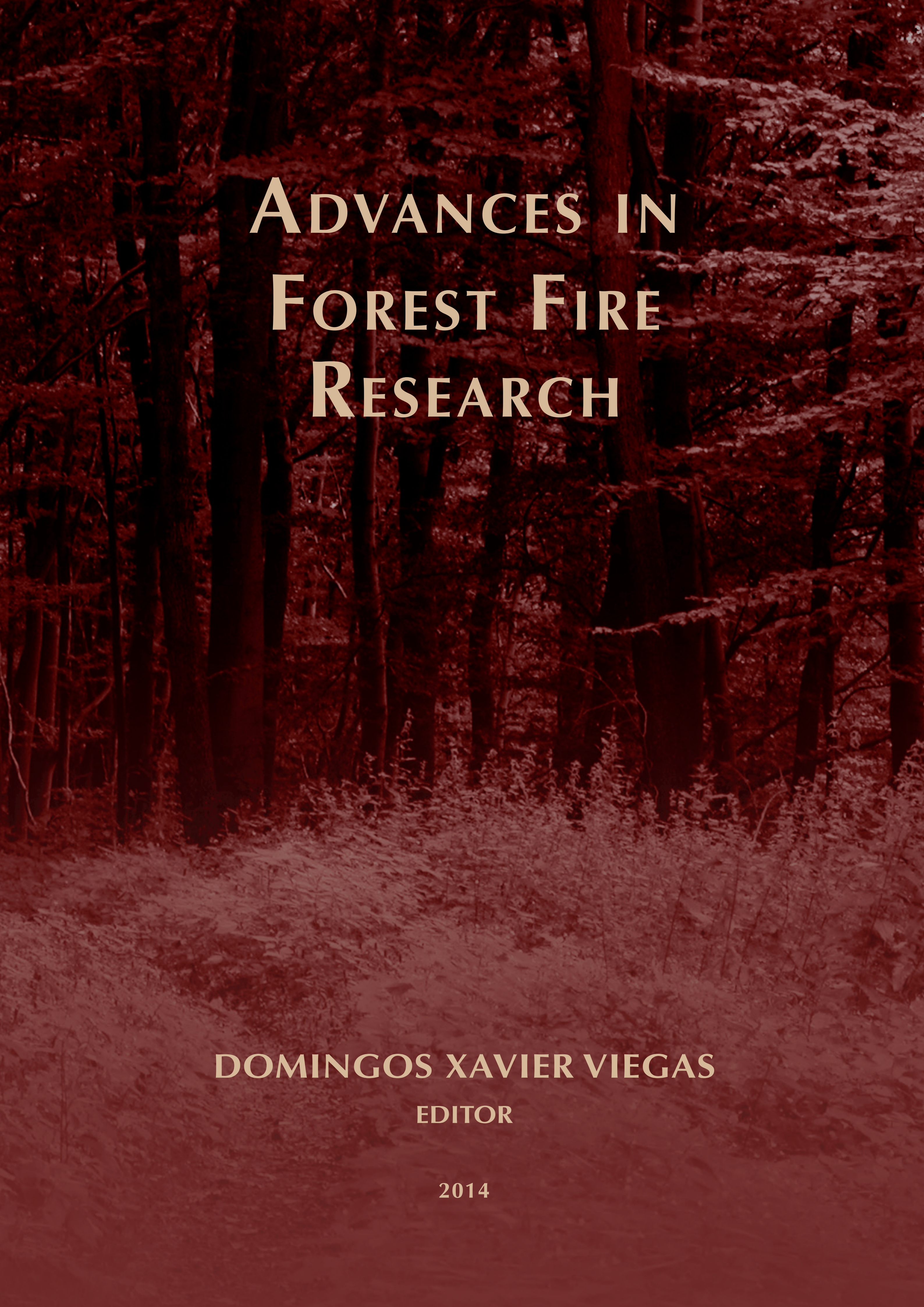

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Assessment of the effectiveness of the forest fire fighting ground forces in Greece

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Abstract
Efficient dispatching of firefighting forces to a forest fire and effective management of those requires good knowledge of their capabilities and limitations. The study presented here tries to develop knowledge and equations for evaluating the performance and limitations of the ground forces attacking fires in Greece taking into consideration the firefighting methods used in the country. It is based on a questionnaire with photos of fires that was answered by 67 individuals with varying firefighting experience and involvement in firefighting. Among the results reported here are equations for selecting "direct attack on all points" of a fire as a function of flame length and of rate of spread and equations for estimating the probability that a fire will be considered as being beyond the capacity of any of a series of suggested firefighting resources combinations. Also, equations were developed for estimating the length of fire front and of fire flank that can be extinguished by a light fire truck with a water capacity of 600 liters and a fire truck with a capacity of 2500 liters, as a function of flame length. The results of the study provide useful input for understanding and modelling forest fire suppression in Greece and can probably be useful for other Mediterranean countries as well.

***Keywords**: Forest fire fighting, fire suppression effectiveness, fire truck, fire extinction rate, direct attack*

1. Introduction

Efficient dispatching of firefighting forces to a forest fire and effective management of those forces in the field of operations requires good knowledge of their capabilities and limitations. Numerous studies in international fire literature have been devoted to assessment of the effectiveness of ground and aerial resources and to modelling of firefighting operations. However, such knowledge and models are not universal as performance is affected by various local factors such as firefighting methods, tools and equipment, firefighter training, professionalism and motivation, weather conditions, vegetation characteristics, topography, road network density, etc. (Hirsch and Martell 1996). Consequently, although published work on the subject is certainly valuable, some local knowledge of firefighting effectiveness is definitely required. In Greece, so far, there have been no published studies on firefighting effectiveness. When such knowledge was required for the development of a decision support system for dispatching of ground and aerial resources the required information was obtained from interviews with a small number of experienced foresters (Xanthopoulos 1994). Since then, a lot has changed in the way firefighting is carried out in the country. For example, firefighting responsibility has been transferred from the Forest Service to the Fire Brigades in 1998, the number of volunteer firefighters increased sharply, firefighting techniques and priorities as well as training changed, and the types of resources improved. On the other hand, the lack of formal knowledge on the effectiveness of the firefighting forces did not change.
The study presented here is an effort to fill this knowledge gap. It focuses specifically on the performance and limitations of the ground forces attacking a fire and takes into consideration the firefighting methods used in Greece. Its findings are certainly of value for Greece but they may be relevant in other Mediterranean countries as well.

2. **Methods**

Aiming to develop a first overall picture of the effectiveness of the ground forces, it was decided to employ specifically designed questionnaires for collecting the necessary data. The choice of the method took into consideration difficulties encountered in other studies for collecting valid productivity information using traditional data collection methods that has sometimes led to discrepancies and made, for example, Fried and Gilles (1989) to embark on a major expert opinion study on fireline construction rates.

	**Estimated** Rate of spread ROS=120 m/h Flame length FLAME=1 m	**Attack method** (Choose **only one**) 1)☐ 2)☐ 3)☐ 4)☐ **Firefighting resources** (Choose **all** that can be used) 1) ☐ 2)☐ 3)☐ 4)☐ 5)☐ 6)☐ 7)☐ 8)☐ 9)☐ **Minimum Resource Required** (Choose **only one**) 1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐ 6) ☐ 7)☐ 8)☐ 9)☐ 10) ☐
	**Estimated** Rate of spread ROS=700 m/h Flame length FLAME=18 m	**Attack method** (Choose **only one**) 1)☐ 2)☐ 3)☐ 4)☐ **Firefighting resources** (Choose **all** that can be used) 1) ☐ 2)☐ 3)☐ 4)☐ 5)☐ 6)☐ 7)☐ 8)☐ 9)☐ **Minimum Resource Required** (Choose **only one**) 1) ☐ 2) ☐ 3) ☐ 4) ☐ 5) ☐ 6) ☐ 7)☐ 8)☐ 9)☐ 10) ☐ The four options in regard to attack method: 1. Direct attack at all points (front, flanks, heel) 2. Indirect attack at the front, direct at the flanks 3. Indirect attack along all the perimeter (from firebreaks, roads, natural vegetation breaks, etc.) 4. Attack impossible until conditions change

Figure 1. Two of the twelve photos of the first question of the questionnaire and the four options in regard to the method of attack for the type of fire shown in each photo.

2.1. **The questionnaire**

The questionnaire consisted of two parts. The first part aimed at collecting information about the respondent including age, sex, employment, education level, general training, training about forest fires, years of involvement in fire management, years and way of participating in firefighting operations. Providing the name and contact data of the respondent was optional.

The second part of the questionnaire consisted of three main questions, each presenting a number of cases illustrated by photos. The first question presented 12 photos of fires and provided an estimated flame length and rate of spread (ROS) for each of those fires. These flame length estimates ranged between 0.2 and 50 m, while ROS ranged between 80 and 2500 m/h. The respondent was asked to choose from four options about the type of attack appropriate for the depicted part of the fire (including a “no-attack possible” option), nine options in regard to the required type of resources, and ten options in regard to combinations of resources that would be required at a minimum to control a 100 m wide fire front of the portrayed type of fire from a 6 m wide road (Figure 1).

The second question presented 9 photos of fires with an estimate of the depicted flame length. Assuming scenarios of fighting such flames at the front or at the flanks (2 cases) by a) One driver and two firefighters with a light fire truck having a 600 liter tank and using 25mm diameter hoses, or by b) the same people with a heavier fire truck (2500 liter tank) using 45 mm diameter hoses, the respondent was asked to provide estimates (in meters) of the length of the perimeter (front or flank) that can be extinguished using the water in the tank of the truck. An option was provided to mark X if direct attack on the flames with the particular resource was considered as impossible. Flame length estimates for the fire fronts ranged between 0.5 and 60 m and for the flanks between 0.3 and 30 m.
The third question presented 6 photos of typical vegetation in Greece. The respondent was asked to provide an estimate of the length of a 2 m wide fireline that an 8 person crew could build within an hour for combinations of slope (flat, medium) and time of day (early morning, midday, night).

3. Analysis and Results

Sixty seven (67) people of varying experience and involvement in firefighting responded to the questionnaire. Forty nine (49) of them work for the Greek Fire Service either as permanent personnel or as volunteers, while fifteen (15) of them belong to the unpaid volunteer groups of the General Secretariat for Civil Protection. Sixteen (16) of the 67 respondents stated that they have high or very high experience in firefighting while 30 more replied that they have average (medium) experience. The data formed a database that was analyzed with the R and SPSS statistical software. Selected results are reported below.
The responses to the first question were examined first in regard to frequencies of selection of certain options (e.g. selection of initial attack). This allowed to investigate trends in the responses versus fire characteristics and to identify certain thresholds. A focal point of the analysis was the assessment made by the respondents about the limits of direct attack. This was done through development of models for the probability of selecting direct attack on the flames on all parts of a fire ($PROB_{direct}$) as a function of flame length (FLAME in m) and of rate of spread (ROS in m/h).
The replies selecting direct attack for the fire depicted in each of the twelve (12) photos of the first question, allowed an estimate of probability of such selection for each flame length. The same was done for ROS. For example, for the upper photo of figure 1, with flame length of 1 m, 88% of the respondents selected the first of the four options “Direct attack at all points (front, flanks, heel)”; no-one selected the fourth option “Attack impossible until conditions change”. For the lower photo with flame length of 18 m, only 7% of the respondents selected direct attack; the majority (45%) chose the third option “Indirect attack along all the perimeter” while 21% of the respondents considered this fire as impossible to attack (fourth option).
The probability of selecting “direct attack on all points” of a fire ($PROB_{direct}$) as a function of flame length and of rate of spread was analyzed using the data set of twelve records (N=12), i.e. one record for each of the photos of the first question. Two regression equations were developed with $PROB_{direct}$ as the dependent variable and the natural logarithm of FLAME and ROS. The equations are as follows:

a) $PROB_{direct} = 64.609 - 19.051 * \ln(FLAME)$ with Adj. $R^2 = 0.857$ (1)

b) $PROB_{direct} = 210.999 - 28.389 * \ln(ROS)$ with Adj. $R^2 = 0.814$ (2)

Both equations are statistically significant (p<0,005). Plotting of the first equation revealed that the probability of direct attack all around the fire perimeter drops to 40% when the flame length is 3.5 m (Figure 2). Plotting of the second equation showed that $PROB_{direct}$ approaches zero when ROS exceeds 1600 m/h (Figure 3). Actually, the equation produces negative $PROB_{direct}$ values for ROS>1689 m/h.

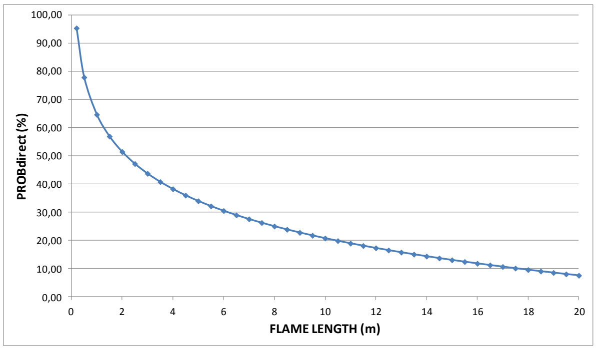

Figure 2. Plotting of the probability to engage in direct attack on all parts of a fire which is exhibiting a particular flame length, according to equation 1.

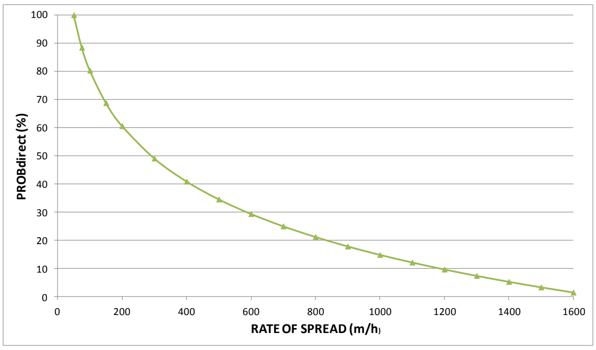

Figure 3. Plotting of the probability to engage in direct attack on all parts of a fire spreading with a particular rate of spread, according to equation 2.

Another important finding, based again on the responses regarding the twelve photos of the first question (N=12), has to do with the probability that a fire will be considered as being beyond the capacity of any of the firefighting resources combinations that were suggested to the respondents (PROB_NO), as a function of FLAME and of ROS. The strongest suggested combination was 4 fire trucks plus aerial resources for fighting a 100 m wide fire front from a 6 m wide road. Again, two regression equations were developed with PROB_NO as the dependent variable and FLAME and ROS as the independent variables respectively. The equations are as follows:

c) PROB_NO = 1.814 + 1.407 * FLAME with Adj. R^2= 0.951 (3)

d) PROB_NO = 6.001 + 0.028 * ROS with Adj. R^2= 0.862 (4)

Both equations are statistically significant (p<0,005).

The second question which focused on the length of extinction of the front and of the flanks of a particular fire, shown in photograph and associated with estimates of frontal and flank flame length. The requested length estimates (m) were for two different firefighting resources as explained earlier. Many respondents omitted providing estimates for some of the photos. Also, many replies were marked X indicating that direct attack on the flames with the particular resource was considered as impossible. The data were analyzed with regression aiming to establish models for estimating extinction lengths of fire front or flank for each resource with flame length as the independent variable. Furthermore, logistic regression analysis provided models for estimating the probability that direct attack is possible. The results are as follows:

Case 1:

Resource: One driver and two firefighters with a light fire truck having a 600 liter tank, using 25mm diameter hoses.

Operation type: Attack to the fire front.

Results: The maximum number of replies from the 67 respondents for the 9 photos was 603. The number of length estimates were 233 while 287 responses were marked with X (direct attack impossible with this resource) and were given a value of 0 for the logistic regression. The number of "no replies" was 83. The equation is:

$$EXT_{600L\_Front} = 1.969 + 37.038 / FL_{front} \quad (5)$$

Where the extinction length EXT_{600L_Front} and the frontal flame length FL_{front} are expressed in meters, Adj. $R^2 = 0.294$, the p-value for the equation is $p<0.001$, the constant's $p=0.282$ and of $1/ FL_{front}$ $p <0.001$.

The logistic regression equation is:

$$P(EXT_{600L\_Front})= \exp(1.537-0.,184*(FL_{front}))/(1+ \mathrm{Exp}(1.537-0.184*(FL_{front}))) \quad (6)$$

Case 2:

Resource: One driver and two firefighters with a light fire truck having a 600 liter tank, using 25mm diameter hoses.
Operation type: Attack to the flank of the fire.
Results: The number of extinction length estimates was 333 while 190 responses were marked with X (direct attack impossible with this resource) and were given a value of 0 for the logistic regression. The number of "no replies" was 80. The equation is:

$$EXT_{600L\_Flank} = 6.321 + 27.711 / FL_{flank} \quad (7)$$

Where the extinction length EXT_{600L_Flank} and the flank flame length FL_{flank} are expressed in meters, Adj. $R^2 = 0.269$, the p-value for the equation is $p<0.001$, the constant's $p=0.019$ and of $1/ FL_{flank}$ $p <0.001$.

The logistic regression equation is:

$$P(EXT_{600L\_Flank})= \exp(1.692-0.152 *(FL_{flank}))/(1+ \mathrm{Exp}(1.692-0.152*(FL_{flank}))) \quad (8)$$

Case 3:

Resource: One driver and two firefighters with a fire truck having a 2500 liter tank using 45 mm diameter hoses.
Operation type: Attack to the fire front.
Results: The number of extinction length estimates were 329 while 192 responses were marked with X (direct attack impossible with this resource) and were given a value of 0 for the logistic regression. The number of "no replies" was 82. The equation is:

$$EXT_{2500L\_Front} = 9.354+77.453 / FL_{front} \quad (9)$$

Where the extinction length EXT_{2500L_Front} and the frontal flame length FL_{front} are expressed in meters, Adj. $R^2 = 0.292$, the p-value for the equation is $p<0.001$, the constant's $p=0.014$ and of $1/ FL_{front}$ $p <0.001$.

The logistic regression equation is:

$$P(EXT_{2500L\_Front})= \exp(1,828-0,1 *(FL_{front}))/(1 + \mathrm{Exp}(1.828-0.1*(FL_{front}))) \quad (10)$$

Case 4:

Resource: One driver and two firefighters with a fire truck having a 2500 liter tank using 45 mm diameter hoses.

Operation type: Attack to the flank of the fire.

Results: The number of extinction length estimates were 405 while 120 responses were marked with X (direct attack impossible with this resource) and were given a value of 0 for the logistic regression. The number of "no replies" was 78. The equation is:

$$EXT_{2500L\_Flank} = 20.756 + 57.493 / FL_{flank} \qquad (11)$$

Where the extinction length EXT_{2500L_Flank} and the flank flame length FL_{flank} are expressed in meters, Adj. $R^2 = 0.236$, the p-value for the equation is $p<0.001$, the constant's $p=0.001$ and of $1/ FL_{flank}$ $p <0.001$.

The logistic regression equation is:

$$P(EXT_{2500L\_Flank})= \exp(2.444-0.163 *(FL_{flank}))/(1+ \mathrm{Exp}(2.444-0.163*(FL_{flank}))) \qquad (12)$$

Figure 4 is a plot of equations 5, 7, 9 and 11 showing the quick drop in extinction effectiveness with increasing flame length.

4. Discussion and conclusions

The results of the study provide useful input for understanding and modelling forest fire suppression in Greece. For example, the result of equation (1) that there is a 40% chance of direct attack on fires with 3.5 m flame length and a 24% chance at 8.5 m flame length, can be evaluated versus the limits of successful attack at the fire front suggested and discussed by Deeming *et al*. (1978), Andrews and Rothermel (1982), Rothermel (1983), Alexander and DeGroot (1988), Alexander and Lanoville (1989), and Hirch and Martell (1996). In interpreting equation (1) it should be taken into consideration that following firefighting practice in Greece the respondents have use of water from fire trucks as the default method of attacking a fire. In general the results of equation 1 appear to be in agreement with the other studies, taking of course into consideration that the photos in the present questionnaire represented various fuel types whereas some of those studies focused on specific fuels types.

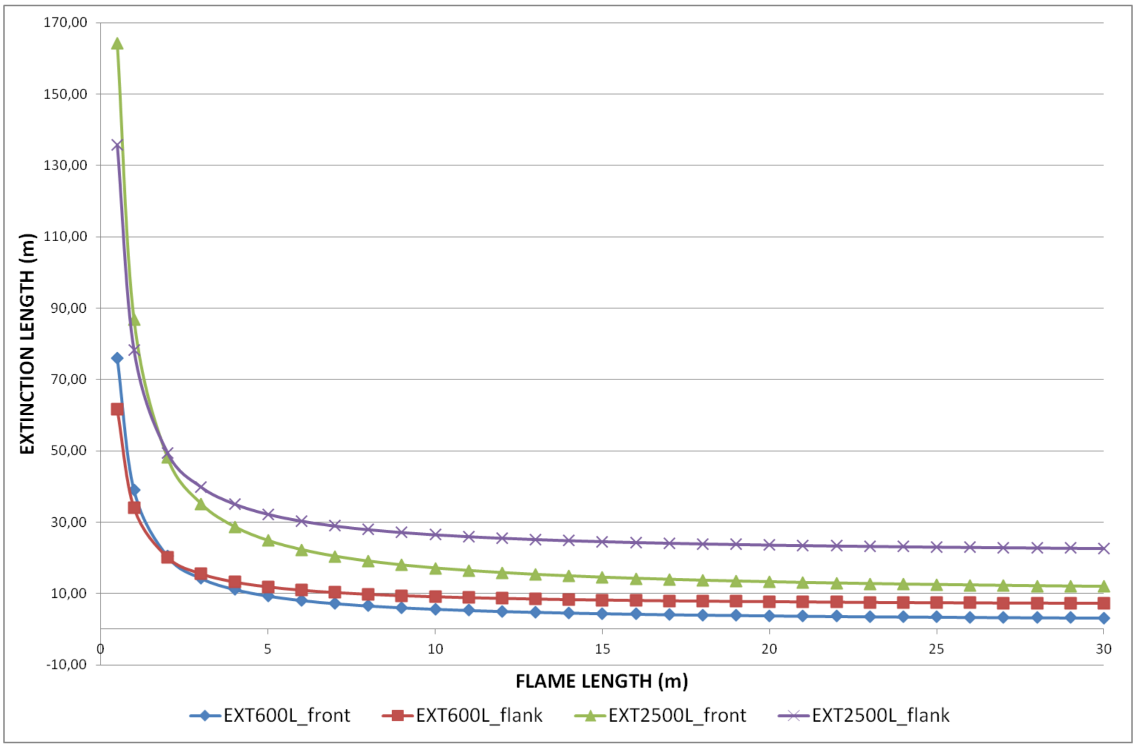

Figure 4.Plotting of the predicted extinction length for a range of flame lengths according to equations 5, 7, 9 and 11.

Equation 2 is also interesting as it provides an estimated ROS limit (1690 m/h) beyond which direct attack is not possible, not taking a particular fuel type into consideration. Such information is less commonly available in the international literature. The results of this equation can be challenged since fast running grass fires can be chased along the flanks by fire trucks equipped with appropriate water spraying capability, aiming to achieve an extinguishing rate faster than the ROS of the fire and ultimately catch and extinguish the head of the fire. Topography, which is generally steep, might make use of such a technique an exception rather than the rule for grass fires in Greece.

Equations 5-12 have generally low Adj. R^2 statistics. This is not surprising as there was a lot of variation in regard to the estimates of extinction length provided by the respondents. Part of this variability is due to the variety of fuel types depicted in the photos. It is well known that the water required to extinguish a grass fire is much less than that needed for a heavier fuel type even if the flame length is the same. The varying background and experience of the respondents is also an important source of variability. Nevertheless, the behaviour of the equations is rational and can provide a good baseline for calculations that will be useful for dispatching of fire trucks for initial attack and for planning extended attack in the future in Greece.

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