CEST 2017

15th International Conference on Environmental Science and Technology

Rhodes, Greece, 31 August to 2 September 2017

Forest Fire Danger Rating Systems Assessment in the Mediterranean Type Environment, Crete, Greece.

Boteva S.[1] And Elhag M.[2]*

[1]Department of Ecology and Environmental Protection, Faculty of Biology, Sofia University, Sofia, 1164, Bulgaria.

[2]Department of Hydrology and Water Resources Management, Faculty of Meteorology, Environment & Arid Land Agriculture, King Abdulaziz University, Jeddah, 21589. Kingdom of Saudi Arabia.

*corresponding author:

e-mail: melhag@kau.edu.sa

Abstract

The Fire Weather Index (FWI) module of the Canadian Forest Fire Danger Rating System (CFFDRS) was tested under the Mediterranean- type conditions of Crete (Greece) for the two fire seasons 2008-2009. High correlations were found between the Fine Fuel Moisture Code (FFMC) and the Duff Moisture Code (DMC. The Drought Code (DC) was poorly correlated with the soil moisture content. No significant correlation was found between the area burned by wildfires and any component of the FWI system during the studied period, unlike fire occurrence with which most of the components were highly correlated. Meanwhile, the Keetch-Byram Drought Index (KBDI) of the American Forest Fire Danger Rating System (NFFDRS) was also evaluated under the same conditions. It provided a useful means of monitoring general wetting and drying cycles, but is inadequate for indicating daily fire danger throughout the fire season in our region. Weak correlations between the KBDI- the fire occurrence and the area burned were found for the two fire seasons studied-2008-2009. Correlations between the KBDI and litter, duff and soil did not give statistically sound results. On the contrary, the KBDI seemed to predict with high accuracy the moisture content of three annual plants.

Keywords: Danger Rating Systems, Data Analysis, Forecasting, Forest Fires, Fires Risk, Moisture Content.

1. Introduction

In regions with Mediterranean climate, fire presents a major disturbance to natural ecosystems, resulting in significant economic and ecological losses. Thus, there is a great advantage to be gained from being able to anticipate, well in advance, the probability of fire occurrence on a given date and its expected severity. Fire danger rating is the expression of both constant and variable environmental factors that influence the occurrence, behavior, suppression efforts and detrimental effects of wildland fires in a certain area (Amatulli *et al*., 2013). The occurrence and propagation of forest fires depend on various environmental and anthropogenic factors. Even in regions like the Mediterranean basin where most fires are caused by humans, natural conditions that affect the fuel properties play a very important role in the number of fires and the burned area (Bajocco *et al*., 2015). Monitoring of live and dead fuel moisture can be used as an indicator of forest fire danger, if combined with simultaneous measurements of meteorological parameters. Forest fire danger rating systems are based on the integration of meteorological parameters with bio-physical properties of the fuels to predict their flammability and combustibility, combined with the risk posed by human activities and natural phenomena (Pereira *et al*., 2011). In reviewing early fire danger research in Canada, two concepts are worth emphasizing. First, the development process was one of evolution in which certain features even though modified, were retained from system to system. Second, there was a trend toward simplification, both in required weather measurements and in the method of calculation (Wrathall 1985). It is well understood that the incidence and behavior of forest fires depend mainly on short-term weather influence of no more than several days duration (Amatulli *et al*., 2013). Yet, throughout the history of fire danger rating, runs a persistent interest in the effects of weather over a much longer term. Accounting for long-term drying is necessary because it provides guidance to the fire manager during critical conditions. This does not imply that fires cannot occur without prior, long-term moisture deficiency (Dimitrakopoulos and Bemmerzouk 2003); in other terms a drought condition is not a prerequisite for the occurrence and spread of fire in any area (Amatulli *et al*., 2013). The Keetch-Byram Drought Index (KBDI) was first introduced. It was defined as a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff or upper soil layers. The material may be soil humus. It may also be organic material that consists of buried wood, such as roots in varying degree of decay, at different depths below the mineral soil surface. The KBDI is a daily index that ranges from 0 to 800, where higher values are associated with drought. The index is calculated from daily observations of precipitation amount and maximum air temperature (Keetch and Byram 1968). Conceptually, the index expresses, in hundredths of an inch, the moisture deficiency in soil, after accounting for density of vegetation coyer, precipitation, and evapotranspiration losses. The objective of this study is to test and evaluate the following forest fire danger rating systems, to propose possible modifications that would better adapt these systems to the Mediterranean conditions. The implemented forest fire danger rating systems are the Canadian Forest Fire Danger Rating System (CFFDRS), and Keetch-Byram Drought Index (KBDI) of the American National Forest Fire Danger Rating System (NFFDRS).

2. Materials and Method

2.1. Study site general description

Field tests were carried out at the Akrotiri region, 6 km east of Chania (Crete, Greece), at an altitude of 185 m above the sea level, located at approximately 35° 31' N and 24° 03' E. The mean annual rainfall is about 600 mm, December, January and February being the period of the higher precipitations (Elhag and Bahrawi 2016). The ecosystem investigated is a typical Mediterranean forest of *Pinus halepensis* with 50% crown closure. The stand is southwest exposed with a slope of 20 %. The experiment was settled for the two fire seasons, 2008 and 2009, and measurements were conducted daily, at 14.00h. Under the forest canopy, litter, duff, and soil samples were collected. The samples were placed into aluminum containers hermetically sealed, to prevent evaporation. For each parameter, three samples were collected. The daily moisture value is the average of the three values. The daily weather data (air temperature, air relative humidity, 10m wind speed, and 24h accumulated precipitation) necessary for computing the (FWI) indexes were obtained from the meteorological station of Akrotiti Airport, located about 5 km from the site where the experimental site was established.

2.2. Canadian Forest Fire Danger Rating System

2.2.1. Fine Fuel Moisture Code (FFMC)

This code is an indicator of the relative ease of ignition and flammability of fine fuel. To permit conversion of moisture content into a code, a scale, called the FF scale, was defined based on the following assumptions and equations:

$$F = \frac{59.5(250-m)}{147.2+m} \qquad \text{eq.1}$$

2.2.2. Duff Moisture Code (DMC)

The basic method was to transfer rectangles of organic matter to trays of 60 x 40 cm in an area set in forest floor, and to weigh daily. The type expression is:

$$P = c[\log(Mmax) - \log(M - E)] \qquad \text{eq. 2}$$

$$P = c[\log(Mmax) - \log(M - E)] \qquad \text{eq. 2}$$

2.2.3. Drought Code (DC)

As an exponential expression of the moisture equivalent Q, the chosen scale equation is:

$$D = 400\ln(800/Q) \qquad \text{eq. 3}$$

2.2.4. Initial Spread Index (ISl)

The ISI is merely the product of functions of wind and fine fuel moisture, together with a reference constant 0.0208. The constant itself was multiplied by 10 to provide a convenient range of numerical values for the ISI. The equation is then formulated as below:

$$R = 0.208f(W)f(F) \qquad \text{eq. 4}$$

2.2.5. Buildup Index (BUI)

When the DMC is near zero, the DC should not affect the daily fire danger, no matter how high its level is. When the DMC and the DC are combined, the BUI is given by:

$$U = 0.8PD/(P + 0.4D) \qquad \text{eq. 5}$$

2.2.6. Fire Weather Index (FWI)

The ISI clearly represents the rate of spread, but BUI is simply a blend of two fuel moisture codes. The intermediate function required to calculate the FWI is expressed as follows:

$$f(D) = 0.1Rf(D) \qquad \text{eq. 6}$$

2.3. Keetch-Byram Drought Index

The KBDI is a daily index that ranges from 0 to 800, where higher values are associated with drought. The index is calculated from daily observations of precipitation amount and maximum air temperature (Keetch and Byram 1968). Conceptually, the index expresses, in hundredths of an inch, the moisture deficiency in soil, after accounting for density of vegetation coyer, precipitation, and evapotranspiration losses. The drought factor dQ, is conveniently computing daily in which case the time increment dt is placed equal to 1 day. The final Spread Index unit equation can be written in the following equation mentioned by Leverkus *et al*. (2014):

$$dQ = \frac{[203.2-Q][0.968\,exp(0.0875T+1.5552)-8.3]dt}{1+10.88exp(-0.001736R)} * 10^{-3} \qquad \text{eq. 7}$$

When T = T0 = 80° F (arbitrarily chosen as the reference temperature) and wc = 800 hundredths of an inch of water, then, from the above equation, t80, 50 = 56.41 days. Hence, it follows that t80, ∞ = 25.64 days. In the derivation of the basic equations, the fuel layer has been included with the soil. In the setting of wc at 8 inches of water, it is assumed that the wc refers both to the soil and the fuel layer.

3. Results and Discussion

3.1. CFFDRS

The observation of the fire danger classes shows that the summer period (June-August) accounts for about 95% of the "Extreme" values recorded during the whole fire season, thus indicating the peak of the fire period (Arpaci *et al*., 2013). May and September also experience a big percentage of FWI values in the "High" and "Extreme" classes. The analyses of the number of fires in relation to FWI classes (Table 1) indicate clearly that more than 80% of fires occur during days within the "Extreme" FWI class.

The statistics parameter indicates that the observed and the predicted values of fine fuel moisture are highly correlated.

A t-test, of paired observed and predicted litter moisture content values, indicated that they were not significantly different at the 95% confidence level. Daily variations of moisture content of predicted and observed fine fuel are shown in Figure 1. The visual observation of comparison chart of predicted and observed duff moisture values (Figure 1) shows that the two sets of points seem to behave differently. In the higher range of moisture content, the predicted values present a delay in time before they start responding to rain occurrence. This may be due to the torrential nature of precipitation in the Mediterranean region, and/or to the discontinuous canopy closure characteristic of the Mediterranean pine forest type, which differs from the Canadian conditions (Parr *et al*., 2007).

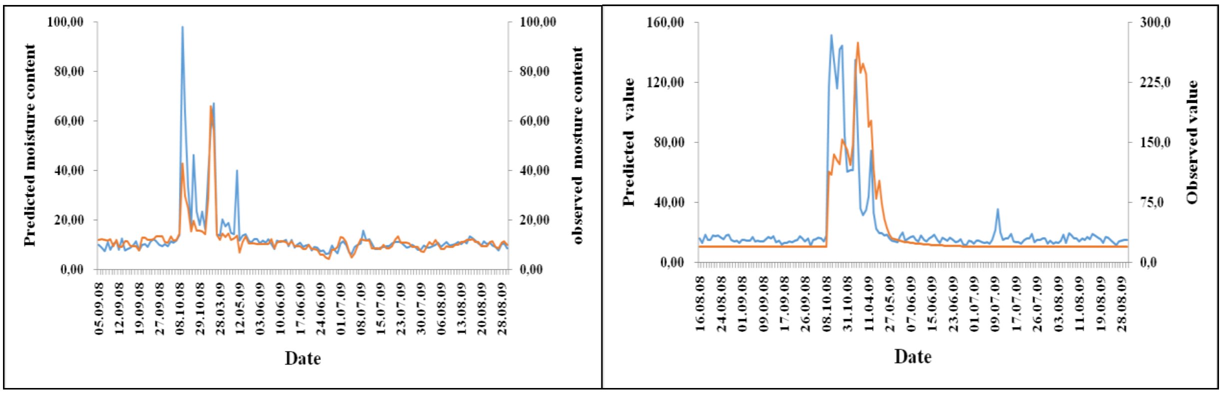
In addition, the duff layer is certainly notably less important in the Mediterranean conditions, regarding depth and quantity, than that of the original Canadian environment. In the lower range, the model seems to be limited in its predictions, as soon as the observed duff moisture content values drop below 20%. This is explained by the fact that the DMC was set with an equilibrium moisture content of 20%, meaning that the lowest value the model can predict should be at least equal to 20. Unlike, during the summer period the duff moisture content, in our ecosystem, is in most cases below the threshold of the model predictions.

3.2. *KBDI*

The study shows a very high drought index, the mean value ± standard deviation was 660 ± 182.9 for the period March 2008 - November 2009 (640 days). In 66.1% of the days the drought index exceeds the value 650 constituting the "Extreme drought" class. An annual trend can be discernible, though the effects of year-to-year differences are non-negligible and the period studied is certainly short. Following the end of the rainyperiod, usually at the beginning of spring, there is a continuous increase in the drought index value, reaching quickly the maximum value by mid of May. The precipitations occurring during the fall period with their small amount and discontinuous feature seem to be insufficient to reduce significantly the drought index. Consequently, the "Extreme" drought persists until the beginning of the winter time, where relatively important and continuous precipitation occurrences combined with low temperature drop the index value to the "High" and "Moderate" class. It is worth noting that the drought index never restored the "Very Low" and "Low" classes.

Table 1. Percentage occurrence of FWI values within fire danger class intervals for 2008 and 2009.

FWI class	**0-1 Very Low**		**2-5 Low**		**6-12 Moderate**		**13-24 High**		**> 24 Extreme**	
Year	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
March	25.8	29.03	51.6	29.03	16.1	25.8	6.45	16.1	0	0
April	3.3	16.66	13.3	3.33	50	23.33	30	33.33	3.3	23.33
May	0	0	0	3.22	38.7	0	39.03	6.45	32.25	90.32
June	0	0	0	0	0	6.66	10	0	90	93.33
July	0	0	0	0	0	0	3.2	0	96.8	100
August	0	0	0	0	0	0	3.2	0	96.8	100
September	0	0	0	0	0	10	13.330	0	86.66	90
October	19.35	3.22	16.12	0	32.25	9.67	19.35	22.58	12.9	64.51
November	23.33	13.33	16.66	10	40	13.33	16.66	20	3.3	43.33



a b

Figure 1. Comparison of observed (red) and predicted (blue) fine fuel (a) and duff (b) moisture content values obtained from the (FWI) in Days

Table 2. Regression equations for estimating plant moisture content (x) from the KBDI (y).

Species	**Equation**	**Regression Coefficient (R^2)**	**Variance explained (R^2)**
Piplatherum miliaceum	y = 904.23 - 1.881 * x	-0.93	0.88
Avena sterrilis	y = 918.67 - 7.961 * x	-0.85	0.72
Parietaria diffusa	y = 925.73 - 7.549 * x	-0.82	0.68
Pinus halepensis	y = 511.78 - 1.934 * x	0.20	0.04

This is probably due to the exceptionally drought weather that occurred during the year 2009. The KBDI seems to over predict in time the end of the fire season. This emphasizes the fact that long-term moisture deficiency cannot be used to forecast critical fire situations, because fires are caused from a combination of factors that occur in conjunction with drought conditions. Consequently, it is not possible to establish precise "threshold value" at which critical fire situations may or may not develop (Dimitrakopoulos and Bemmerzouk 2003). Linear and exponential equations were tested for four species (*Avena sterilis, Parietaria diffusa, Piplatherum miliaceum* and *Pinus halepensis*) to see which equation best fits the relationship of plant moisture content and the KBDI (Table 2).Most fluctuations in plant moisture content are accounted for by the KBDI for the species monitored: *Piplatherum miliaceum* (variance explained 88%), *Parietaria diffusa* (68%), and *Avena sterillis* (72%). For *Pinus halepensis*, the variance explained was very low (4%). The T test was performed for the three-herbaceous species showing strong correlation with the KBDI whose results indicated that the observed and the predicted (from the KBDI) moisture content values are not significantly different at the 95% confidence level. On the other hand, and according to (Clavero *et al*., 2011), predictions of herbaceous plant and shrubs moisture content within 20% are scientifically sound and adequate for prescribed fire planning (Brown *et al*., 2015).

4. Conclusions

In the first part, the (FWI) system was tested against real data covering two fire seasons and showed several aptitudes for its use as a meteorological fire risk assessment method for the country. The FWI supports to indicate the duration of the fire season, which is variable from one year to the other. This highly risky period is generally confined between May and the end of September in Chania region. The FWI indicates, also, with a relatively high accuracy the beginning, the peak, and the end of the fire season. The analysis of the number of fires in its relation to FWI classes, for the two fire seasons analyzed, revealed that about 95% of fires occur during "High" and "Extreme" days. Highly significant correlations were found between "number of fires" and duff moisture content DMC (r = 0.89), drought code DC (r = 0.78), buildup index BUI (r = 0.90), and the fire weather index FWI (r = 0.60). On the contrary, no significant correlation was found between the "burned area" and any component of the (FWI). According to Alcaniz *et al*. (2016), this is not necessarily a reflection on the accuracy and usefulness of the Fire Weather Indices. The analysis of longer time series for further stations with similar environmental conditions to the one investigated would bring more certainty about this specific point. In the second part, the KBDI was tested, and showed to provide a useful means of monitoring general wetting and drying cycles, but was inadequate for indicating daily fire danger throughout the fire season in Chania region. Weak correlations between the KBDI and fire occurrence (r = 0.24) and the area burned (r = 0.03) were found for the two fire seasons studied-2008-2009. This may be due to several reasons. The KBDI supports to predict with high accuracy the moisture content of three annual plants *(Piplatherum miliaceum, Parietaria diffusa, Avena sterillis)* with shallow rooting system representing the understory of *Pinus halepensis* in Chania region. Separate models are developed for determining their moisture content. This indicates that the index is adequate, to a certain extent, to represent the upper soil layers' water status, while it shows to be inapt to predict the needles moisture content of *Pinus halepensis*, which has a deep rooting system. The KBDI proved to be a satisfactory way of monitoring general wetting and drying cycles, and thus warning fire managers in the early stages about exceptionally wet and dry years. Furthermore, it is believed that monitoring foliage moisture content of the main species in the Mediterranean region as regard to their abundance and dominance and their involvement in most fires, and determining the relationships with the KBDI would give accurate predictive models and would make it easier to establish periods when conditions are convenient for fire management planning such as prescribed burning.

Acknowledgment

This article was funded by the Deanship of Scientific Research (DSR) at King Abdulaziz University, Jeddah. The authors, therefore, acknowledged with thanks DSR for technical and financial support.

References

Alcaniz M., Outeiro L., Francos M., Farguell J., and Úbeda X. (2016), Long-term dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgri Massif, Catalonia, Spain), *Science of the Total Environment*, 572, 1329-1335.

Amatulli G., Camia A., and San-Miguel-Ayanz J. (2013), Estimating future burned areas under changing climate in the EU-Mediterranean countries, *Science of the Total Environment*, 450-451, 209-222.

Arpaci A., Eastaugh C. S., and Vacik H. (2013), Selecting the best performing fire weather indices for Austrian ecoregions, *Theoretical and Applied Climatology*, 114, 393-406.

Bajocco, S., Dragoz E., Gitas I., Smiraglia D., Salvati L., and Ricotta C. (2015), Mapping forest fuels through vegetation phenology: the role of coarse-resolution satellite time-series, *PLoS One*, 10, e0119811.

Brown L. E., Palmer S.M., Johnston K., and Holden J. (2015), Vegetation management with fire modifies peatland soil thermal regime, *Journal of Environmental Management*, 154, 166-176.

Clavero M., Brotons L, and Herrando S. (2011), Bird community specialization, bird conservation and disturbance: the role of wildfires, *The Journal of Animal Ecology*, 80, 128-136.

Dimitrakopoulos A. P. and Bemmerzouk A. M. (2003), Predicting live herbaceous moisture content from a seasonal drought index, *International Journal of Biometeorology*, 47, 73-79.

Elhag M. and Bahrawi J. (2016), Deliberation of hilly areas for water harvesting application in western Crete, Greece, *Global Nest Journal*, 18, 621-629.

Keetch J. J. and Byram G. M. (1968), A drought index for forest fire control, Res. Pap. SE-38. Asheville, NC: US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 35 p.

Leverkus A. B., Lorite J., Navarro F. B., Sánchez-Cañete E. P., and Castroa J. (2014), Post-fire salvage logging alters species composition and reduces cover, richness, and diversity in Mediterranean plant communities, *Journal of Environmental Management*, 133, 323-331

Parr C. L., Andersen AN, Chastagnol C, and Duffaud C. (2007), Savanna fires increase rates and distances of seed dispersal by ants, *Oecologia*, 151, 33-41.

Pereira P., Ubeda X., Martin D., Mataix-Solera J., and Guerrero C. (2011), Effects of a low severity prescribed fire on water-soluble elements in ash from a cork oak (Quercus suber) forest located in the northeast of the Iberian Peninsula, Environmental Research, 111, 237-247.

Wrathall J. E. (1985), The hazard of forest fires in southern France, Disasters, 9, 104-114.