Historical relationship between climate and fire regime in Asagı Köprüçay Basin (Antalya, Turkey)

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Abstract

In this work, we analyzed fire regime, climatic trend and relationships between fire and climate in the Asağı Köprüçay basin (Antalya, Turkey), an area of about 205,000 hectares. The study area is intensively affected by forest fires. Since the historical data on fires were consistent in detail after 1979, we analyzed the historical period 1979-2009. Regarding the climate analysis, data of four meteorological stations representing the different climatic conditions of the study area were taken into consideration. Daily records of maximum, mean and minimum temperatures, precipitation, wind speed and direction, relative humidity were used for the analysis. In the study period, mean and minimum temperatures showed a statistically significant increasing trend with time. The trends of fire number, burned area and meteorological data were analyzed by using correlation and linear regression techniques. Regarding the historical trends in terms of fire number, no statistically significant trends were observed, because of the high inter-annual variability of the data. The burnt areas showed a general increasing trend that is not statistically significant. No statistically significant correlation between fire number and burnt area was observed. The relationships between weather parameters and the main indicators of fire activity: fire days (FD, at least 1 fire per day), large fire days (LFD, at least 20 hectares per day), multiple fire days (MFD, more than 1 fire per day), were investigated by the application of the logistic regression. The historical relationship between weather variables and the main indicators of the fire activity (FD, LFD, MFD) were analyzed by a set of logistic regression models. In particular, 4 models provided the best combined response in predicting the different fire activity indices on both annual and seasonal data. The different models were characterised by low estimation accuracies for FD, while the best results were obtained for LFD. Temperature and relative humidity are the weather variables mostly correlated with the fire activity probability as predicted by the logistic models. An increase in the accuracy was generally obtained where the 3 and 7 days minimum and maximum average values were used instead of the daily mean values of the weather variables.

Keywords: Antalya, Climate, Fire, Logistic regression, Turkey.

1. INTRODUCTION

Total forested area in Turkey is 21.5 millions of hectares (27.6% of all land) (Anon. 2011). The largest amount of forests is represented by Mediterranean type ecosystems such as *Pinus brutia* forests and maquis, mainly dominated by *Arbutus andrachne*, *Arbutus unedo*, *Calicotome villosa, Ceratonia siliqua*, *Quercus coccifera*, *Myrtus communis*, *Phillyrea latifolia*, *Pistacia terebinthus*, *Pistacia lentiscus*, *Spartium junceum, Styrax officinalis*. These fire prone ecosystems especially appear in southern and western parts of Turkey. Each year, many forest fires occur in these areas. Thousand hectares of forested areas are affected by fires; additionally, they threat the rural and urban life. Forest fires are the most important issues of the forestry management activities in south and western Turkey. Big amount of the budget dedicated to forestry practices are spent for fire prevention and suppression efforts. In this context, investigations on fires and on the related issues are crucial in order to improve fire management. Weather conditions are one of the most important factors that influence forest fires (Pausas, 2004) and directly affect fire ignition, spread and severity. Because of that, the relationships between forest fires and weather conditions were analyzed in this work and for this goal the trends of forest fires and weather factors were firstly defined and then the relationships between these components were analyzed for the study area.

2. MATERIAL AND METHODS

In Turkey, one of the areas most intensively affected by forest fires is the Antalya province; the Aşağı Kopruçay basin, with 8 forest provinces and 80 forest villages, was defined as the study area in the work (Figure 1). The study area is approximately 205,000 hectares of which about 120,000 hectares are represented by forests, and about 70,000 hectares by agricultural areas. The main vegetation type in the study area is characterized by *Pinus brutia* forests that have been intensively affected by fires.

Figure 1. Map of the study area. Legend indicates the altitudinal variation

The fire data from the period 1979-2009 were used in this work. During this period, 1084 forests fires occurred in the area and about 30,000 hectares were burned. The years with the highest burned areas were 2008, 1994, 1979 and 2000 respectively. The year 2008 was especially important since the largest fire of the history of Turkey was observed in this year, with a burned area of more than 15,000 hectares. Moving to the meteorological analysis, we used the data of Antalya and Manavgat weather stations, which represent an indicator of the typical weather conditions of the lowlands and coasts of the study area, where the fires are mostly concentrated. The trends of fire number, burned area and meteorological data were analyzed by correlation and linear regression techniques. Regarding the relationship between historical weather and fires, only the meteorological data showing important correlations with fire data were reported in the text. The weather data were analyzed considering both the average annual and seasonal (July-October) values, in order to investigate the historical trends and the relationship between fires and weather. The analyses were carried out with the R software.

The relationships between the weather parameters and the main indicators of fire activity: fire days (FD, at least 1 fire per day), large fire days (LFD, at least 20 hectares per day), multiple fire days (MFD, more than 1 fire per day) were detected by the application of the logistic regression, which is one of the main methods used in this field (Martel et al. 1987, Andrews et al. 2003). Due to the large numbers of weather parameters, the first steps of the analysis were conducted by automatic methods, mainly by the stepwise regression, in order to find the weather parameters characterized by high values of significance. The analysis was conducted (i) on daily basis using the mean values of the weather parameters, and (ii) on a moving window of 3 days and 7 days calculating the maximum, the minimum and the summation of the values observed during the period. The estimates provided by the logistic regressions are characterized by a large number of statistical indicators, and the evaluation of the best models can be obtained only by an interactive process considering an integrated response between different parameters, mainly the classification accuracy, the Hosmel-Lemeshow test, and the values of the coefficient of determination (r^2). Two different groups of estimations were realized, considering two different sets of daily data, covering the entire years (1st set) and only the period from May to October (2nd set). The two set were characterized by large differences in number of records (≈ 11,300 for annual data and ≈ 3,800 for seasonal data) and in the variability of the weather parameters; therefore, the statistics are affected by these aspects and the accuracy of the models should be analysed separately for annual and seasonal data. The use of the interactive methods (mainly stepwise regression) produced logistic models characterized by a large number of independent variables, and therefore may lead to a limited accuracy in predicting the values of the fire danger indices on new data not used in this developing phase. In addition these models, and the values of their independent variable coefficients, are characterized by a low explanatory content and by a high degree of cross correlation between variables characterised by similar physical nature. For this reason, a limited set of models were developed by manual selection of the independent variables by using both the results of the statistical tests and the evaluation of the accordance with the physical and theoretical expectations.

3. RESULTS AND DISCUSSION

Regarding the historical trends of fire number, it is important to highlight that no statistically significant trends were observed, because of the high inter-annual variability of the data. Similarly the burnt areas in time showed an increasing trend that is not statistically significant. When we look to the correlation between fire number and burnt area, there is an increasing correlation, which is not statistically significant. This correlation did not show a statistically significant trend even if the big fire of 2008 is excluded.

Regarding the trend of weather parameters in time, maximum temperature, relative humidity and cumulated rain (precipitation) did not show relevant statistical trends. On the other hand, the trends of mean and minimum temperatures showed increases in time and these changes were also statistically significant (Figure 2, 3). The most frequent wind directions were WNW, S, SSE and SSW and no significant trends for wind directions and frequencies were observed for the study area. The correlations between fires and mean and minimum temperatures were not statistically significant (Figure 4,5,6,7).

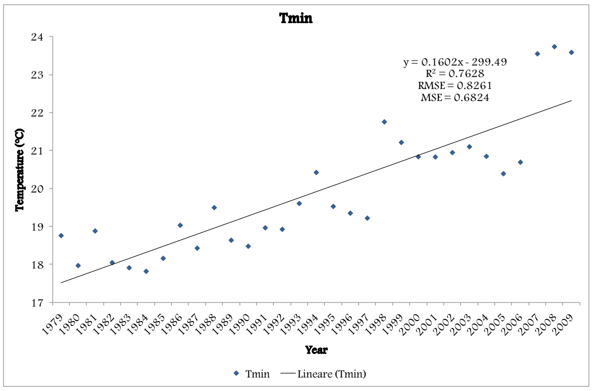

Figure 2. Minimum temperature trends: linear regression (slope significance < 0.0001)

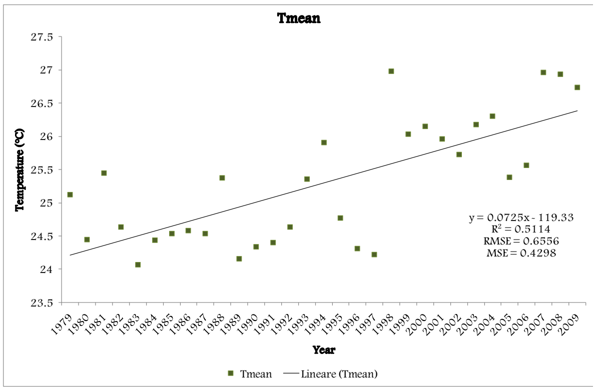

Figure 3. Mean temperature trends: linear regression (slope significance: <0.0001)

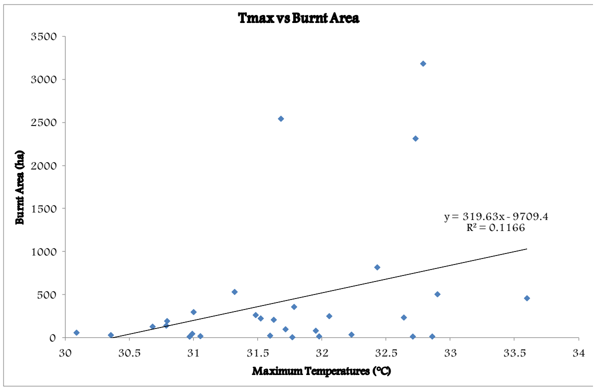

Figure 4. Correlation between Tmax and Burnt Area (excluding 2008)

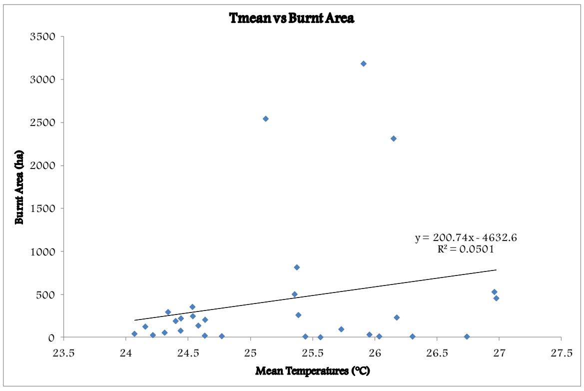

Figure 5. Correlation between Tmean and Burnt area.

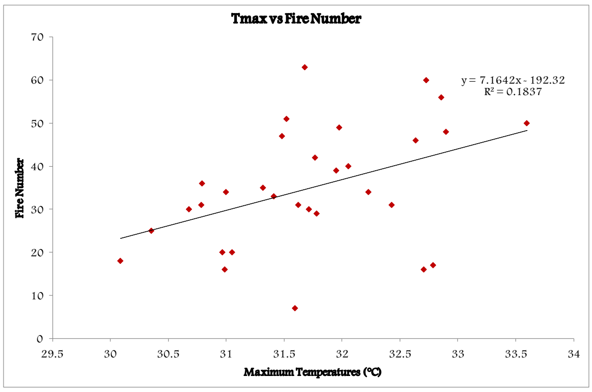

Figure 6. Correlation between Tmax and Fire Number

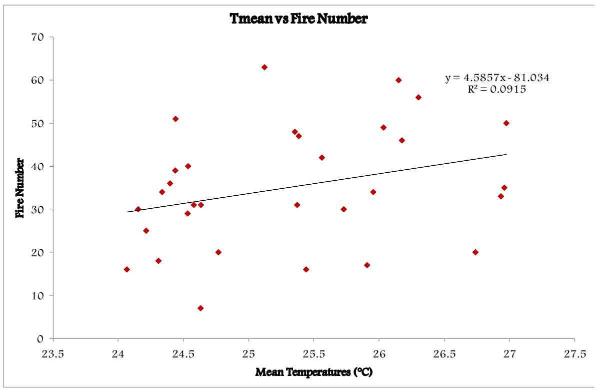

Figure 7. Correlation between Tmean vs Fire Number

Regarding the relationships between the weather parameters and the main indicators of the fire danger season (FD, LFD, MFD) we reported only a set of four logistic models (Table 1), developed by manual selection of the variables. These models provided the best combined response in predicting the different fire danger indices on both annual and seasonal data (Table 2); the statistical parameters provided by the logistic regression permitted to find the variables with the lower values of both the significance of the coefficients and the prediction accuracy. Table 3 reported the parameter estimates for the different models and dependent variables (FD, LFD, MFD).

Table 1. Independent variables included in the models. Tx3, Maximum value of the temperature observed on the previous 3 days; Tx7, Maximum value of the temperature observed on the previous 7 days; Tn3, Minimum value of the temperature observed on the previous 3 days; Tn7, Minimum value of the temperature observed on the previous 7 days; RHx3, Maximum value of the relative humidity observed on the previous 3 days; RHx7, Maximum value of the relative humidity observed on the previous 7 days; RHn7, Minimum value of the relative humidity observed on the previous 7 days.

Model n°	Independent variables
1	Tx3, Tn7, RHx3, RHn7
2	Tx3, RHx3
3	Tx7, RHx7
4	Tn3, RHn3

On both the seasonal and the annual data the different models (Table 2) are characterised by low estimation accuracies for the variable FD (correct classification lower than 33.6%), while the best results were provided by the variable LFD (correct classification greater than 82.5%). In few cases the Hosmer and Lemeshow test provided values lower than the P threshold of 0.05, and this is an indicator of lack of fit. This is true in particular for the models predicting FD by using annual data. The lack of fit is an indicator on limited generalization capacity on new data. The variable MFD is generally characterised by intermediate performances, with values of correct classification lower than 79.6% on annual data and 28.70% for seasonal data.

*Table 2. Statistical parameters used in order to define the accuracy of the models. ** Significance of the Hosmer and Lemeshow test (P=0.05) indicating no evidence of a lack of fit.*

Model n°	Dependent variable	Time step	Rescaled r^2	% Concord.	P-value Hosmer Lemeshow Chi-Square	% Correct classific.
1	FD	Annual	0.18	79.00	0.00	33.60
2	“	“	0.18	78.50	0.00	29.70
3	“	“	0.16	77.10	0.00	30.10
4	“	“	0.18	79.00	0.00	30.50
1	“	Seasonal	0.06	63.20	0.02	17.30
2	“	“	0.05	62.30	0.48**	17.30
3	“	“	0.03	58.30	0.58**	17.30
4	“	“	0.07	64.90	0.57**	17.30

Table 2. Continued

Model n°	Dependent variable	Time step	Rescaled r^2	% Concord.	P-value Hosmer Lemeshow Chi-Square	% Correct classific.
1	LFD	Annual	0.28	85.60	0.84**	94.80
2	"	"	0.23	84.40	0.35**	94.70
3	"	"	0.17	82.20	0.17**	95.00
4	"	"	0.27	86.30	0.01	94.10
1	"	Seasonal	0.23	85.70	0.91**	86.30
2	"	"	0.16	80.50	0.44**	84.70
3	"	"	0.09	72.90	0.92**	83.50
4	"	"	0.21	83.50	0.00	82.50
1	MFD	Annual	0.19	84.30	0.21**	85.10
2	"	"	0.18	83.30	0.58**	85.20
3	"	"	0.13	79.10	0.82**	79.60
4	"	"	0.20	85.50	0.84**	84.50
1	"	Seasonal	0.12	74.10	0.50**	54.40
2	"	"	0.10	72.40	0.17**	51.50
3	"	"	0.05	63.70	0.15**	28.70
4	"	"	0.13	76.90	0.63**	55.80

Table 3. Parameter estimates for the selected models.

Model n°	Time step	Dependent variable	Parameter estimates for the independent variables
1	Annual	FD	-2.41+0.02•Tx3+0.10•Tn7-0.03•RHx3-0.02•RHn7
2	Annual	FD	-3.05+0.12•Tx3-0.03•RHx3
3	Annual	FD	-2.65+0.12•Tx7-0.03•RHx7
4	Annual	FD	-3.22+0.12•Tn3-0.03•RHn3
1	Seasonal	FD	-1.14+0.09•Tx3-0.05•Tn7-0.02•RHx3-0.01•RHn7
2	Seasonal	FD	-1.37+0.06•Tx3-0.03•RHx3
3	Seasonal	FD	-0.91+0.05•Tx7-0.03•RHx7
4	Seasonal	FD	-1.00+0.04•Tn3-0.03•RHn3
1	Annual	LFD	-4.57+0.28•Tx3-0.15•Tn7-0.03•RHx3-0.08•RHn7
2	Annual	LFD	-6.55+0.19•Tx3-0.06•RHx3
3	Annual	LFD	-8.13+0.22•Tx7-0.04•RHx7
4	Annual	LFD	-4.29+0.15•Tn3-0.10•RHn3
1	Seasonal	LFD	-2.77+0.36•Tx3-0.32•Tn7-0.02•RHx3-0.07•RHn7
2	Seasonal	LFD	-6.91+0.20•Tx3-0.05•RHx3
3	Seasonal	LFD	-7.27+0.20•Tx7-0.04•RHx7
4	Seasonal	LFD	-2.97+0.11•Tn3-0.11•RHn3
1	Annual	MFD	-3.53+0.14•Tx3-0.02•Tn7-0.03•RHx3-0.03•RHn7
2	Annual	MFD	-0.15+0.12•Tx3-0.05•RHx3
3	Annual	MFD	-4.87+0.14•Tx7-0.04•RHx7
4	Annual	MFD	-3.33+0.11•Tn3-0.08•RHn3
1	Seasonal	MFD	-2.26+0.21•Tx3-0.17•Tn7-0.03•RHx3-0.02•RHn7
2	Seasonal	MFD	-3.10+0.10•Tx3-0.05•RHx3
3	Seasonal	MFD	-3.02+0.09•Tx7-0.04•RHx7
4	Seasonal	MFD	-1.60+0.05•Tn3-0.07•RHn3

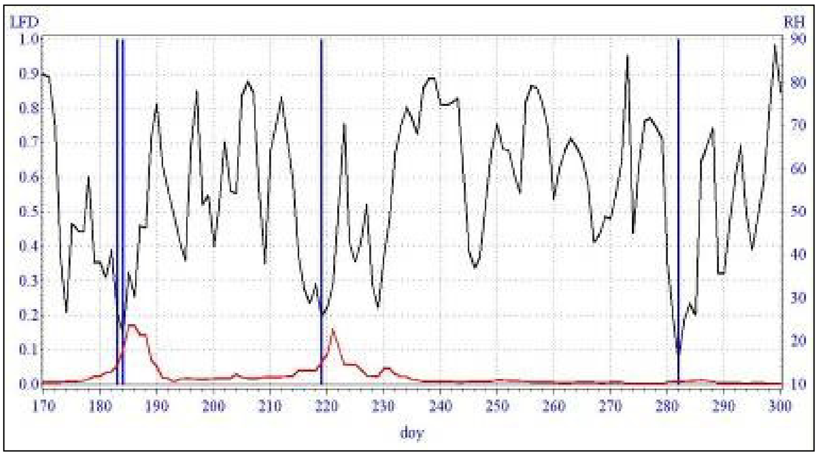

Figure 8. Estimation probability provided by the model n° 3 using annual data (red line); year 1998; the daily values of the relative humidity are also plotted (black line) in order to show the relationship with the actual events (LFD events, blue vertical lines). In many cases the lower peak values of relative humidity are associated with the short time probability of fires.

Temperature and relative humidity were the weather variables mostly correlated with the probability estimated by the logistic models, and therefore with the fire danger indices (LFD, MFD, FD). An increase on accuracy was generally obtained where the 3 and 7 days minimum and maximum values were used instead of the daily mean values of the weather variables; this fact is an indicator of a sort of summation of the short term effects of weather variables on fire danger indices; this is true in particular for the relative humidity; Figure 8 showed the pattern of the relative humidity, the relationship with the fire danger indices, and the associated pattern of probability. Relative humidity and temperatures are the variables that explain most of the variability of fire danger indexes, and showed a similar distribution of data and relationship with the estimated probability (Figure 9 and Figure 10). The explanatory value of the wind speed and precipitation is very low, and the stepwise regression found low values of significance for their coefficients.

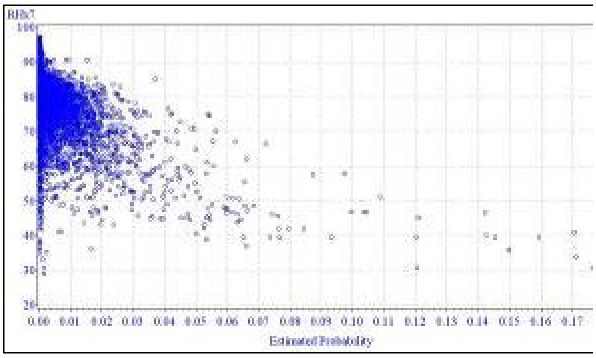

Figure 9. Relationship between the estimated probability provided by the model 3 and the maximum values of the relative humidity observed in the previous 7 days.

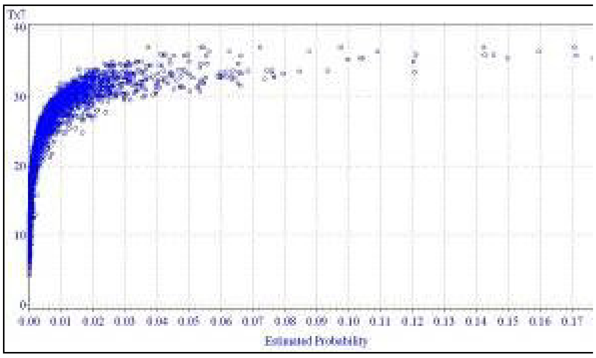

Figure 10. Relationship between the estimated probability provided by the model 3 and the maximum values of the temperature observed in the previous 7 days.

4. ACKNOWLEDGEMENTS

This work was partially funded by the European Union Seventh Framework Programme (FP7/2007-2013) under Grant Agreement 243888 ("FUME" Project - Forest fires under climate, social and economic changes in Europe, the Mediterranean and other fire-affected areas of the world)

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