ADVANCES IN FOREST FIRE RESEARCH 2022

Edited by

DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Simple firefighting demand modelling and its use for estimation of the potential influence of fuel treatment scenarios on the number of required firetrucks on the island of Kythira, Greece

Gavriil Xanthopoulos[1]*; Miltiadis Athanasiou[1]; Vassiliki Varela[2], Konstantinos Kaoukis[1], Panagiotis Xanthopoulos[1]

[1]**Hellenic Agricultural Organization "Demeter", Institute of Mediterranean Forest Ecosystems. Terma Alkmanos, 11528, Athens, Greece, {gxnrtc@fria.gr, info@m-athanasiou.gr, kako@fria.gr, panosxant@hotmail.com}*
[2] *Center for Security Studies (KEMEA). 4, P. Kanellopoulou str., 101 77, Athens, Greece, {v.varela@kemea-research.gr}*

**Corresponding author*

Keywords

forest fire, fire suppression, firefighting demand, fuel management

Abstract

The island of Kythira, in Greece, suffered a devastating forest fire that started on August 4, 2017. After that, it became evident that the location of the island, away from aerial fire suppression resources bases and with limited capacity for quick arrival of significant ground firefighting reinforcements, necessitates careful fire prevention and presuppression planning to avoid repetition of the disaster. The study presented here aimed to examine the adequacy of the available 13 firetrucks on the island to successfully carry out initial attack under similar conditions to those of 2017, and to evaluate what could be the effect of four alternative fuel treatment scenarios on reducing the potential of a future disaster. A map of the forest fuels on the island, a weather scenario similar to the conditions at the start of the 2017 fire, and the Digital Elevation Model (DEM) of the island were used with a fire spread simulator (G-FMIS) first to simulate the actual fire and to examine if it matches the observed fire spread in 2017. Once good agreement was verified, four fuel treatment scenarios were applied on the fuels. The accordingly adjusted fuel map was used for further simulations. The resulting fire perimeter growth, taking flame length into consideration, was examined against the capacity of ground forces (firetrucks) to control lengths of the perimeter using a simple but effective fire suppression model, that is based on an equation developed earlier for assessment of the effectiveness of such forces in Greece. The results showed that under broadcast grazing on the island the risk of escaped fires can be minimized, reducing the need for heavy aerial support in case of a fire.

1. Introduction

In Greece, the island of Kythira, which lies south of Peloponnese, suffered a devastating forest fire that started on August 4, 2017, and spread actively for three days. It finally burned 2,471 ha (8.91% of the island) creating significant problems to the environment and the economy of Kythira including its important tourism sector. In the frame of a post-fire effort to reduce the chance of repetition of such a disaster (Xanthopoulos et al. 2022) it was needed to estimate the requirement of firefighting resources for suppression of potential fires and compare it with those currently available on the island. The island's location, away from the bases of aerial resources, and with a long time requirement (4-6 hours) before significant ground reinforcements can arrive by boat, means that the initial attack must be handled by the locally stationed 13 firetrucks with their crews. An analysis of the firefighting requirement was identified as important for highlighting the need for effective fire prevention to the local authorities and population, both in regard to mitigation of fire starts and to fuel treatment for biomass reduction. Furthermore, it can demonstrate the importance of quick and strong mobilization of resources in case of a fire start under weather conditions that could lead to a failure of initial attack and repetition of the 2017 disaster. The effort for estimation of the firefighting requirement, using fire spread simulation both with the actual fuels and those under different fuel management scenarios, is described here. The study uses the area of the August 4, 2017 burn as an example, because it spans the most typical fuel types on the island.

2. Methodology

In the frame of the post-fire fire prevention effort on Kythira, a forest fuels map was developed for the island (Xanthopoulos et al. 2022). The fire behavior and the growth of the August 2017 fire was documented in detail and it was possible to reconstruct fire evolution with good accuracy. Next, the G-FMIS fire spread simulator, was used for simulating fire spread (Xanthopoulos et al. 2022). Inputs included a weather scenario similar to the conditions at the start of the 2017 fire, the forest fuels map and the DEM of Kythira. The outcome was a realistic simulation, matching well the true evolution of the fire (Xanthopoulos et al. 2022). Once good agreement was verified, G-FMIS was used to examine the effect on fire spread, that four potential fuel treatments could have if they had been applied, prior to the fire event, to the area that burned. The four scenarios were:

- Scenario 1: Mechanical treatment (tractor) only in agricultural areas
- Scenario 2: Mechanical treatment (hand tools) only in agricultural areas
- Scenario 3: Grazing everywhere (in all types of vegetation)
- Scenario 4: Intense grazing everywhere (in all types of vegetation)

Modified post-treatment fuel models were estimated for the four scenarios, based on scientific literature review, the forest fuel map was adapted accordingly, and new fire spread simulations, using the same weather conditions as those at the time of the 2017 fire, tested the effect of the fuel treatment on fire perimeter growth and flame length under the four scenarios. Fire spread was simulated for six hours in time steps of 1 hour. The fire perimeter of the simulated fires under the four scenarios, for each time step, were traced manually and the perimeter length for each of five classes of flame length (m) was calculated. The classes were a) 0-1.5 m, b) 1.5-2.5 m, c) 2.5-3.5 m d) 3.5-10 m e) >10 m.

The effect of the fuel treatments on the firefighting demand (firetrucks) was assessed using a published formula for calculating the length of the flank of a fire that can be extinguished by a firetruck having a water carrying capacity of 2500 l, as a function of flame length (Simos and Xanthopoulos 2014). The formula is as follows:

$$EXT2500L\_Flank = 20.756 + 57.493 / FLflank$$

Where the extinction length EXT2500L_Flank and the flank flame length FLflank are expressed in meters. Table 1 is based on the equation above.

Table 1- Length of the fire perimeter of a fire (EXT2500L_Flank) that can be extinguished by a 2500 l firetruck, as a function of flame length

Flame length class	**FL value used in simulation**	**Extinction of perimeter (m) per 2500l firetruck load**
1: up to 1.5 m	1.2	68.7
2: up to 2.5 m	2.2	46.9
3. up to 3.5 m	3.5	37.2
4. up to 10 m	10.0	26.5
5. more than 10m	20.0	23.6

In order to develop a more realistic firefighting requirement estimation, the reduction in the effectiveness of the firetrucks due to the need for refilling with water needs to be taken into consideration, as well as the average time for emptying the load of a firetruck to the fire (Joerscke 1999). Assuming a typical average distance of 4 km to water sources at Kythera, a fire truck travel speed of 50 km h^{-1} on the winding and narrow road network of the island, and a time of 15 minutes for using-up one water load on the fireline, the truckloads that can be achieved by a firetruck per hour were calculated as shown in Table 2.

Table 2- Estimated fight and reload rounds per hour (LOADS_PER_HOUR) that can be achieved by a firetruck with a 2500 l water carrying capacity on Kythira island.

Average distance (km)	ADIST	4.00
Firetruck speed (km/h)	SPEED	50.00
Water loading time with delays	WLT	5.00
Travel time (min)	TRAVEL=WLT+((2*ADIST/SPEED)*60)	14.60
Time for using-up one water load (min)	WUT	15.00
Total time needed per truckload for each round (min)	TT=TRAVEL+WUT	29.60
Fight & reload rounds per hour	LOADS_PER_HOUR=60/TT	2.03

The required firetruck loads for extinguishing a length of the perimeter of each flame length class at each time step, was estimated by dividing the length of the perimeter by the corresponding EXT2500L_Flank for that flame length. The number of hours for each time step (1 to 6 hours), divided by the LOADS_PER_HOUR, provided an estimate of the truckloads that can be delivered by a firetruck in this step's hours. Thus, the required number of firetrucks to deliver the needed truckloads at each time step was calculated by dividing the required firetruck loads for extinguishing the perimeter until then, with the truckloads that can be delivered by a firetruck.

3. Results

Figure 1 shows the simulated growth of the August 4, 2017 fire, in hourly steps, indicating through different colours the flame length along the perimeter. The flame length classes correspond to the broadly accepted limits for firefighting (Tedim et al. 2018). It is noted that at no point across the perimeter, a flame length over 10 m is predicted. Figure 2 illustrates the effect that the four fuel treatment scenarios would have on the burned area and flame length along the perimeter

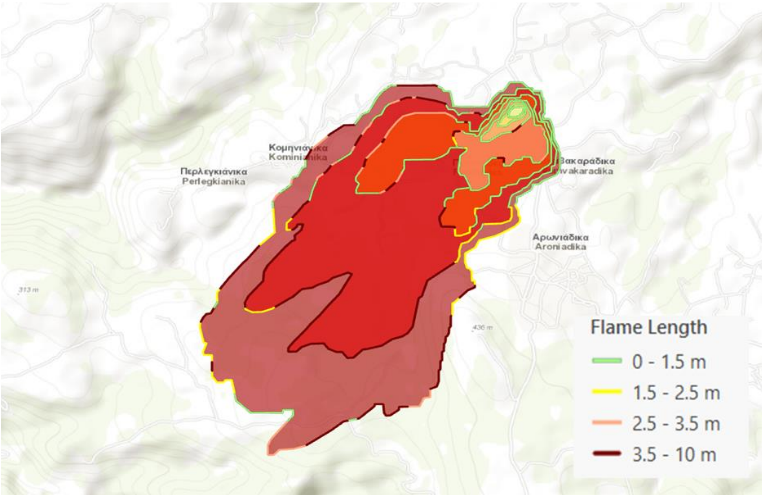

Figure 1- Simulation of the August 4, 2017 fire on Kythira based on the existing fuels at the time, showing the flame length classes along the perimeter at each (hourly) simulation step.

Figure 3 presents the growth of the perimeter with time along the 6-hour simulation, including the simulation with the "real" fuel situation (i.e. the fuels that actually burned in the 2017 fire) and the simulations with the four fuel treatment scenarios. The significant effect of grazing (treatments 3 and 4) is obvious. On the other hand, treatments 1 and 2 seemingly have little effect. This is explained by the relatively small percentage (7.19%) that agricultural areas that receive these treatments, occupy within the specific burned area.

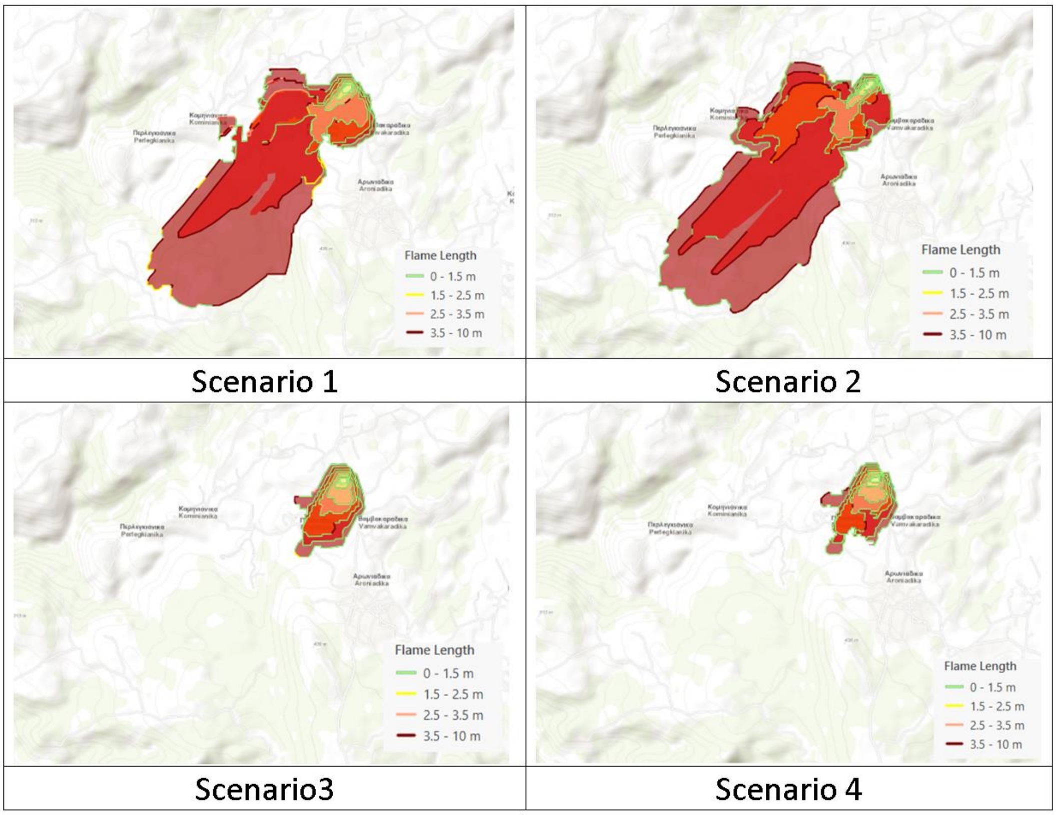

Figure 2- Influence of the four fuel treatment scenarios on burned area and flame length along the perimeter (simulation of 6 hours)

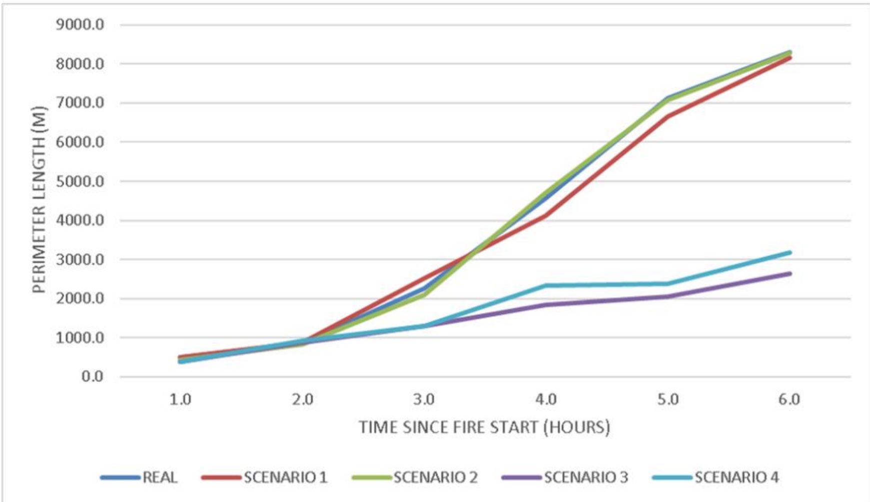

Figure 3- Fire perimeter length growth with time for the simulations with the real fuels and under four fuel treatment scenarios

The treatments also have an effect on flame length along the perimeter, which influences the firefighting requirements, as shown in table 4 which presents the required of firetruck loads (T) with time. As an example, the perimeter length after 3 hours of simulation with the real fuels, indicated as PL_3 in table 4, is 2271.4 m. It consists of 1924.5 m of FL class 1 (i.e. 1.2 m), 85.5 of FL class 2 (2.2 m), 121.2 m of FL class 3 (3.5 m) and 140.2 of FL class 4 (10.0 m). Taking table 1 into consideration, the 1924.5 m of FL class 1 require 1924.5/68.7= 28.0 truckloads. The other parts of the perimeter require 1.8, 3.3, and 5.3 truckloads respectively for a total requirement of 38.4 truckloads in 3 hours.

Table 4- Estimated requirement of 2500 l firetruck loads (T) for extinguishing the fire Perimeter at each time step (i=1-6), taking the Flame Length of all the parts of the perimeter (in classes) into consideration (PL_i)(m)

Fuels	PL_1	T	PL_2	T	PL_3	T	PL_4	T	PL_5	T	PL_6	T
Kythira fire fuels	505.8	7.4	864.3	14.2	2271.4	38.4	4572.6	88.2	7117.3	204.0	8302.3	202.4
Scenario 1	504.3	7.3	867.4	14.1	2516.8	40.8	4118.6	76.7	6654.9	162.3	8153.4	175.9
Scenario 2	438.1	6.4	841.2	12.3	2093.8	36.2	4703.6	102.8	7084.1	183.5	8275.3	189.6
Scenario 3	394.0	5.7	875.9	12.8	1292.2	19.3	1839.0	29.0	2060.6	30.0	2629.0	41.4
Scenario 4	388.6	5.7	917.7	13.4	1292.7	19.7	2328.8	36.2	2379.6	34.7	3190.1	51.2

Continuing on the previous example, using LOADS_PER_HOUR = 2.03 from table 2, it is calculated that a firetruck can transport and use 3 x 2.03= 6.1 truckloads in 3 hours. The number of firetrucks that can achieve the required 38.4 truckloads, are 38.4/6.1 = 6.3 firetrucks. Figures 4 and 5, present the estimated evolution of required truckloads as the fire spreads, and ultimately the number of the required firetrucks for the 6 hours of the simulation.

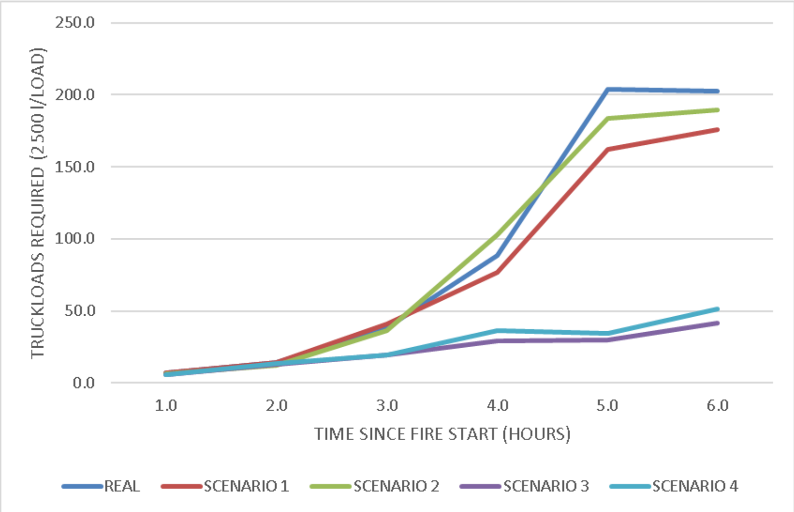

Figure 4- Number of required truckloads of 2500 l for extinguishing the fire perimeter with time, for the five simulations

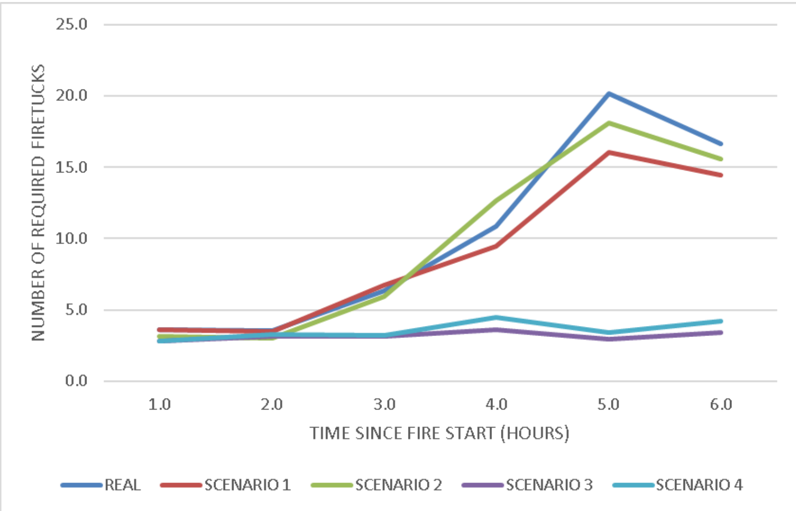

Figure 5- Evolution of the required number of firetrucks for controlling the perimeter of the fire as a function of time, for the five simulations

4. Conclusions

In conclusion, the simple method developed here for estimating ground firefighting demand has produced some very interesting results. It demonstrated the need for increased prevention and better presuppression planning and the value of systematic broadcast grazing as a fuel treatment across the island. Under such fuel treatment the 13 available firetrucks could be able to control starting fires even under difficult conditions. Aerial resources, if dispatched, could have an auxiliary role. The concept presented here can be used for similar analyses elsewhere.

5. Acknowledgements

The study was supported by the project “PREVAIL PREVention Action Increases Large fire response preparedness” (826400 — PREVAIL — UCPM-2018-PP-AG), funded by the European Union Humanitarian Aid and Civil Protection (DG-ECHO).

6. References

Joerscke, J. D. (1999). Pumping Apparatus: Driver Operator's Handbook. International Fire Service Training Assn.

Simos, M., & Xanthopoulos, G. (2014). Assessment of the effectiveness of the forest fire fighting ground forces in Greece. In proceedings of the 7th International Conference on Forest Fire Research on “Advances in Forest Fire Research”, November 17-20, 2014. Coimbra, Portugal. Viegas D. X., (editor). ADAI/CEIF, University of Coimbra, Portugal. pp. 665-672.

Tedim, F., Leone, V., Amraoui, M., Bouillon, C., Coughlan, M. R., Delogu, G. M., Fernandes, P., Ferreira, C., McCaffrey, S., McGee, T., Parente, J., Paton, D., Pereira, M., Ribeiro, L.M., Viegas, D. X., & Xanthopoulos, G. (2018). Defining extreme wildfire events: difficulties, challenges, and impacts. Fire, 1(1), 9.

Xanthopoulos, G., Athanasiou, M., Nikiforaki, A., Kaoukis, K., Mantakas, G., Xanthopoulos, P., Papoutsakis, C., Christopoulou, A., Sofronas, S., Gletsos, M., & Varela, V. (2022). Innovative Action for Forest Fire Prevention in Kythira Island, Greece, through Mobilization and Cooperation of the Population: Methodology and Challenges. Sustainability, 14(2), 594.