



# Investigation of the relationship between burned areas and climate factors in large forest fires in the *Çanakkale* region

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**Abstract** Fires pose a serious threat to the forests that lay on the western and southern coastline of Turkey that start with North Aegean coasts and end with the provincial boundaries of Hatay. *Çanakkale*, a western province of Turkey, is located in the North Aegean boundary and its topography (Dardanelles Strait), climate, and vegetation cover combine to form an inviting recipe to forest fires. Although the province is located in a transitional zone in terms of climate and vegetation, each year it witnesses highly dry and hot fire seasons. Thus, large forest fires occur periodically. In this research, the relationship between the large periodic fires (larger than 100 ha) and the climate data was investigated, with a particular focus on the most severe 8 fire seasons from 1969 to 2007. We established that there is a relationship between 1977, 1985, and 1986 fire seasons and the climate data for the corresponding periods. The remaining 5 seasons in which conflagrations occurred were also found to coincide with the days with high daily severity indices

(DSR). These are 1969, 1977, 1985, 1987, and 2008. Additionally, 2008 was determined as the year with the highest fire risk, followed by year 1969.

**Keywords** Burned area · Climate factors · Daily severity index · Forest fires · Seasonal severity index

## Introduction

The forests under the administration of *Çanakkale* Forestry Department are under a high risk due to their vegetation covers, climate, and topographic properties. This region undergoes highly hazardous, hot and windy fire seasons each year. *Pinus brutia* (also known as Turkish Pine) is among the tree species which are highly sensitive to forest fires in Turkey. Despite of that, *Pinus brutia* has evolved to adapt in such major disturbances caused to the forest ecosystems such as forest fires (Naveh 1975; Tavşanoğlu 2010). Several studies have been carried out to investigate the fire behaviors of *Pinus brutia* forests (Kucuk et al. 2012; Bilgili and Kucuk 2008; Kucuk and Bilgili 2008; Kucuk and Bilgili 2007; Coşkuner et al. 2014). Combinations of *Pinus brutia* forests with maquis shrub lands pose even higher fire risks. In such forests, decreased closure increases maquis vegetation at the lower layer leading to an increased risk of fire (Saribaşak et al. 2010). Mediterranean maquis shrub lands showed the highest average fire intensity values among fuel types while the lowest fire intensity was observed in the grasslands (Salis et al. 2016). Assessing forests areas with carbon storage

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depends on the amount of by trees (Kaya 2009; Yucedag and Kaya 2016; Yucedag and Kaya 2017; Kaya et al. 2018a,b; Bozdogan Sert et al., 2019; Yucedag et al., 2019).

*Maquis* and *phrygana* scrublands are also important in evaluating processes such as desertification and fire hazards (Atalay 2011). Mediterranean climate is effective particularly in coastal and central regions of *Çanakkale* where forest fires occur on a large scale. This region however generally exhibits the characteristics of a climate referred to as *Marmara* climate which is a transitional climate between Black Sea and Mediterranean climates (Atalay and Mortan 1997; Sensoy et al. 2011).

In general, nine climate types are observed in Turkey. These are the Mediterranean climate, wet Mediterranean climate, partially wet Mediterranean climate, Black sea climate, partially Wet Marmara climate, steppe climate, partially dry central Anatolian climate, partially dry south east Anatolian climate, and continental east Anatolian climate (Koçman 1993; Akman 1999; Ozturk et al. 2010; Cetin 2019; Kaya et al., 2019; Cetin et al., 2019). Climate is important for forest planning and management (Cetin 2019; Kaya et al., 2019; Cetin et al., 2019). Atalay proposed a more general classification for the climate types in Turkey based on the climate classifications adopted on a global scale (Atalay and Mortan 1997) as follows.

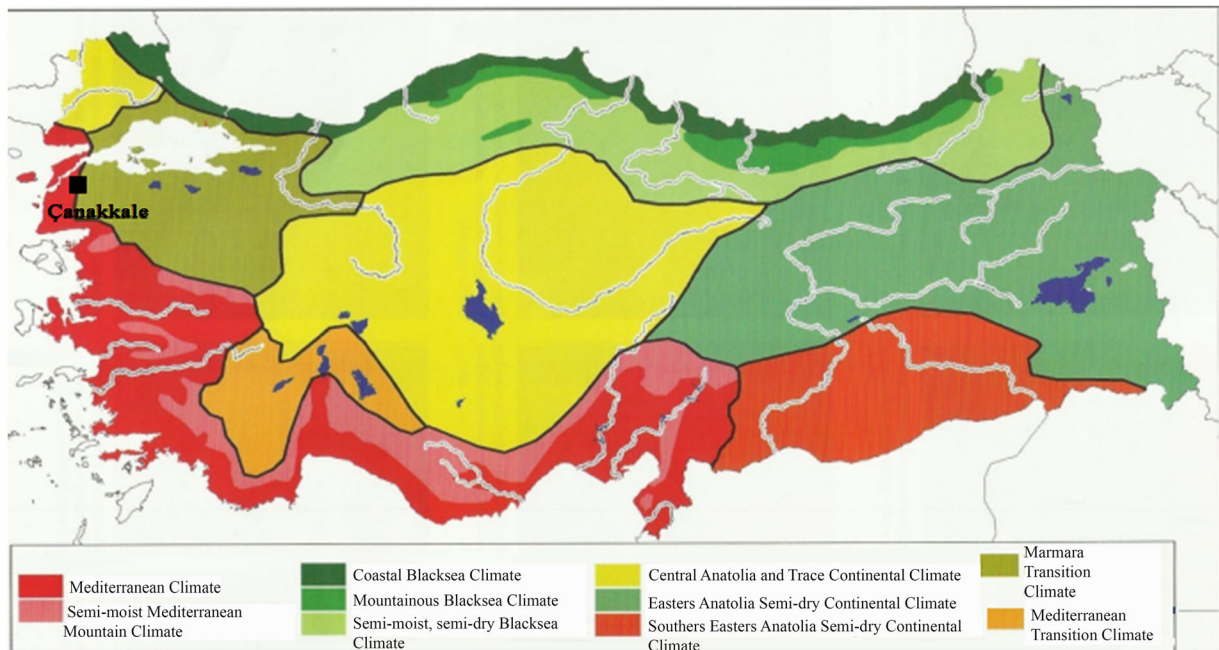
1. Continental climate
2. Mediterranean climate
3. Marmara (transitional) climate
4. Black Sea climate

Marmara climate is observed in the South of Marmara Region and the North of Aegean Region. This climate type has winters that are not as temperate as the Mediterranean climate's, and summers are not as rainy as in the Black Sea's. Because winters and summers are as cold and hot as their counterparts in the continental climate, many consider Marmara's climate a transitional one between the Black Sea and the Mediterranean climates (Fig. 1). At the lower and coastal regions, the characteristics of the Mediterranean climate prevail. Accordingly, the natural vegetation of *Çanakkale* and *Gallipoli* rather consists of plants and forests of Mediterranean origin (Sensoy et al. 2008). The same region was reported to be located in Mediterranean macroclimate zone and to have Mediterranean precipitation regime, by Murat Türkeş et al. (2011). Despite having a transitional

climate, this region is expected to feature a drier and hotter climate in the near future. As also reported by Şen (2013) in a research on predictions for Turkey's future climate, even the Black Sea region might reflect the characteristics of the Mediterranean Region, although it has a more temperate climate compared with *Çanakkale's* (Şen 2013). Climate change is likely to pose an increased risk of forest fires for Turkey (Kayhan 2007; Öztürk 2002; Türkeş 2012). As also reported by Şen et al. (2013), recent years have witnessed earlier snowmelt and a more distinct increase in temperatures, in addition to the increased number of heavy rainfall, storms, heat wave, forest fires, and hydro-meteorological events such as flood and overflow. In the estimations of Turkey's future climate, temperature is forecasted to increase up to 5 °C, and declines in rainfall up to 30% in the southern and western regions are predicted (Şen et al. 2013).

The time interval in which fire frequency reaches a peak differs for different regions and ecosystems. This interval is commonly referred to as fire season. This period generally covers a period of 5 months starting from May and ending at the end of September in Turkey. Fire season is in essence one of the constituents of a fire regime that consists of factors such as fire frequency, duration, intensity, severity, seasonality, extent, and spatial distribution (Duffy et al. 2005). Under the hot and dry conditions caused by the climate change, fire seasons occur in extended periods and fires occur and spread at a greater pace. Changes in extreme weather conditions and climate events are more likely to induce increased risks of severe fire seasons (IPCC 2007; Liu et al. 2010). A research on forest seasons conducted in Canada revealed that—should the scenarios predicting a twofold increase in CO<sub>2</sub> levels in the atmosphere be realized—fire seasons will correspondingly become more severe (Wotton and Flannigan 1993). Flannigan et al. (2013) reported in their experimental research that the current annual increase in fire seasons in the northern hemisphere is around 20 days. They also stated that the world will undergo more severe fire seasons in the future and the conventional firefighting techniques are most likely to fail (Flannigan et al. 2013). Wotton and Flannigan (1993) also predicted an average increase of 22% or 30 days in fire seasons in the future (Wotton and Flannigan 1993; Flannigan et al. 2013; Flannigan et al. 2005).

We investigate the relationship between the climate data of 1969–2017 period and the 8 most severe fire



**Fig. 1** Climate map of Turkey (Atalay, 2011)

seasons that took place in Gallipoli and Central regions of *Çanakkale* within this period. The majority of studies on large fires were conducted on those that occurred in North America. However, a significant number of studies have also been conducted on conflagrations in Europe in the last decade, though European countries fall behind North America and Australia due to organization, budget, and experience differences. Large fires in the USA showed a significant increase as of mid-80s with significantly higher frequencies, periods, and seasons. The average fire season period showed an increase of 78 days (64%) between 1970–1986 and 1987–2003 periods and annual average fire seasons displayed a corresponding increase due to reasons such as spring and summer temperatures and early snowmelt (Westerling et al., 2006).

**Material and methods**

*Çanakkale* is located in the coordinates 39° 27' 12.0" N–40° 44' 38.7" N and 26° 03' 48.9" E–27° 32' 01.9" E. As mentioned earlier, *Çanakkale*'s climate, vegetation, and topography characteristics render it a risk zone to large forest fires. Hence, this region has been the subject of many other studies on large forest fires. As reported by Tatlı et al. in 2017, *Çanakkale* is among the high and

very high-risk zones in terms of forest fires (Tatlı et al. 2017). Fire statistics for *Çanakkale* region were used as a research material. Canadian Forest Fire Weather (FWI) and Seasonal Severity Rating (SSR) index values were calculated for the 8 largest fire seasons that occurred since 1969 in the study area. The corresponding likelihood of fire incidents was examined in relation to the index values of these seasons.

FWI is a globally used fire hazard prediction system that is primarily based on daily meteorological observations (Wotton 2009). This system consists of 6 components. Three of them are the fuel codes, namely, Fine Fuel Moisture Code (FFMC), the Duff Moisture Code (DMC), and the Drought Code (DC), and the remaining three are the fire behavior indices, namely, the Initial Spread Index (ISI), the Buildup Index (BUI), and the Fire Weather Index (FWI). FWI system is based on daily dry-bulb temperature, relative humidity, a 10-m open wind speed, and 24-h cumulated precipitation recorded at noon in the local standard time. Currently, the application of CFFDRS has been extended to countries other than Canada, such as New Zealand, Indonesia, Portugal, and the countries of southern Europe (Wotton 2009).

Seasonal severity rating (SSR), used in the calculation of fire severity, is the final constituent of the Canadian forest fire weather index (FWI) (Van Wagner 1987; Flannigan and Wotton 2001). SSR can be calculated

after the calculation of daily severity rating (DSR). DSR was developed to measure the difficulty in extinguishing a forest fire and is highly sensitive to variations in air temperature and relative humidity (Van Wagner 1987; Williams 1959; Skinner et al. 2006). As the season average of DSR, SSR shows the seasonal status of daily fire control difficulty derived from the determination of the potential severity of fire (Flannigan et al. 2009; Flannigan et al. 2006; Flannigan et al. 2000). SSR is calculated through consecutive evaluation of daily severity rating (DSR) and monthly severity rating (MSR). SSR calculations were used to evaluate the effect of climate change on fire weather severity in several studies. Flannigan and Van Wagner (1991) compared seasonal severity ratings for different fire seasons (Flannigan et al. 2009; Flannigan et al. 2006).

Stocks et al. (1998) calculated the daily FWI values of Russia and Canada. Afterwards, the daily DSR values were assessed against the values determined by Williams (1959) and modified by Van Wagner (1970) using the calculated FWI values. SSR values for the fire season were accordingly calculated using these daily values (Stocks et al. 1998). In addition to the studies on calculation of past and present SSR values, studies on prediction of future severity ratings are also available. As reported by Flannigan and Van Wagner (1991), the occurrence of 2xCO<sub>2</sub> scenario results in 44% increases in burned areas in Canada. Seasonal severity rating (the average DSR over the fire season) was used to predict this increase (Flannigan et al. 2005). SSR values for the 2xCO<sub>2</sub> ratio were calculated. The results showed that SSR will increase by 10–50% in most parts of North America in the future. On the other hand, it will show a slight change or decline in some regions. Increased SSR is expected to result in increased fire incidents (Skinner et al. 2006).

## Results and discussions

The forests within the territory of Çanakkale Forestry Department were examined in terms of large fires, and 8 fire seasons were determined as the most severe seasons within the stated period of 49 years. These specified seasons are those in which large forest fires occurred from year 1969. These are 1969, 1972, 1977, 1985, 1986, 1994, 2000, and 2008. The largest fires that occurred in the stated seasons took place in 1985—6000 ha, 1994—4049 ha, 1972—1610 ha, 1986—

1500 ha, 2008—1464 ha, 1969—1400 ha, and 1986—1076 ha (Fig. 2). In addition to these statistics, Canada fire weather index (FWI) was used to determine the changes that occurred in fire weather conditions. Daily severity rating (DSR), Monthly severity rating (MSR), and Seasonal severity rating (SSR) of these 8 fire seasons were calculated. The daily meteorological data of these seasons between 1969 and 2008 were received from the Turkish Meteorology Service for the required calculations. As some of the values in FWI calculation have a cumulative characteristic, using data only for the month of the large fire is likely to result in inaccurate calculations. Hence, the values of FWI for the entirety of the season were used for a more accurate calculation.

During the research, Mann-Whitney, Pearson, and regression analyses were used for statistical evaluation. The Pearson correlation of the areas burned in the conflagrations of 8 fire seasons was calculated. First the normal correlation, then the natural correlation (“ln” value) were calculated. Accordingly, a high correlation was detected between the burned areas and DSR index values of the fires that took place in years 1977, 1985 and 1986 (Table 1).

However, no such correlation was detected for the other fire seasons. Consequently, the performed Mann-Whitney test did not indicate a normal data distribution either. The results of the following regression analysis showed correlations between some of the years, while no correlation was found for most of the years (Table 2).

Linear equations for DSR for 1977, 1985, and 1986 are as follows:

$$1977 \text{ BAY} = \text{DSR} \times 159.92 - 17.55$$

$$1977 \text{ ln}y = \text{DSR} \times 0.6 + 3.8$$

$$1985 \text{ BAY} = \text{DSR} \times 3.85 + 3 \times 10^{-4}$$

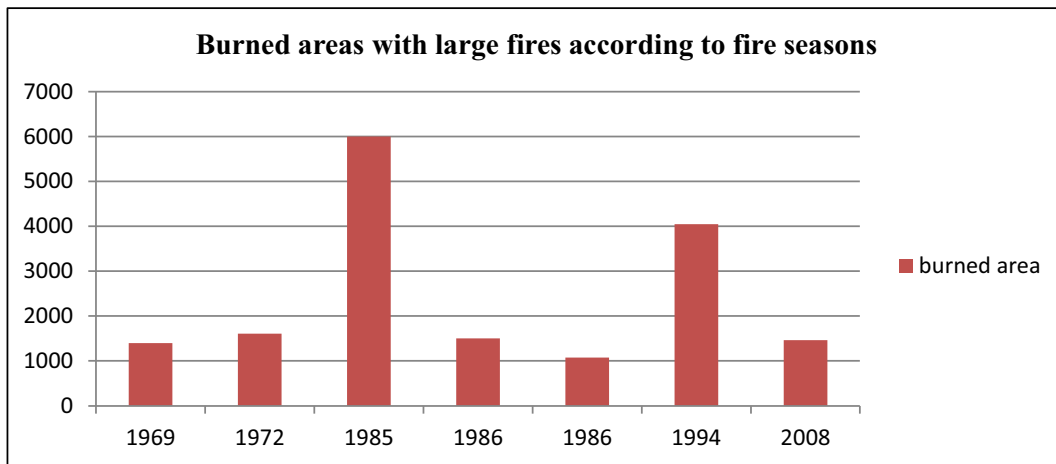
$$1985 \text{ ln}y = \text{DSR} \times 0.68 + 0.04$$

$$1986 \text{ BAY} = \text{DSR} \times 417.3 - 778.2$$

$$1986 \text{ ln}y = \text{DSR} \times 0.81 + 3.22$$

In the graphs below, the five fire seasons, in which a relationship between high DSR values and large fires was detected, were chosen for the research. The MSR values of the fires that took place in these years are shown in the below Figs. 3, 4, 5, 6, and 7.

In the graphs, the values with the red font indicate the DSR value of the day in which a large fire occurred. This does not necessarily mean that no fires occurred on other days, as the graphs only show fires larger than 100 ha. Although some large fires occurred at low DSR



**Fig. 2** Burned areas with large fires according to fire seasons

values, the likelihood of occurrence of fires larger than DSR 4 and 5 is significantly high. In 1969, DSR 5.76 as the second largest value after DSR 5.79 corresponds to the largest fire of the season (1400-ha burned area) which occurred on 8 October 1969. The largest fire of year 1977 occurred with a DSR value of 4.52, which is relatively lower than the other years. An area of 971 ha burned in the fire that occurred on August 22, 1977. It is worth noting that, despite the relatively low DSR values, long-term dry seasons with steadily increasing values pose a significantly greater risk for large fires. Some of the years witnessed more severe and successive large fires within specific periods. In the occurrence of such conflagrations, administrative measures, fuel condition, and intensity play a major role. Moreover, the year 2008 was observed to have significantly high DSR values with the highest risk values for large fires as from year 1969. The largest fire of Çanakkale region within the studied period of 49 years occurred 8 days before the day with the highest DSR value of 1985 (5.75) on the day with the second highest DSR value of the same season (5.66). An area of 6000 ha was burned in this fire. Likewise, the largest fire of year 1986 (1500 ha)

occurred on 20th September which was the day with the second highest DSR (5.09) after the day with the highest DSR (5.17), which was 4 days after. The year 2008 underwent the highest large fire risk of a long period which started in the last week of June and ended on the rainy 11th day of August. Türkeş and Altan also reported in their research on the fires that took place in 2008 in Çanakkale that, Keetch-Byram drought index reached its highest (530) on 10th August (Türkeş and Altan 2012). In this period, another large forest fire occurred on 30th July which had a DSR value of 7.02.

As indicated in the monthly MSR values, the above-stated period of 5 years stands out in Fig. 8 as well. Although it shows a sudden decline later (it reaches almost 6), yet it is significantly higher compared with the other seasons. The highest DSR across these 8 most severe large fire seasons within the 49 years period of 1969–2017 was observed on August 7, 2008, which was followed by 1969 and 1985 as the second and third most severe fire seasons. Despite falling behind these three years, 1986 can also be recognized as a severe fire season.

The SSR values of the studied 8 years are displayed in Fig. 9. In addition to the seasons with large fires associated with high DSR values, years that witnessed large fires despite low SSR values such as year 2000 are also available.

The table below shows the total burned areas in the fire seasons with large fires. These values indicate significantly large burned areas, which further indicate an upward and/or downward trend due to the enhanced technology and improved firefighting organizations and/or increasing climate change and global warming

**Table 1** Pearson correlation of some extreme burned area years (1977, 1985, 1986) for Çanakkale region

Years	Spearman Rho Coef. (DSR-BA)	Spearman Rho Coef. (DSR-Ln BA)
1977	0.317	0.567
1985	0.704	0.853
1986	0.795	0.883

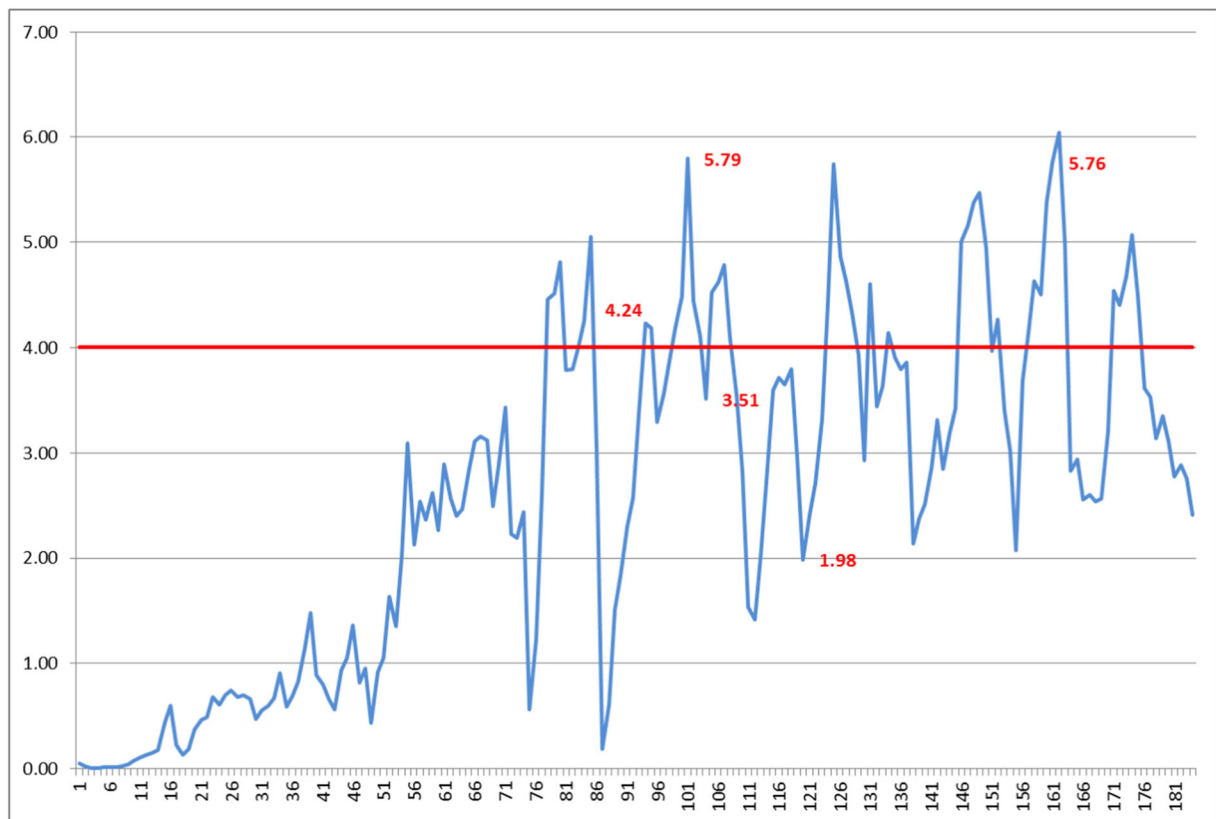
**Table 2** Regression analysis results of some extreme burned area years for *Çanakkale* region

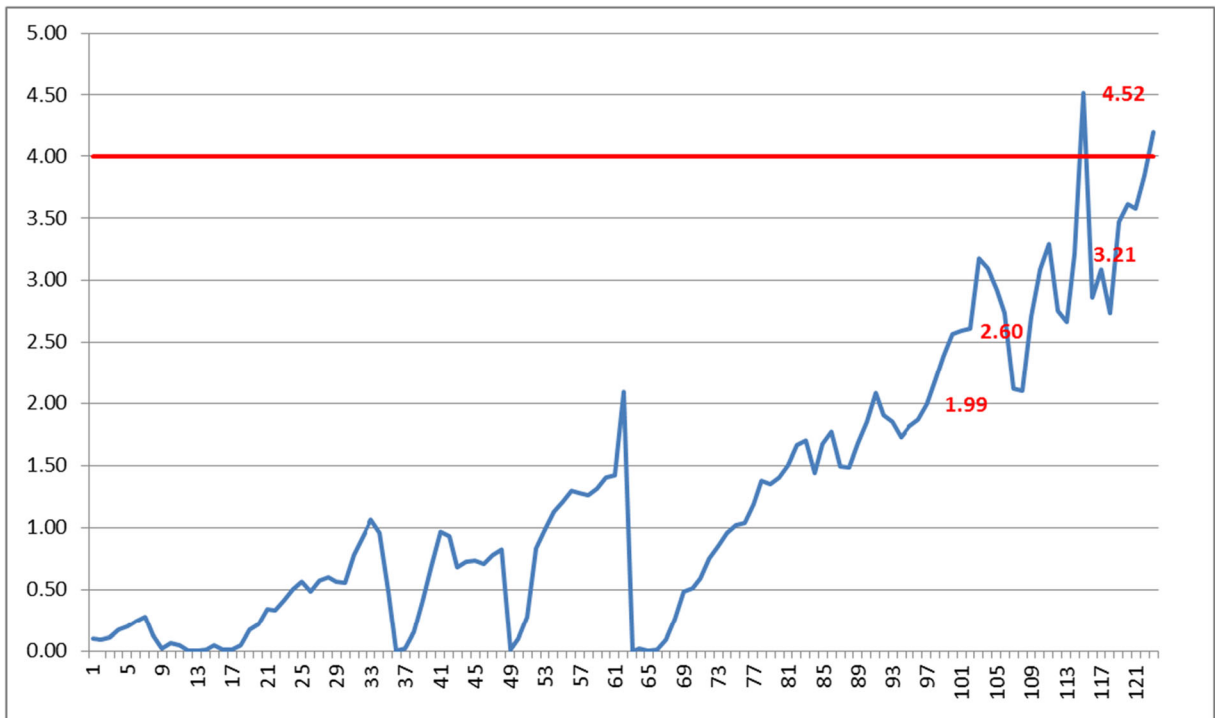
Years		R square
1977	DSR-burned area (BA)	0.101
	DSR-(Ln BA)	0.322
1985	DSR-(BA)	0.496
	DSR-(Ln BA)	0.727
1986	DSR-(BA)	0.633
	DSR-(Ln BA)	0.779

(Table 3). As indicated by research data, the amount of burned areas is largely determined by the extent of large fires, whereas the largest burned area is determined by the largest fire among the large fires. In 1980, two fires occurred with a burned area higher than 1000 ha, and all studied fire seasons resulted in significantly high burned areas. Among these seasons, the one with the highest burned area (6000 ha) occurred on August 16, 1985 which was also the year with the highest total amount of burned areas (6956 ha).

As a result of improved road networks and firefighting organizations, a significant reduction was observed in the average burned area in 2000s compared with previous years. After the highly severe fire seasons of 1980s and 1990s, a downward trend in the severity and frequency of large fires is observed in 2000s.

Harvey et al. (1986) also calculated the DSR and SSR values for the different fire seasons to make a comparison between the severities of forest fire weather conditions. They chose the Northern Alberta region of Canada as the subject area of their research and reported a twofold increase in burned areas against a slight increase in SSR (Harvey et al. 1986). In general, DSR values of a fire within a specified period are correlated with the severity of the fire. On the other hand, no correlation was detected to some large fires. An example is with the MSR value (0.11) of the fire that took place on April 5, 2000 (845 ha). It should be also noted that the largest or the majority of the fires in a season generally took place in the months with the highest MSR values. The days with the highest DSR values

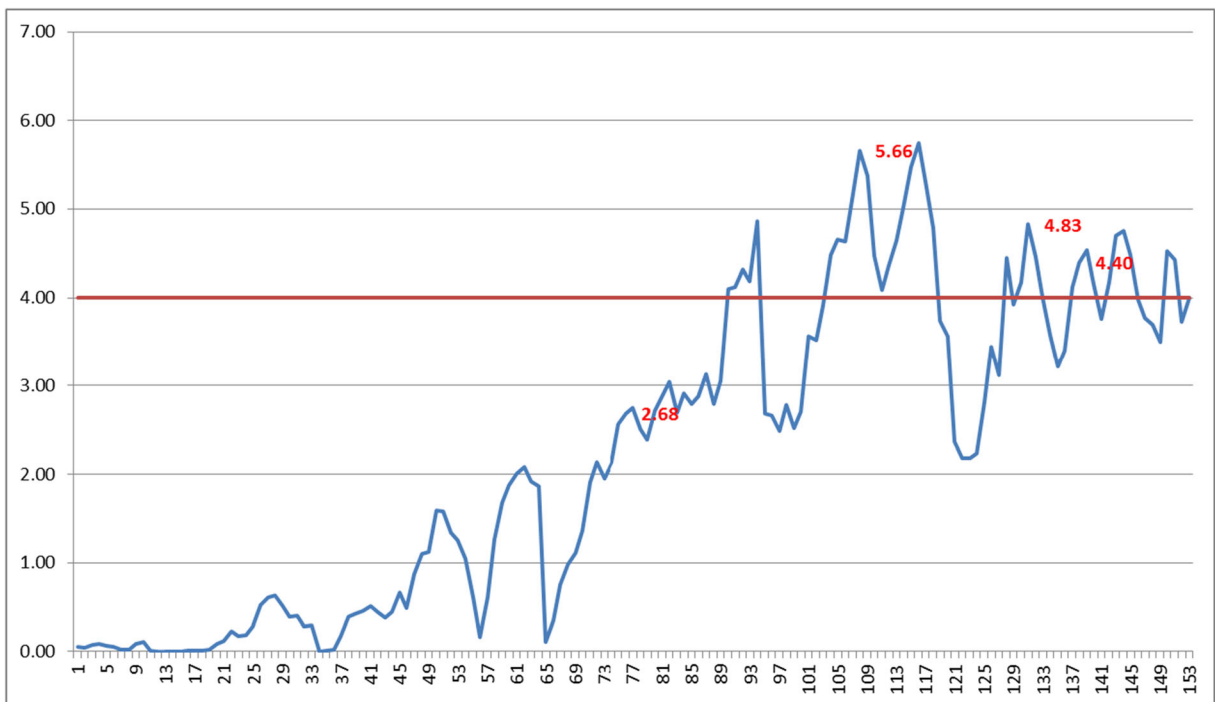
**Fig. 3** 1969 fire season MSR values



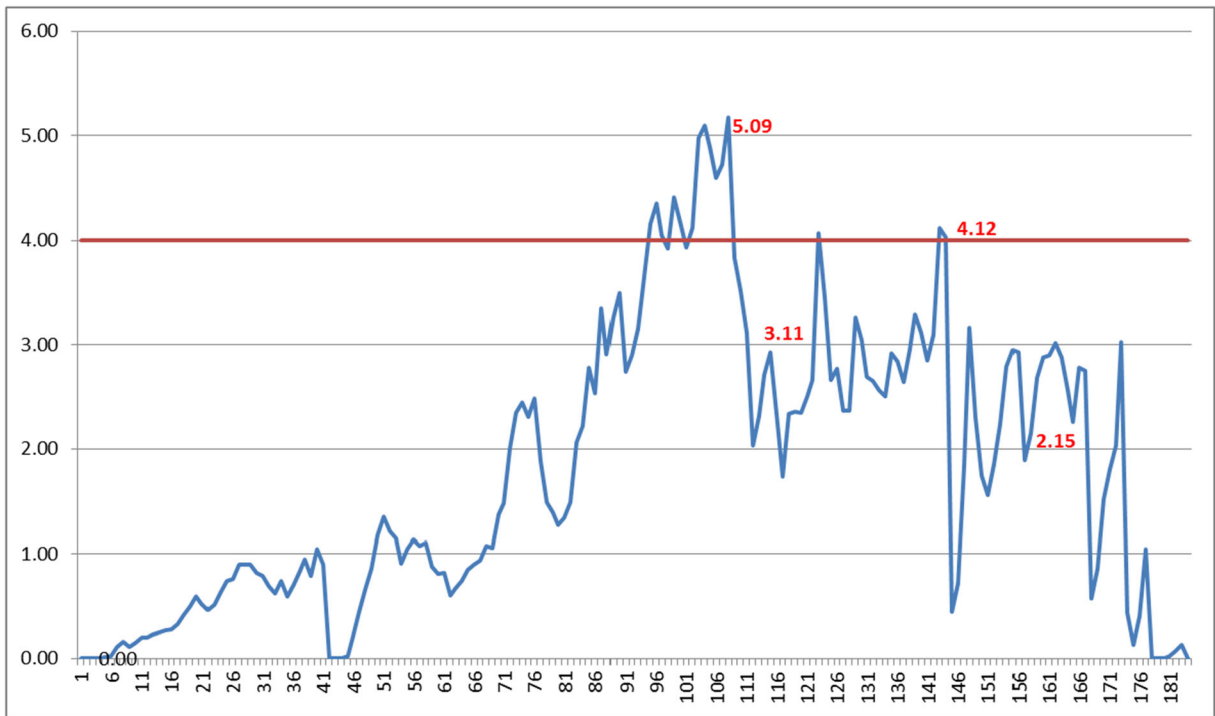
**Fig. 4** 1977 fire season MSR values

within the specified fires seasons are as follows: 6.57 on 30 July, 2008, 5.76 on 8 October, 1969, 5.66 on 16

August, 1985, and 5.09 on 12 August, 1986. Here, an area of 1464 ha was burned on the day (July 30, 2008)



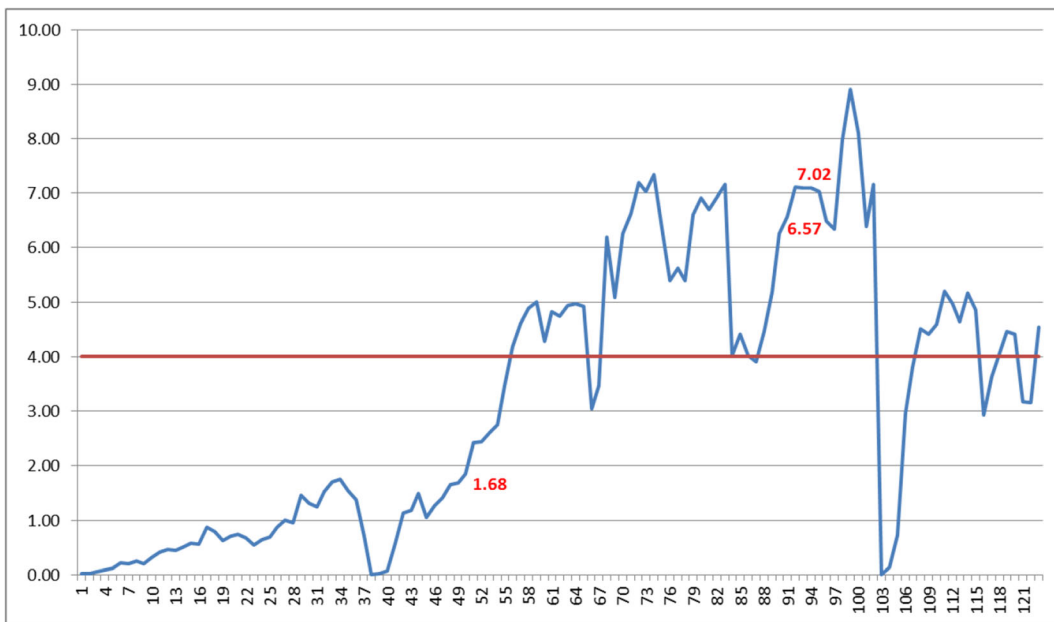
**Fig. 5** 1985 fire season MSR values



**Fig. 6** 1986 fire season MSR values

with the highest DSR value. Among the above-stated values, the fire that took place on 16 August 1985 is reported to be the largest fire (6000 ha) since 1969. Index components indicate that the highest DSR value

within the subject period is 8.91 that were recorded in 7 August 2008. The highest DSR values recorded in the other seasons are as follows: 1969—6.05, 1985—5.65, 1986—5.17, 1977—4.52, 2000—4.16, 1972—2.96,



**Fig. 7** 2008 fire season MSR values



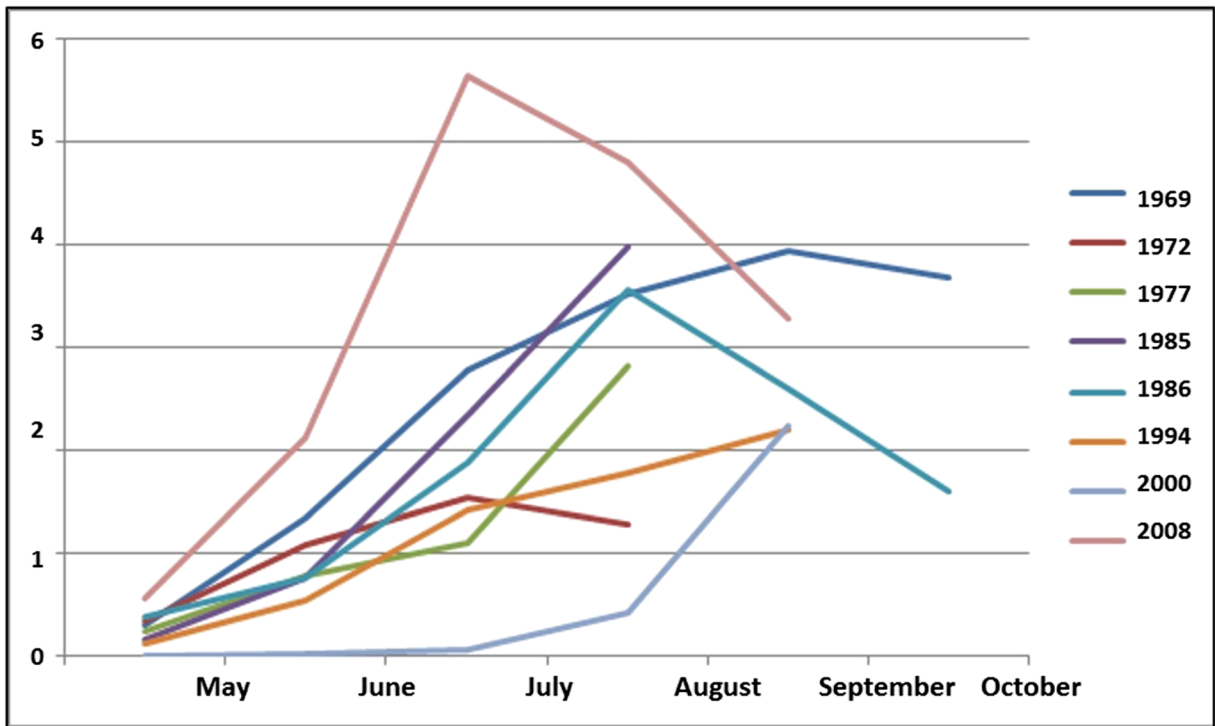


Fig. 8 MSR values of the seasons with large fires

and 1994—2.90 in the descending order. Among these values, the highest DSR values recorded in 1969, 1972, 1977, and 1985 are also reported as the dates on which the largest fires occurred. These findings are indicative of the success of DSR in estimating large fires. Indeed,

the occurrence of large fires on the days with the highest DSR values—though not always—is an expected outcome of the index. The most severe month in terms of fire hazard was July 2008 with an MSR value of 5.64. It was respectively followed by August 2008 (4.81),

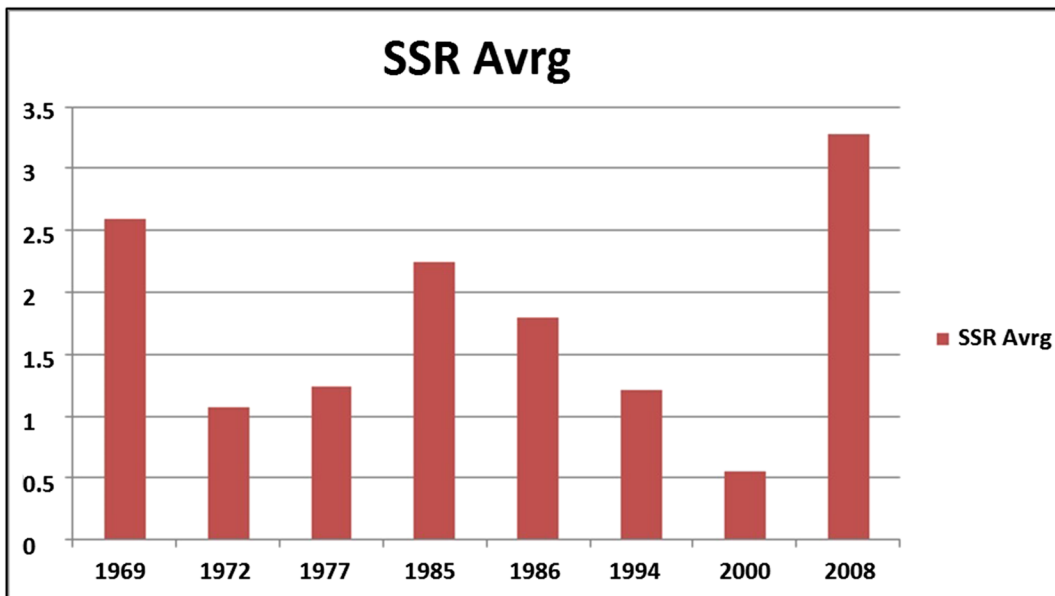


Fig. 9 Seasonal severity rating (SSR) values of large fire seasons

**Table 3** Burnt areas of large fires according to fire seasons in years of 1969, 1972, 1977, 1985, 1986, 1994, 2000, and 2008

Year	Total areas burned in large fires (ha)
1969	3268
1972	2325
1977	1900
1985	6956
1986	2926
1994	4498
2000	1757
2008	1949

August 1985 (3.99), September 1969 (3.95), October 1969 (3.69), and finally August 1969 (3.52). Another month that exceeded the value 3 is August 1986. The most severe months were also investigated in terms of SSR. The year with the highest average SSR among all seasons is 1985 with 3.99, followed by 2008 with 3.28 and 1977 with 2.82.

## Conclusion

This research aimed to examine the most severe fire seasons that took place in *Çanakkale* region, one of the most important fire zones of Turkey, since the fire season of 1969; and to determine whether there is a relationship between the large fires that took place in the subject seasons and the corresponding climate factors. Within the specified period of 49 years, 8 fire seasons were determined as the most severe ones in terms of large fires. These are the fire seasons of 1969, 1977, 1985, 1986, 1994, 2000, and 2008. Among these seasons, 1977, 1985, and 1986 are the ones that with an average DSR, which are correlated with the corresponding burned areas. Although no correlation was found in the DSR values of the other extreme seasons, particularly years 1969, 1977, 1985, 1986, and 2008 are reported to witness large fires that followed high index values. Year 2008 seems to have the most extreme DSR values, although severe fire seasons have been widely distributed among the subject fire seasons. The obtained findings show that there is a correlation between the DSR values and the burned areas of the large fires for three of the eight subject seasons. This correlation was detected by Ertuğrul and Varol (2016) between the SSR values of some of the important fire zones of Turkey and

the corresponding burned areas, with a lower accuracy compared with *Muğla* and *İzmir* Regions of the *Çanakkale* fire zone. Accordingly, the method used in this research is likely to yield more accurate results for the other fire prone zones of Turkey (Ertuğrul and Varol 2016). However, as inferred from the graphs, the large fires of a given season occurred particularly following the high DSR values of that season. For such reasons, performing DSR estimations for the following 3 to 5 days on the basis of daily and weekly weather forecasts is very likely to be useful for the prediction and prevention of large forest fires. Even though it is not completely possible to make an accurate prediction of forest fires with the current fire and drought indices, occurrence of the largest fires with the highest frequency following the days with the highest index values is an important indicator of the consistency of the used indices in prediction of forest fires (Türkeş and Deniz 2011). Wind has particular importance for *Çanakkale* region, as it is the only forest fire weather factor that we can control, by installing windbreakers on dominant wind directions will be useful for this region, as also suggested by Neyişçi for *Pinus brutia* forests in Antalya (Neyişçi 1987).

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**Author contributions** Mehmet and Hakan conceived and designed the experiments, and Mertol and Halil performed the experiments. Mertol, Halil, and Tugrul analyzed the data; Mertol, Halil, Tugrul, Mehmet, and Hakan contributed reagents/materials/analysis tools; and Halil, Hakan, and Mehmet wrote the paper.

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**Compliance with ethical standards**

**Conflict of interest** The authors declare that they have no conflict of interest.

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