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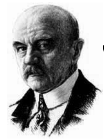

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FOREST FIRES IN PORTUGAL — THE CONNECTION WITH THE ATLANTIC MULTIDECADAL OSCILLATION (AMO)

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Abstract: The data on forest fires in Portugal in the period 1980–2015 were used in the research: the annual number of forest fires, the annual burned area and the average burned area per fire. Increasing trend of the annual number of forest fires (statistically significant at $p \leq 0.01$), non-significant increasing trend of the annual burned area and decreasing trend of the average burned area per fire (statistically significant at $p \leq 0.01$) were recorded. Portugal is the most endangered country by forest fires in comparison with the other European countries. During the research period, fires in Portugal covered 23.6% of the total burned area in five the most affected European countries (Portugal, Spain, France, Italy and Greece). In the research of the connection between forest fires and the Atlantic Multidecadal Oscillation (AMO) Pearson correlation coefficient (R) was used. Monthly, seasonal and annual values of the AMO index were used in calculations. All R values recorded for the annual number of fires were positive and statistically significant at $p \leq 0.01$. The highest values were recorded for August (0.543) and for summer (0.525). With the annual burned area all R values were also positive and the highest one on the seasonal level was for summer (0.359). With the average burned area per fire all R values were negative (−0.428 was recorded for winter). The results of the research could be applied in the fire danger forecast for periods of several months. Other climate indices should also be considered in future research.

Key words: forest fires, burned area, AMO, Portugal

Introduction

Portugal is extremely affected by forest fires. The main fire season is summer and the greatest damages during recent decades were recorded in 2003 and 2005. According to European Commission data, 425,726 ha were burned during 2003 (San-Miguel-Ayanz et al., 2016), which is 4.62% of the territory of Portugal. These fires burned over 280,000 ha of forests (Gomes, 2006). Only two years

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later, catastrophic fires occurred again and the burned area was 338,262 ha. Gomes & Radovanovic (2008) in the case of Portugal cite solar activity as a possible cause of fire. There is a possibility that the high energy particles of the solar wind penetrate into the magnetosphere and, after the opening of the electric field, come into contact with vegetation and cause fires.

Most European authors use the term “forest fires”, regardless of the type of the vegetation affected, so the term was used in this paper. However, for catastrophic fires, which are common in Portugal, more appropriate term is “wildfire”, which is used primarily in North America. As defined by the National Wildfire Coordinating Group (NWCG) a wildfire presents: “an unplanned, unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out” (https://www.hsdl.org/?view&did=34510).

In addition to undetectable environmental damage, forest fires significantly jeopardize forest production. Forestry is very important for Portugal. According to FAO (2015), 35.3% of the territory of Portugal is covered by forests, which are mostly opened (fragmented). The most common species are pines (*Pinus* spp.), which account for about 31% of the area under forest and cork oak (*Quercus suber* L.) with about 23%. Plantations of the *Eucalyptus* spp. account for 21%. The aforementioned tree species are extremely vulnerable to fire. In Portugal in recent decades, special attention has been given to the use of forest biomass, which is a renewable source of energy. The bulk of the biomass obtained is just from pine and eucalyptus. However, a significant part of the biomass is lost in fires (Milenković, Dedić, & Doljak, 2016).

The main aims of the paper are: the analysis of the forest fire trends using the newest available data, comparison of the results with the other European countries strongly affected by fires and the research of the climate influences of the Atlantic Multidecadal Oscillation (AMO). As for the AMO, it is the pattern of the natural variability of the sea surface temperature (SST) in the northern part of the Atlantic Ocean. It is characterised by the warm (positive) and cold (negative) phases that last 20 to 40 years.

The research in which forest fires were brought into connection with the AMO was primarily for some parts of North America (Sibold & Veblen, 2006; Skinner, Shabbar, Flannigan, & Logan, 2006; Schoennagel, Veblen, Kulakowski, & Holz, 2007). Milenković and Barović (2015) determined the sinphase correlation between the AMO and the annual burned area for the entire territory of the United States. However, research on the effects of the AMO and the other climate indices on forest fires in Europe is less often conducted. This paper should be a contribution to this research.

Data and methods

The main source of the data on forest fires in Portugal was the European Commission report (San-Miguel-Ayanz et al., 2016):

– http://forest.jrc.ec.europa.eu/effis/reports/annual-fire-reports/

The data on forest fires in Portugal in the period 1980–2015 cover:

– the annual number of forest fires – N;
– the annual burned area – B;
– the average burned area per fire – A.

The average burned area per fire was determined on the basis of the other two items (A=B/N).

For these datasets linear trends were determined. In addition, statistical significance of linear trend was determined for (n-2) and on the basis of the coefficient of determination (R^2). For the testing of the significance t test was used:

$$t = R\sqrt{\frac{n-2}{1-R^2}} \qquad (1)$$

where n — the length of the series.

Monthly and seasonal values of the AMO index were used in the research. The AMO index data were downloaded from the Earth System Research Laboratory, National Oceanic & Atmospheric Administration, U.S. Department of Commerce:

– http://www.esrl.noaa.gov/psd/data/correlation/amon.us.data

For the calculation of correlation Pearson correlation coefficient (R) on the basis of linear trend was used. Statistical significance was tested on $p \leq 0.05$ and $p \leq 0.01$. Calculation did not use the data for the period October to December, since the main fire season in Portugal is in summer.

Results and discussion

Forest fires — linear trends

In Portugal in the period 1980–2015, an increasing trend of the annual number of forest fires was recorded (Figure 1). It was determined that the trend is statistically significant at $p \leq 0.01$.

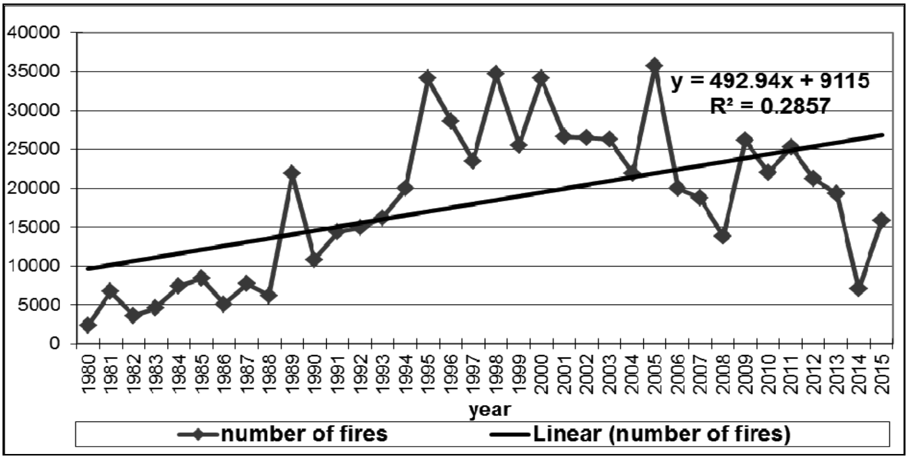

Figure 1. The annual number of forest fires in Portugal (1980–2015)
Source: authors on the basis of San-Miguel-Ayanz et al. (2016)

An increasing trend of the annual burned area was also noted. (Figure 2). The increase is slow and the trend is not statistically significant at $p \leq 0.05$.

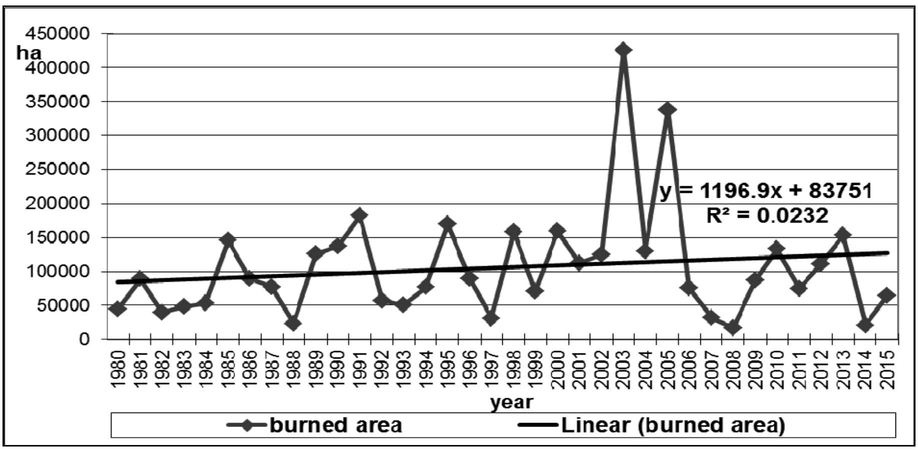

Figure 2. The annual burned area in Portugal (1980–2015)
Source: authors on the basis of San-Miguel-Ayanz, et al. (2016)

In accordance with the previously shown data, a decreasing trend of the average burned area per fire was recorded (Figure 3). The trend is statistically significant at $p \leq 0.01$.

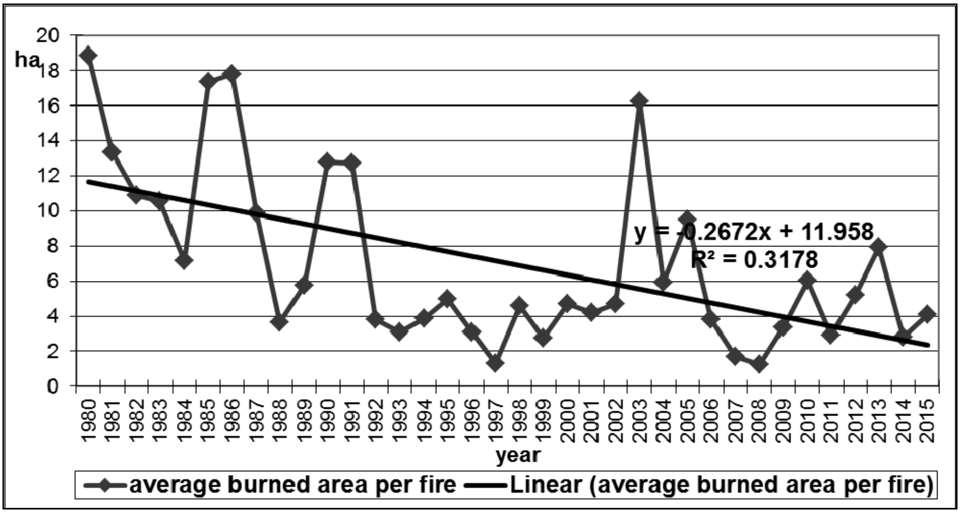

Figure 3. The average burned area per fire in Portugal (1980–2015)
Source: authors on the basis of San-Miguel-Ayanz et al. (2016)

Thus, in Portugal in the period 1980–2015, the increase of the annual number of forest fires was significant, and the increase of the annual burned area was slow, so the decrease of the average burned area per fire was statistically significant.

Portugal, Spain, France, Italy and Greece are most endangered countries by forest fires in Europe (San-Miguel-Ayanz et al., 2016). It is interesting that only in Portugal there is a growing trend of the annual burned area (yet non-significant) and in the other four countries the trends are decreasing. The total burned area recorded in Portugal in the period 1980–2015 is approximately 23.6% of the total burned area in all five most threatened countries. Since Portugal is by far the smallest of these countries, it is clear that the share is disproportionately high. Thus, Portugal should be considered the most endangered country by forest fires in Europe.

Correlation between forest fires and AMO index

The results of the research of correlation between forest fires in Portugal and AMO index are shown in Table 1.

Table 1. Pearson correlation coefficient (R): Forest fires in Portugal (1980–2015) — AMO index

	AMO index											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Winter	Spring	Summer
N	0.493**	0.506**	0.494**	0.488**	0.482**	0.484**	0.502**	0.543**	0.513**	0.507**	0.509**	0.525**
B	0.169	0.148	0.313	0.257	0.249	0.285	0.353*	0.399*	0.421*	0.158	0.264	0.359*
A	-0.393*	-0.426*	-0.282	-0.304	-0.275	-0.245	-0.239	-0.249	-0.215	-0.428*	-0.300	-0.251

* significant at p≤0.05;** significant at p≤0.01; N — annual number of fires; B — annual burned area; A — average burned area per fire.

All the values of R for the annual number of fires and the annual burned area are positive (synphase correlation). On the contrary, all the values for the average burned area per fire are negative (antiphase correlation).

The highest values of R were recorded for the annual number of fires. On the monthly level, the highest values are for August (0.543), September (0.513), February (0.506) and July (0.502), and at the seasonal level for summer (0.525) (Figure 4). All these values are significant at p≤0.01.

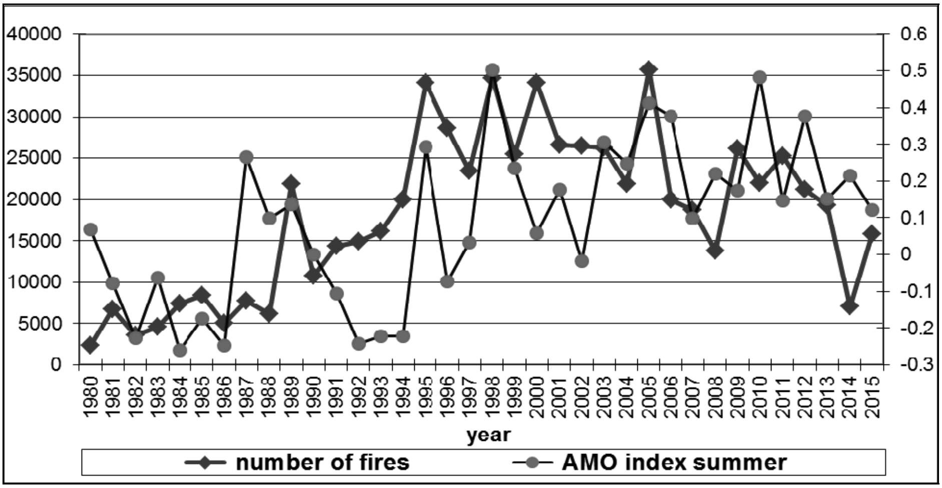

Figure 4. The annual number of fires in Portugal (1980–2015) — AMO index summer: R=0.525 (significant at p≤0.01)
Source: authors on the basis of San-Miguel-Ayanz et al. (2016) and http://www.esrl.noaa.gov/psd/data/correlation/amon.us.data

For the annual burned area the highest values of R were recorded in September (0.421), August (0.399) and July (0.353). Accordingly, the highest seasonal value is for summer (0.359). The values are significant at p≤0.05.

For the average burned area per fire the R value for winter is −0.428 (Figure 5), whereas for February −0.426. The values are also significant at p≤0.05.

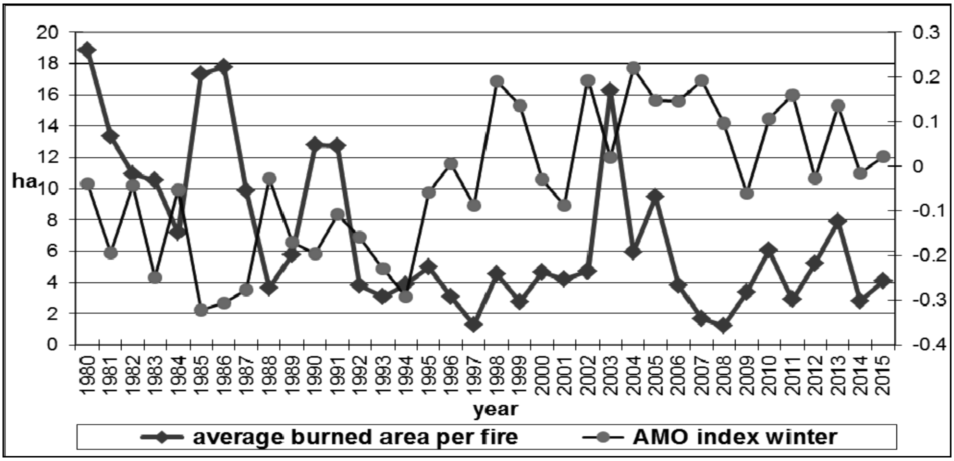

Figure 5. The average burned area per fire in Portugal (1980–2015) — AMO index winter: R=−0.428 (significant at p≤0.05)
Source: authors on the basis of San-Miguel-Ayanz et al. (2016) and http://www.esrl.noaa.gov/psd/data/correlation/amon.us.data

In contrast to these results, similar research for forest fires in France indicated that the highest values of R were recorded for the AMO index and the annual burned area, as well as the average burned area per fire. It is interesting that in this case all values of R (for the annual number of fires, the annual burned area and the average burned area per fire) were negative (Milenković, Ducić, Burić, & Lazić, 2016).

Results of the research of the connection between the AMO index and forest fires could be applied in forecasting fire danger for periods of several months. However, in the future the other climate indices should also be considered, for example the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO). The forecast of the fire risk should be based, not only on climate indices, but also on the analysis of the Sun activity (Radovanović et al., 2015; Radovanović, Vyklyuk, Milenković, Vuković, & Matsiuk, 2015). The possibility that the climate indices, as well as forest fires, are under the influence of the process on the Sun should also be considered.

Conclusion

In the period 1980–2015, Portugal was the most affected country by forest fires in comparison to the other European countries. The data analysis showed a statistically significant (at p≤0.01) increasing trend of the annual number of fires. A non-significant increasing trend of the annual burned area was also recorded. With the average burned area per fire statistically significant (at

$p \leq 0.01$) a decreasing trend was determined. In the research of the connection between the Atlantic Multidecadal Oscillation (AMO) and the forest fires in Portugal in the period 1980–2015 a synphase correlation was determined for the annual number of fires and the annual burned area, and an antiphase correlation for the average burned area per fire. The highest values of the Pearson correlation coefficient were recorded for the number of fires. On a monthly basis, the highest value was for August (0.543), and on a seasonal basis for summer (0.525) — significant at $p \leq 0.01$. For the annual burned area the highest value on a seasonal level was also recorded for summer (0.359) and for the average burned area per fire for winter (−0.428). Further research of the impact of the AMO and the other climate indices could contribute to the improvement of the long-term forecast of the risk of forest fires.

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