study area encompasses two administrative regions in Dalmatia, Croatia.

## 3. Data and methods

### *3.1. Data*

This paper analyses the fires which occurred in two Dalmatian counties in 2013. Compared to long-term averages from 1981 to 2010, fire season of 2013 on the Adriatic coast was average or slightly above average which makes it suitable for this research (Tomašević & Vučetić, 2014). Of the 771 fires recorded in that year, the 275 fires larger than 0.3 ha were taken for analysis. Those 275 fires accounted for over 98% of the total burnt area. The data on the **date of the start of the fires**, their **location** and the **area** they burnt as well as **the type of burnt vegetation** were taken from the Croatian National protection and Rescue Directorate (DUZS). The type of burn vegetation (from the DUZS database) was attributed to each fire-location by local fire-fighters in the field; therefore this category has been additionally checked using the Habitat map of

Croatia during georeferencing. In cases where a fire burnt different types of vegetation, we selected the type which was burnt the most, thus only one vegetation type has been attributed to each recorded fire. The vegetation types in the studied area were divided into seven categories: 1. coniferous forest; 2. deciduous forest; 3. mixed forest; 4. shrublands (maquis); 5. grasslands; 6. olive groves; and 7. other agricultural land.

The altitude variable in this research was calculated by using digital elevation data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER GDEM). Altitude was divided into 0-200 m, 200-500 m, 500-1000 m and >1000 m categories representing the main landscape features of the region.

The socio-economic data in this paper are based on the 1961, 1991 and 2011 population censuses as well as the 2003 Agricultural census and the 2013 Statistical Yearbook. They encompass data on general population change and population ageing, agricultural population change, tourism arrivals and land use. It should be emphasized that some of these processes must be observed over a longer period in order to show the changes in the landscape, such as land abandonment or urban sprawl which are proven to be linked with fire occurrence (Catry, Rego, Bação, & Moreira, 2009; Lampin-Maillet et al., 2010; Nunes, 2012; Sluiter & de Jong, 2007). Therefore we selected the period of 1961-2011 to represent the trend of overall demographic change in the study. For changes in agricultural population we have chosen the 1991-2011 period because of inconsistencies in Census methodology prior to the 1991 Census.

All data in this research were standardized to account for surface area variability of the units of study (municipalities) and their population sizes. Municipalities were selected for this research as they are the smallest administrative units for which our socio-economic data exist.

### *3.2. Methods*

All of the analysed 275 fires were georeferenced by using the Habitat Map of the State Institute for the Protection of Nature and the digital topographic map of the area (1:25,000) available from the Croatian State Geodetic Administration Database (DGU). This way we were able to calculate fire density (number of fires per 100 $km^2$) for each municipality in the studied area. With the aid of auxiliary data (the Habitat Map) we calculated the proportion of burnt areas for various types of vegetation as well as fire occurrence per surface area for each vegetation type.

The spatial distribution of fires and their spatial clustering were analysed with the Global Moran's Index and Anselin Local Moran's Index. The spatial units of the analysis were municipalities, but due to their different shapes and sizes we compared them to a 10x10 km fishnet overlay.

The analysis of factors which influence the fire occurrence in the region was analysed through multiple linear regression analysis (OLS). Regression modelling techniques are empirical approaches used in exploring the relationship between a dependent variable and a set of explanatory variables. Linear regression is frequently applied in modelling the drivers of fire occurrence or determining probability of fire occurrence on local, regional as well as continental scales (Koutsias, Martínez-Fernández, & Allgöwer, 2010; Martínez-Fernández, Chuvieco, & Koutsias, 2013; Oliveira et al., 2012). In this research, fire density (number of fires per 100 $km^2$) was used as the dependent variable, and the selection of independent variables was based on expert knowledge and literature (Martínez-Fernández et al., 2013; Oliveira et al., 2012). In line with our research question and available data, the independent variables were selected to represent the main processes we hypothesised could have an impact on fire occurrence. Variables representing population and population change (Koutisas et al., 2010; Martínez-Fernández et al., 2013), percentage of rural/agricultural population,

agricultural land and its changes (Martínez et al., 2009; Nunes, 2012;), tourism activities (Ganteaume & Jappiot, 2013) as well as different physical-geographical characteristics (Oliveira et al., 2012; Sebastián-López, Salvador-Civil, Gonzalo-Jiménez, & San-Miguel-Ayanz, 2008) have previously been established as drivers of fire occurrence in different studies in Southern Europe. The aforementioned variables were adapted to available data sources in Croatia and subsequently used in regression modelling.

Before including the variables in multiple regression analysis, multicollinearity of independent variables was checked by excluding variables if its pair-wise correlation with another variable exceeded 0.8. Subsequently, the variables were plotted to a scatter diagram to investigate the linearity of the relationship between the dependent and the independent variables.

The remaining variables considered in the modelling were:

- POP_CHAN61 (population change 1961-2011)
- USED_LAND (percentage of all types of agricultural land in total surface area in 2011);
- ABAND_ARABLE (percentage of abandoned agricultural land in 2011)
- AGRI_POP11 (number of people employed in the agricultural sector in 2011)
- CHAN_AGRI_POP (changes in number of people employed in the agricultural sector 1991-2011)
- AGRI_DENSITY (agricultural population density[2]);
- TOURIST_ARRIV (number of tourist arrivals in 2013)

[2]Not the same category as „population employed in agriculture“ because it includes subsistence farmers as well.

- ALTIT<200 (percentage of territory below 200 m altitude)
- ALTIT200-500 (percentage of territory between 200 and 500 m altitude)
- GRASS (percentage of territory covered by grasslands)
- MAQUIS (percentage of territory covered by Mediterranean shrubland)
- FOREST (percentage of territory covered by forests)

Various models were fitted and evaluated by including and excluding different independent variables in the model and analysing the subsequent changes in the overall model performance (regression diagnostics) as well as changes in the independent variables' coefficients. Afterwards the spatial autocollinearity of the residuals was checked via Global Moran's I. The final model consisted of four out of thirteen initially included variables. Taking into consideration that the data on vegetation type of burnt area was recorded for each fire, additional analyses were conducted on that variable. All analyses were done by SPSS 20 and ArcMap 10.3 software (Figure 2).

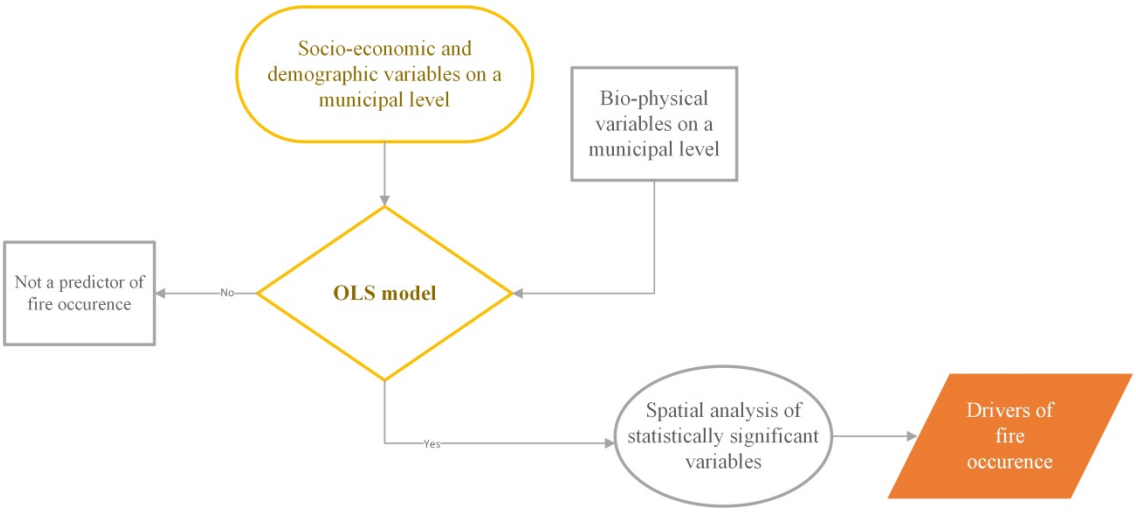


Figure 2. Data, methodology and structure of research

## 4. Results

### *4.1. Spatial distribution of fires*

The results have demonstrated that the Dalmatian littoral is the area in our study that is most affected by fires. Almost 1/5 of the total number of fires in the region have been recorded in the coastal municipalities of Šibenik and Omiš (Figure 3). Generally, a large number of fires occur in the northern hinterland and other coastal municipalities, with the exception of most islands (low number of fires). Almost 3000 ha of burnt area are recorded in total, which is around 0.4% of the total surface area of the studied region. The average size of a fire is 2 ha (median) or 10.8 ha (mean), demonstrating the prevalence of smaller fires in the region – three quarters of all studied fires were under 5 ha. Only 9 fires were larger than 100 ha, with the largest fire burning 440 ha.

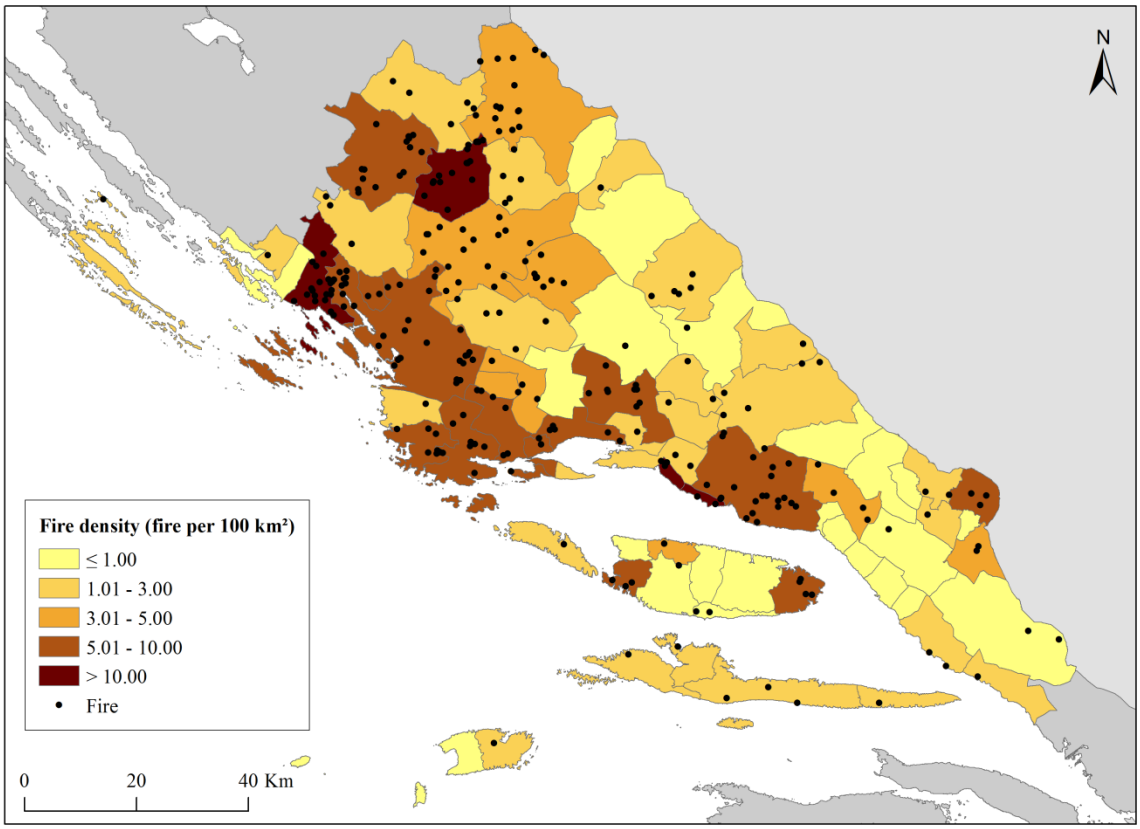


Figure 3. Distribution of fires in the studied region during 2013.

Spatial autocorrelation analysis showed that there is a statistically significant spatial clustering of fires in the studied region (Global Moran's Index=0.2, z=3.06, $p<0.01$). The Anselin Local Moran's Index analysed on both the municipal scale and on the 10 x 10 km fishnet demonstrated a statistically significant level of fires clustered in coastal areas around the cities of Šibenik and Omiš and the northern hinterland areas, with the analysis using the fishnet expanding further inland in the north and encompassing larger areas on the coastline (Figure 4).

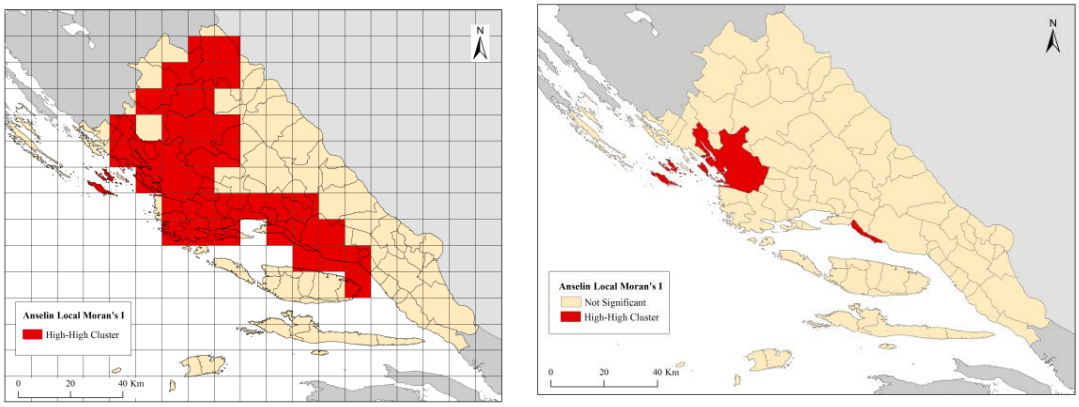


Figure 4. Spatial clustering of fires (Anselin Local Moran's I) using the 10x10 km fishnet (left) and on the municipal level (right).

In terms of fires in areas of different vegetation types, around 1614.8 ha (54.2%) of burned area was recorded in grassland and shrubland vegetation, 1249.9 ha (41.9%) in forests, and the remainder on agricultural land. In absolute values, most fires (147) and the second largest total burnt area (1021.4 ha) were recorded in areas with the vegetation type of grassland. Coniferous forest has a low number of fires (23), but the largest total burnt area (1150 ha). The largest analysed fires in the region occurred in the coniferous forest category (5 of the 10 largest fires; average size 50 ha). Apart from the grasslands, shrublands stand out with a large number of fires (75), and the third largest total burnt area (593.4 ha). Fires recorded in grassland and shrubland are generally

small, with the mean fire size around 7 ha. The deciduous forest category is characterized by a relatively low number of fires and a low total burnt area (Figure 5).

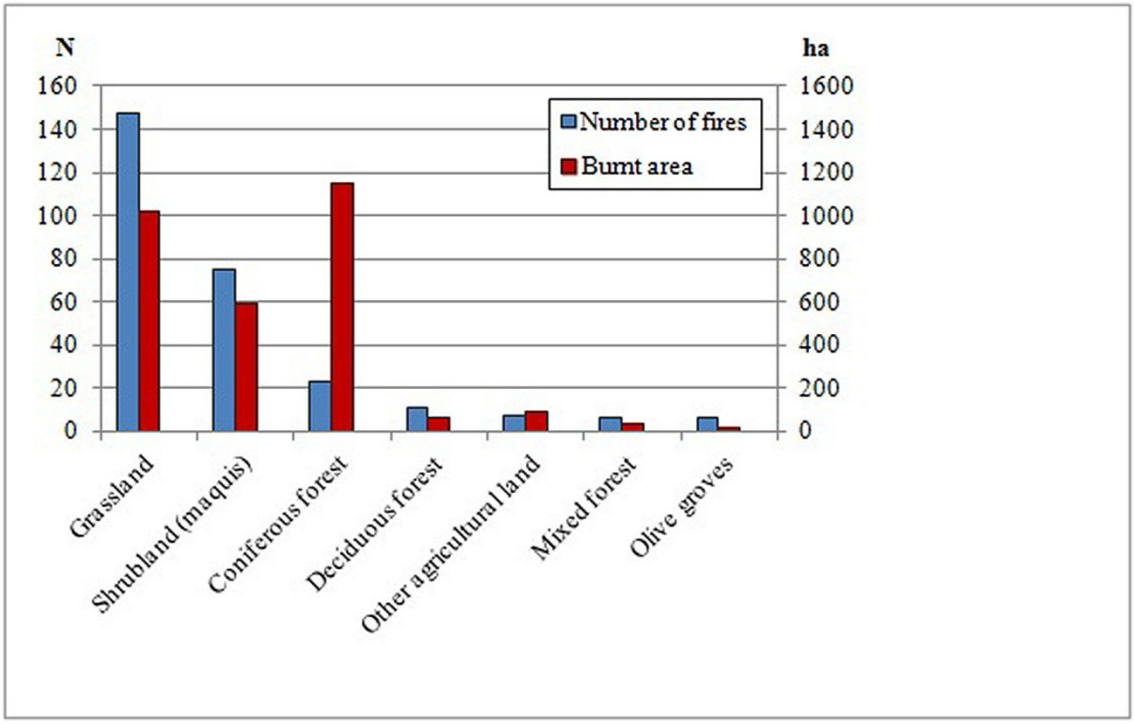


Figure 5. Number of fires and size of burnt area for the main vegetation categories

Regarding relative values, shrubland stands out as having the highest fire occurrence per surface area (1.32 fires/1000 ha) and the second highest percentage of burnt area (1.1%). Apart from shrubland, a high percentage of burnt area is recorded in the coniferous forest category (1.92%). In relative shares of fire occurrence and burnt area the lowest values were recorded in the deciduous forest category. Regarding the fire susceptibility of agricultural land, olive groves show relatively higher values for both fire density and burned area than other agricultural categories (Figure 6).

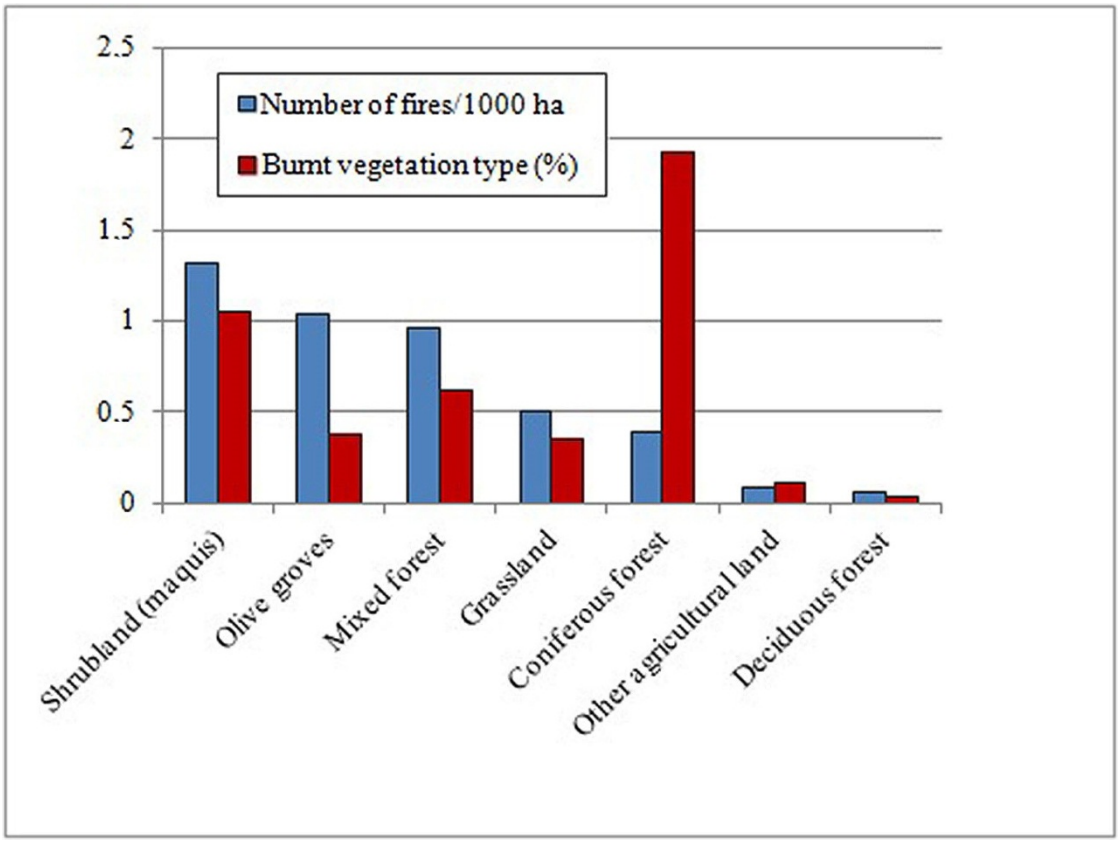


Figure 6. Number of fires/ha and percentage of burned vegetation for the main vegetation categories

### *4.2. Regression modelling results*

The global OLS model explained 41% of the variance of the dependent variable. Out of 13 original explanatory variables, three were significant at the 99% confidence level and one at the 95% confidence level (Table 1). They were

a) Population change 1961-2011

b) Percentage of territory < 200 m a.s.l.

c) Percentage of territory between 200 m and 500 m a.s.l.

d) Percentage of territory covered by grasslands

Table 1. Summary of OLS regression results

| Variable | Coefficient | StdError | t-Statistic | Probability | VIF |
|---|---|---|---|---|---|
| **Intercept** | -0.0351 | 0.01414 | -2.48 | 0.002* | --- |
| **POP_CHAN61** | 0.00018 | 0.00003 | 5.30 | 0.000* | 1.1 |
| **ALTIT<200** | 0.00048 | 0.00015 | 3.16 | 0.000* | 1.8 |
| **ALTIT200-500** | 0.00050 | 0.00019 | 2.57 | 0.005* | 1.7 |
| **GRASS** | 0.00047 | 0.00020 | 2.27 | 0.028* | 1.1 |

## 5. Discussion and conclusion

Our results have demonstrated that several factors play a role in fire occurrence in our study region. They include bio-physical factors such as altitude and vegetation, but socio-geographic and demographic factors cannot be discounted either.

### *5.1. Vegetation*

Regarding vegetation, the results show that grassland and shrubland are the most fire-prone land cover types in absolute terms. These two vegetation categories account for 54.2 % of total burnt area and 80.7% of total number of fires. Grassland was also a statistically significant variable in OLS model, positively related to fire occurrence. The Mediterranean shrubland, despite having the highest fire occurrence in relative terms, (1.32 fires/1000 ha) was not a significant predictor of fire occurrence in the model. This can be considered unusual compared to other studies in the Mediterranean, where shrubland is the most fire-prone vegetation type and an important variable in the models of fire danger (Ganteaume & Jappiot, 2013; Mouillot et al., 2003; Nunes et al., 2005; Oliveira et al., 2012). The role of shrublands in fire occurrence was confirmed in earlier

studies of fire susceptibility of different vegetation types in Dalmatia as well (Durbešić, 2012).

To understand this, we have to analyse the spatial distribution of grasslands and shrublands in the region. The category of Mediterranean shrubland is almost exclusively confined to islands and Northern Dalmatian littoral (Figure 7). At the same time, the very fire-prone area of the Northern Dalmatian littoral is characterized by a very high percentage of grasslands (Figure 8). Through a more detailed analysis of the vegetation category, it appears that in these municipalities with high percentage of grasslands, it was often the shrubland rather than the grassland that was burning. This was despite the shrublands' relatively lower share in area surface. Therefore, by generalizing data on a municipal level, a certain level of data loss has evidently occurred, emphasising the need for a more detailed study of vegetation outside the OLS model.

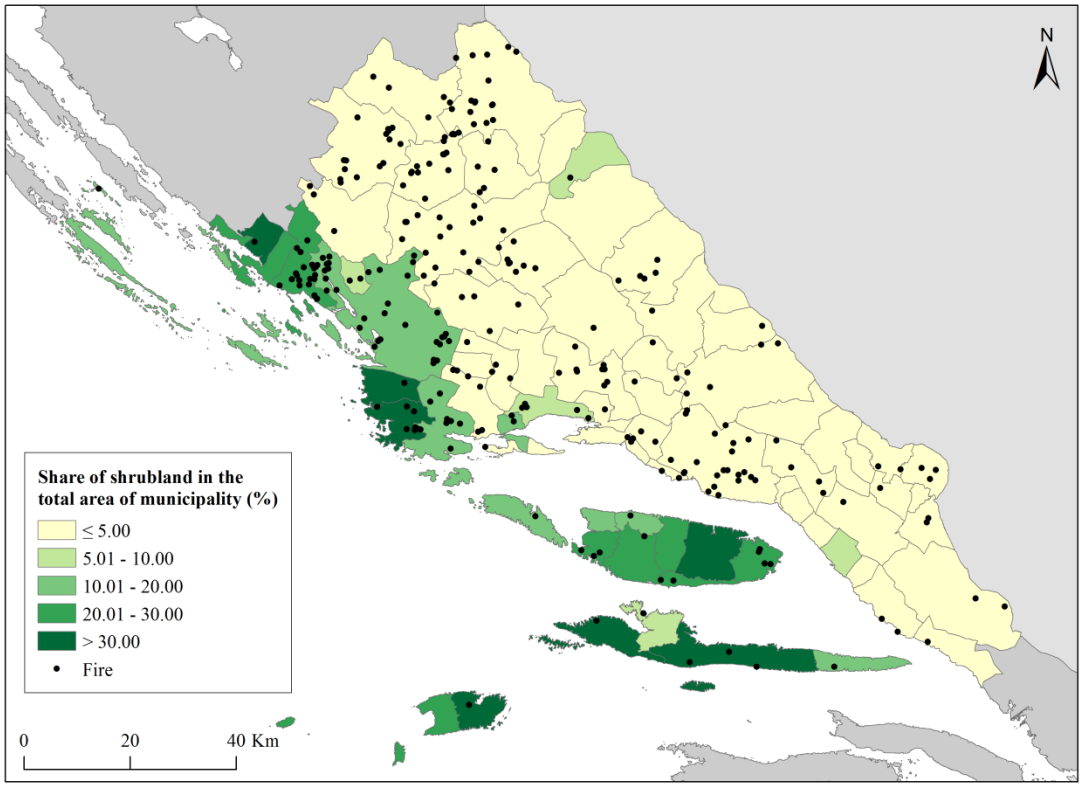


Figure 7. Percentage of shrubland in total area surface of Dalmatian municipalities

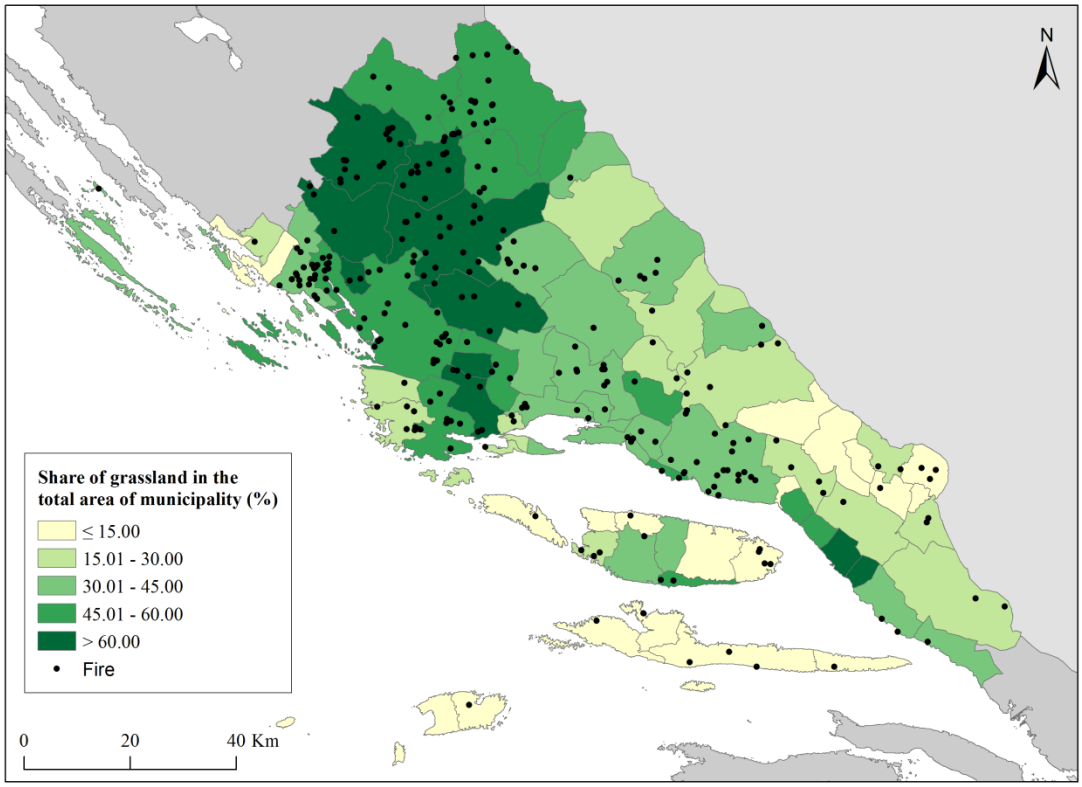


Figure 8. Percentage of grasslands in total area surface of Dalmatian municipalities

Additional problems could have arisen from the definition of the grassland/shrubland category itself. These types of vegetation are naturally highly intermingled and there is no strict border separating grasslands and low shrublands from the Mediterranean maquis. Grasslands and shrublands can be seen as different stages of the process of secondary succession of vegetation on abandoned pastures or arable land (Bonet, 2004; Casado et al., 1986) which makes their precise mapping and categorization a difficult task, but also points to the importance of agricultural abandonment and cessation of pasturing in the analysis of fire occurrence.

In other parts of the Mediterranean most studies have also concluded that shrubland is the cover type most likely to burn (Ganteaume & Jappiot, 2013; Moreira, Vaz, Catry, & Silva, 2009; Nunes et al., 2005), but grassland also appears as an important variable in the models of fire danger (Martínez-Fernández et al., 2013;

Oliveira et al., 2012). Research in Corsica showed that low shrublands (5.7%), mixed shrub-grasslands (6.3%), and grasslands (5.8%) are the vegetation types that were most affected by fires, indicating that fires occurred more frequently in the middle and early stages of succession (Mouillot et al., 2003). Research in Portugal showed that different fire types characterize different types of land cover; shrubland cover is known for fires in the small and middle size category, whereas maritime pine is where the larger fires tend to take place (Nunes et al., 2005). In other parts of the world, e.g. sub-Saharan Africa, the herbaceous vegetation proportion is an important factor in relation to fire occurrence (Mbow, Sambou, Ba, & Goudiaby, 2003; Sá et al., 2011). Similar results have been gathered by this research as well.

The connection between fire occurrence and shrubland is usually explained by the process of land abandonment in rural areas which has been evident in most parts of the Mediterranean for the last one hundred years. The rapid expansion of first grasslands and later shrubland onto abandoned fields results in fuel accumulation and thereby an increased fire risk (Moreira, Rego, & Ferreira, 2001; Mouillot, Ratte, Joffre, Mouillot, & Rambal, 2005). This process is driven by many factors including environmental, socio-economic, and political constraints such as a high proportion of wildland vegetation, distant location, low mechanization level, high unemployment and a low or ageing population (Moreira et al., 2001; Mouillot et al., 2005; Viedma, Moity, & Moreno, 2015). Agricultural activities have been decreasing in Croatia since the beginning of 20th century, and the most significant decline took place after World War II, during the socialist era. In the period 1948-1991 the share of the agricultural population in Dalmatia decreased from 72.1% to 3.4%, leading to massive land abandonment. At the same time, there was growth in the secondary and tertiary sectors, particularly in tourism which has become the most important economic activity in the

study area – especially since 1970s (Glamuzina & Glamuzina, 1996; Nejašmić & Toskić, 2013). Similar trends have been recorded during post-socialism: in the 1991-2011 period, 54 out of 74 municipalities in our study recorded a significant decrease in the number of employees in agriculture, and, at the same time, a 7% increase of the 323-*Mediterranean sclerophylle vegetation* category occurred in the study area[3] during the 1980 – 2010 period, with the strongest rate of increase happening from 1990 to 2000. Similar research in the area of Dalmatia which included analyses on a centennial basis has also established a strong connection between agricultural abandonment and the process of shrubland expansion (Fuerst-Bjeliš, Cvitanović, & Durbešić, 2015).

As well as shrublands, coniferous forests have demonstrated high fire susceptibility and have the highest average burnt area per fire in our study region. Coastal coniferous forests in Dalmatia are dominated by the widely distributed Aleppo pine (*Pinus halepensis* Mill). This species has had an important role in planned reforestation interventions of degraded karst vegetation in Dalmatia, especially after World War II. To date it shows continuous and intensive expansion in Dalmatia due to not only reforestation but also its natural proliferation ability and its ability to regenerate on burnt areas (Prgin, 2005; Tekić, Fuerst-Bjeliš, & Durbešić, 2014). The Aleppo pine is a pyrophite species, meaning that fire helps its reproduction but also eliminates competition which aids young plants. Natural restoration of the Aleppo pine is so successful and abundant that it prevents the growth of other species like the Evergreen oak (*Quercus ilex* L.). The studies showed that the lack of native vegetation in areas affected by fire makes the expansion of Aleppo pine in Dalmatia invasive (Dubravac, Vrbek, & Lalić, 2006). Aleppo pine forests are extremely flammable and represent approximately 1/3 of the total annual burnt area in the Mediterranean (Quezel, 2000).

[3] according to Corine Land Cover database

In this analysis, coniferous forests are characterized by large burnt areas but a relatively lower fire occurrence/ha. The development of severe and large fires is made more likely by the large amount of fuel in the canopy and on the forest floor (Nunes et al., 2005). Lack of forest cultivation in the studied area (i.e. reducing the number of plants per area and clearing the lower branches and underbrush) and the accumulation of wood mass greatly increases the risk of severe fires in the forests of Aleppo pine (Mitsopoulos & Dimitrakopoulos, 2007; Rosavec, Šikić, Španjol, Barčić, & Vučetić, 2013).

### *5.2. Altitude*

In terms of altitude and fire occurrence, a negative correlation was established. Taking into consideration that the majority of fires are anthropogenic in origin, and that higher altitudes are more sparsely populated with weak traffic networks, this correlation is not surprising. Additionally, due to the orographic effect on precipitating clouds, higher altitudes have more precipitation (González, Palahí, Trasobares, & Pukkala, 2006). Furthermore, the average density and height of vegetation usually decreases as altitude increases. Forests turn into shrublands and grassland, and at the highest altitudes vegetation can disappear completely, preventing the possibility of accumulation of fuel for burning (Martínez-Fernández et al., 2013; Schoenberg, Peng, Huang, & Rundel, 2003; Sebastián-López et al., 2008). Similar results have been recorded in Catalonia, where most forest fires occur at elevations ranging from 0 to 700 m, while fire occurrence declines sharply above 700 m (González et al., 2006). In the model for Southern Europe elevation was also negatively correlated with fire occurrence (Sebastián-López et al., 2008).

### *5.3. Changes in population*

Regarding socio-economic and demographic factors, the only remaining statistically significant factor in our OLS analysis is the population increase in the 1961-2011 period which is positively correlated with fire occurrence. The results are in accordance with previous research which has demonstrated a correlation between an increase in population and an increase in fire occurrence (Catry et al., 2009; Ganteaume & Jappiot, 2013; Zumbrunnen et al., 2012). The research conducted by Costa et al. (2011) also suggests that areas with medium or high population density are comparatively more fire prone, but the total burnt surface area is smaller due to better and quicker fire-fighter intervention.

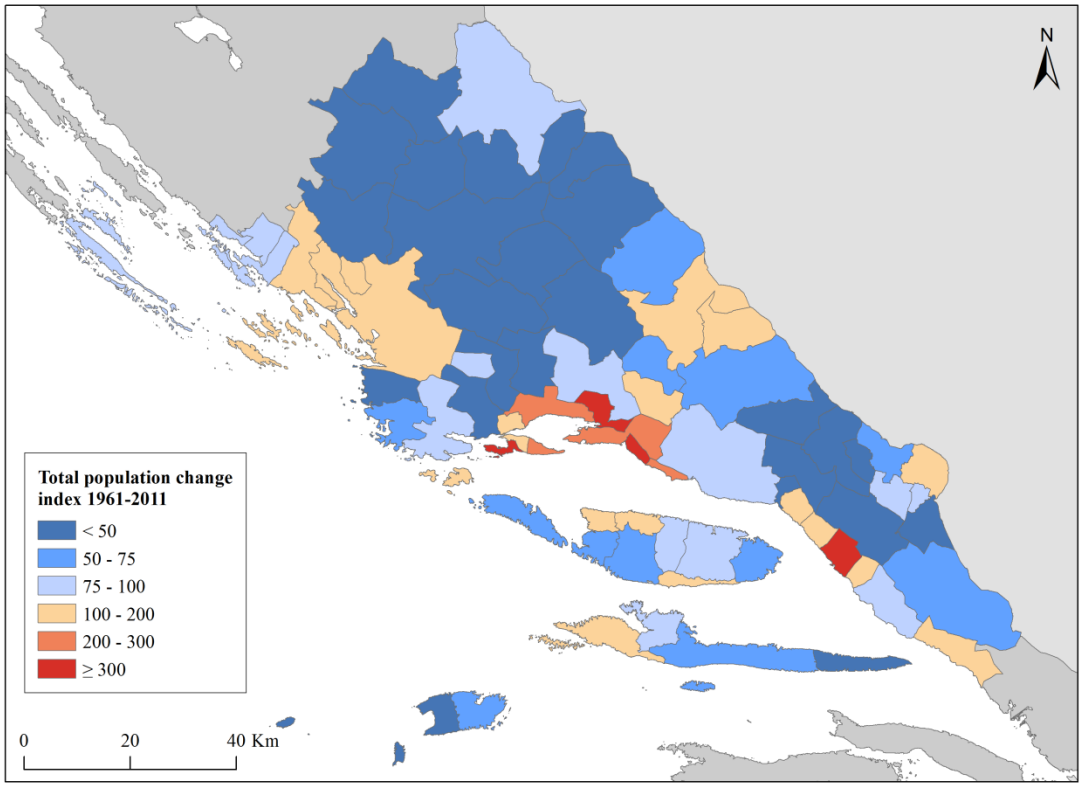


Figure 9. Population change index in Dalmatian counties 1961-2011

An increase in fire occurrence in the studied area has been recorded in municipalities with an increase in population (or a relatively small decrease) in the

1961-2011 period. They are mostly littoral municipalities with, on average, a higher population density, a higher percentage of urban population and higher economic activity, suggesting that there is a connection between population increase, littoralization and fire occurrence (Figure 9). The correlation between fires and areas with a population increase (in this case the littoral) has been confirmed by the spatial clustering analysis as well. The coastal area of Dalmatia combines several characteristics connected to fire occurrence – lower altitudes, favourable climatic characteristics, widespread Aleppo pine and maquis shrubland, strong socio-economic restructuring which favours agricultural abandonment and an overall increase in (urban) population.

Other, more stochastic factors which are hard to include into a model, could have also played a role in fire occurrence in the region. According to Badia, Saurí, Cerdan and Llurdés (2002), human causes of fire include smokers, assorted negligence, intentional fire-setting, waste dumps as well as other causes. Intentional fires can be consequences of land use conflicts that generally occur among sectors in rural areas, such as multiple forest uses or urbanization pressure. Consequently, fire risk increases closer to human settlements, especially in the wildland-urban interface, due to urban growth and the spread of recreational activities and tourism into forest areas (Gallardo, Gómez, Vilar, Martínez-Vega, & Martín, 2016; Lampin-Maillet et al., 2010; Romero-Calcerrada, Barrio-Parra, Millington, & Novillo, 2010). Darques (2015) also emphasizes that the highest fire risk exists in cities that have completely abandoned their agricultural activities while developing buildable land reserves (subject to land speculation and an increasing reliance on globally-supplied markets).

Some studies emphasized that areas facing land abandonment are frequently facing an ageing of the (agricultural) population, a factor that is positively correlated to

fire occurrence (Koutsias et al., 2010; Martínez-Fernández et al., 2013; Nunes, 2012). The older population is more accustomed to traditional methods in agriculture, including the use of fire for eliminating stubble, weeds and shrubs (Mamut, 2011; Velez, 2009). In this research, it is important to notice that an ageing population was evident in all study units although that variable was not indicated as statistically significant in any of the fitted OLS models. The complexity of human factors causing wildland fires is indicated by some contradictory results such as a concomitant correlation between fire occurrence and land abandonment but also relatively higher agricultural population (Martínez et al., 2009; Martínez-Fernández et al., 2013). One of the reasons why the ageing of population did not appear to be statistically significant in our research could be the relatively short period of our analysis due to which changes in demographic and socio-economic structures still had not manifested themselves in landscape change. Similar conclusions can be made about the changes in agricultural population and the percentage of people employed in agriculture.

To sum up, wildfires in the study area of the eastern Adriatic are a result of a combination of physical-geographical factors which in a way "encourage" the occurrence of fire. However, socio-economic changes also play a role in creating a fire-prone environment. These socio-economic changes manifest themselves in the landscape, particularly in connection to the abandonment of land and traditional agricultural activities on one hand and littoralization and urbanization on the other. These processes are two faces of the same trend, generally affecting all industrialized countries (Martínez et al., 2009).

In addition to the studied variables, temperature and precipitation (which were not included in this study) have also been noted as important. In the last decades in the Mediterranean region, temperatures have risen faster than the global average and model

projections agree on its future warming and drying, with a likely increase in heat waves and dry spells (Giorgi & Lionello, 2008; Lionello et al., 2014). The increase in summer temperatures and the decrease in rainfall will modify the water budget and prolong the drought periods, which will eventually lead to increased fire frequency and fire risk throughout the Mediterranean (Moriondo et al., 2006; Mouillot, Rambal, & Joffre, 2002; Sarris et al, 2013). The continuation of other trends recorded in this research, such as accelerated littoralization, and continual land abandonment in certain areas (which is beneficial to shrubland expansion) also tend toward an increase of fire occurrence, especially in the coastal, densely populated areas of Dalmatia where tourism is the most important economic activity.

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