Where and when large fires occur in southern Europe, where they stop, and simulated influence of fuel treatments on firefighting demand

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Large forest fires in Europe

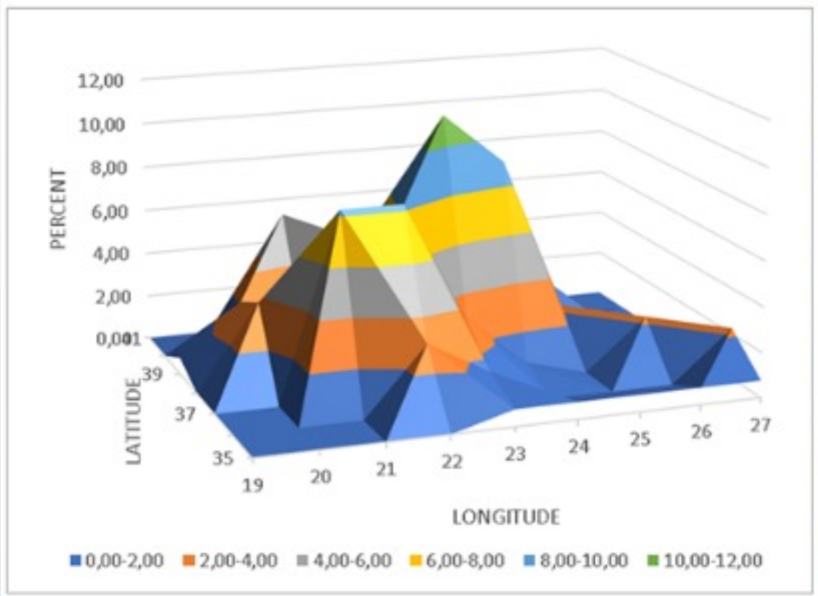
- Large fires are at the center of attention around the world and in Europe
- PREVAIL aimed to understand them and improve their prevention
- We assembled and analyzed a database of 360 large (>500 ha) fires, from Greece, Italy, Portugal and Spain (Catalonia), that occurred in the 2000-2019 period, as well as 495 “small” fires selected in a systematic way, from the national databases.

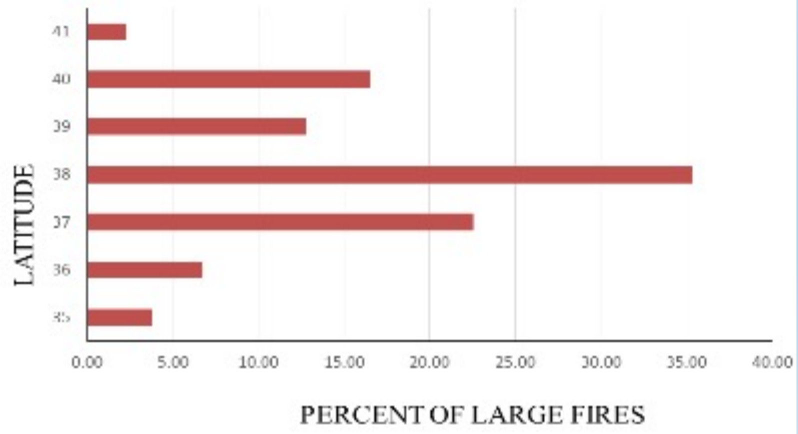
Country/Region	**Number of fires>500ha**	**Number of fires<500ha**	**Period**
Catalonia, Spain	26	168	2000-2018
Greece	133	125	2000-2019
Italy	40	40	2017
Portugal	161	162	2009-2018
Total	360	495	

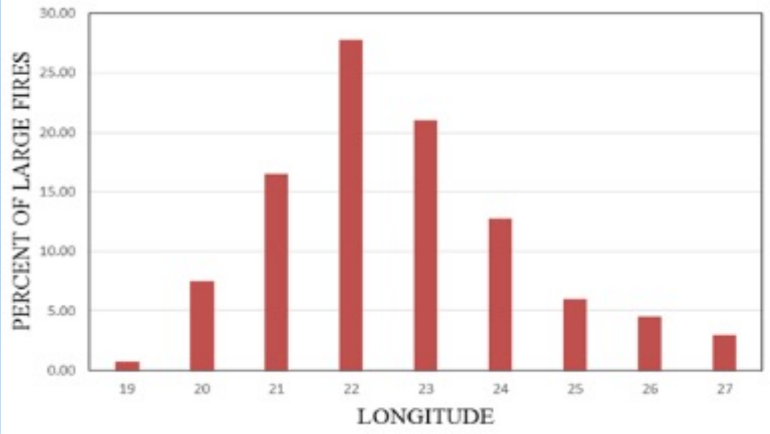
Database variables

- The database includes:
  - the coordinates (**LATITUDE** and **LONGITUDE**) of the starting point of each fire,
  - the **DATE** and **TIME**,
  - the **ELEVATION**, and the SLOPE,
  - the weather conditions (TEMPERATURE, RELATIVE HUMIDITY, WIND SPEED),
  - the **AIRDISTANCE** from the fire to the nearest base of aerial resources and the distance of the closest source of water for the aerial resources (**WATERDISTANCE**), be it a lake, river, or the sea,
  - the time of the first firefighting intervention (**FIRSTINT**),
  - the forest area that burned (**BURNEDFOREST**) and the total **BURNEDAREA**
  - an index describing the fire hazard level of the **VEGETATIO**N
  - the number of parallel fires (**PAR_FIRES**) and large fires (**PAR_LFIRES**) on that day
  - the firefighting resources (**FIREFIGHTERS**, others contributing (**OTHER_CONTR**), **FIRETRUCKS, HEAVYMACHINES, AIRPLANES** and more specifically **AMPHIBIAN** airplanes, and **HELICOPTERS**.

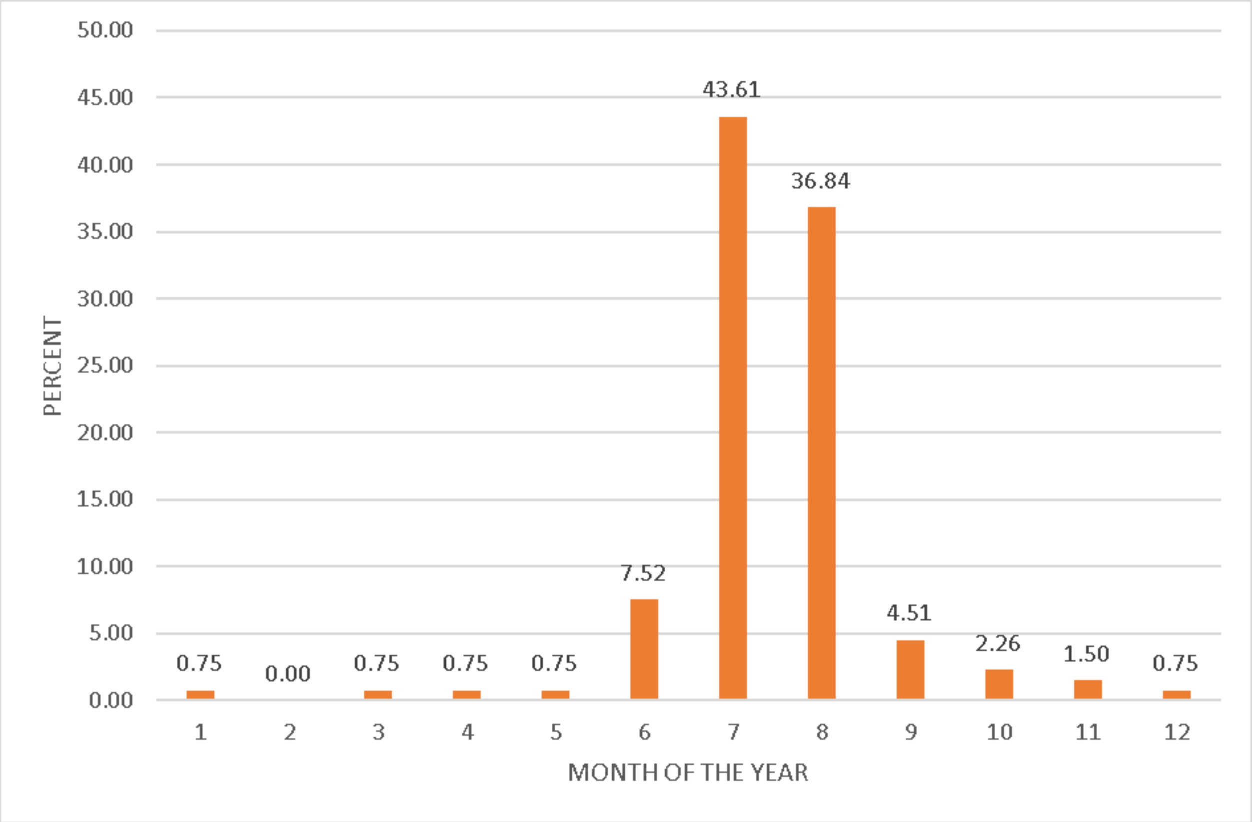
Where do large fires occur in Greece?

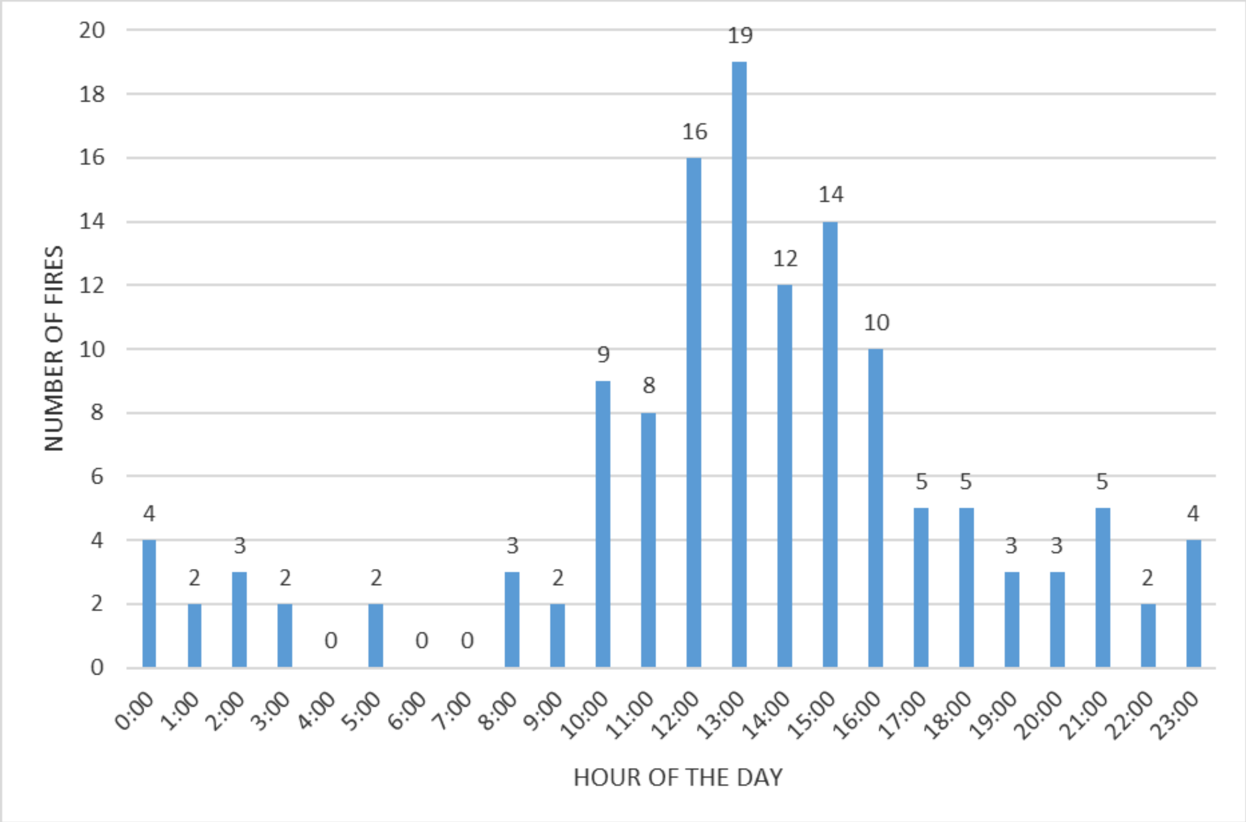




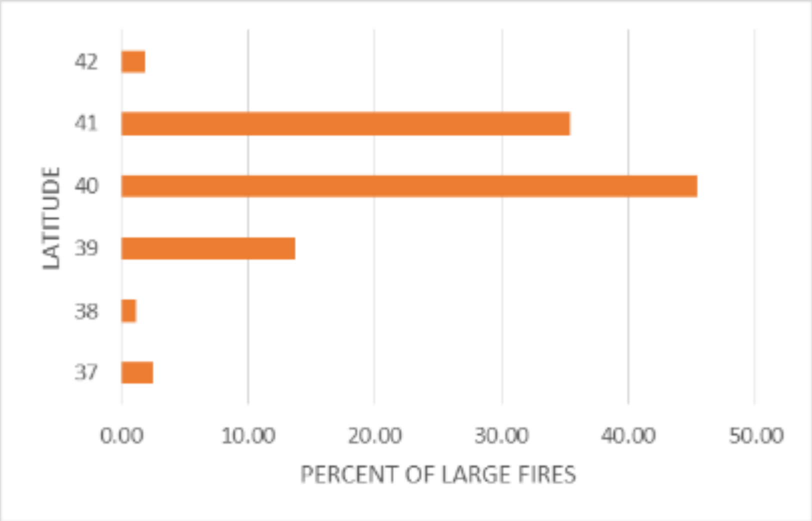


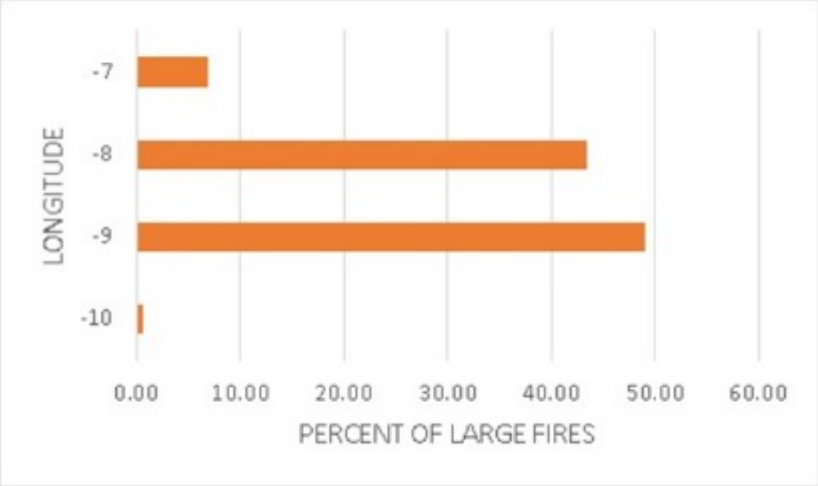
When do large fires occur in Greece?

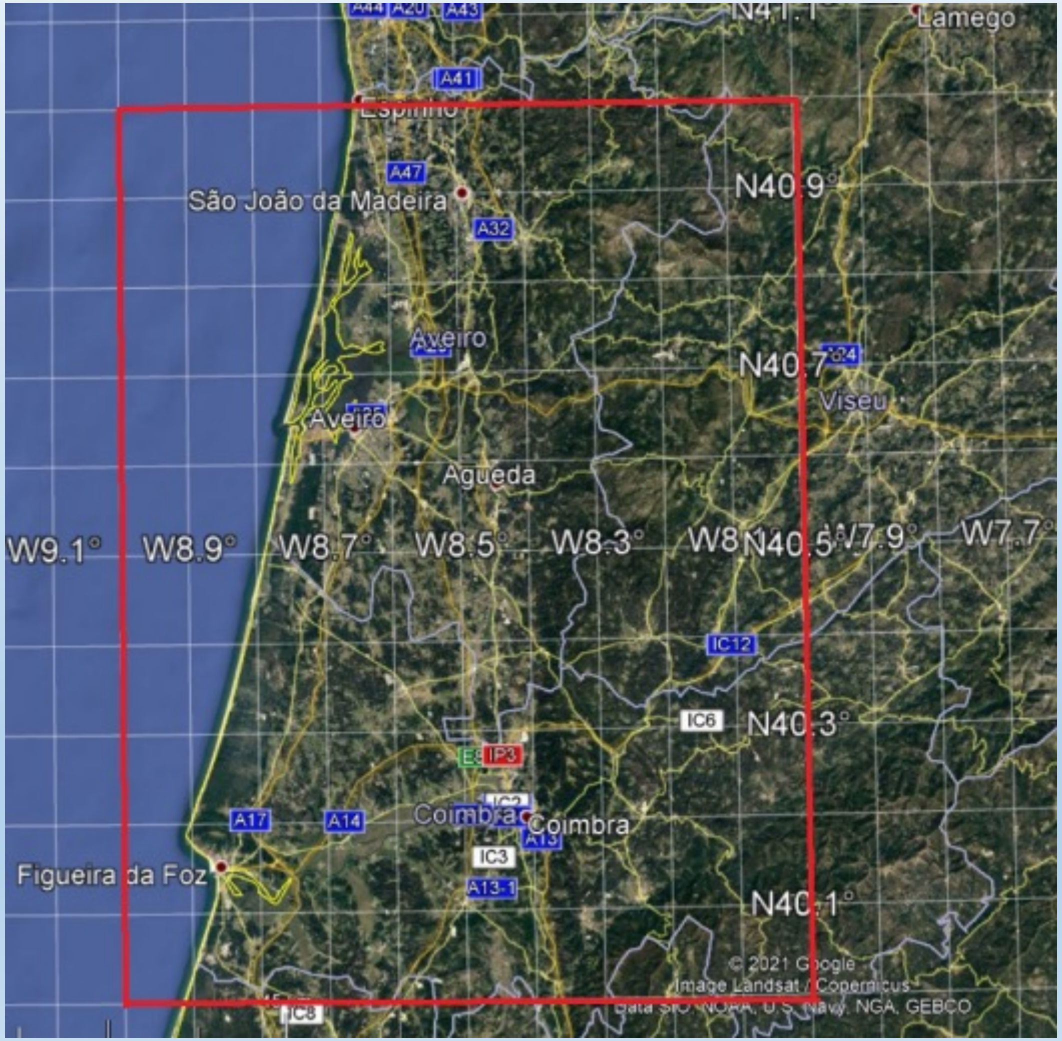




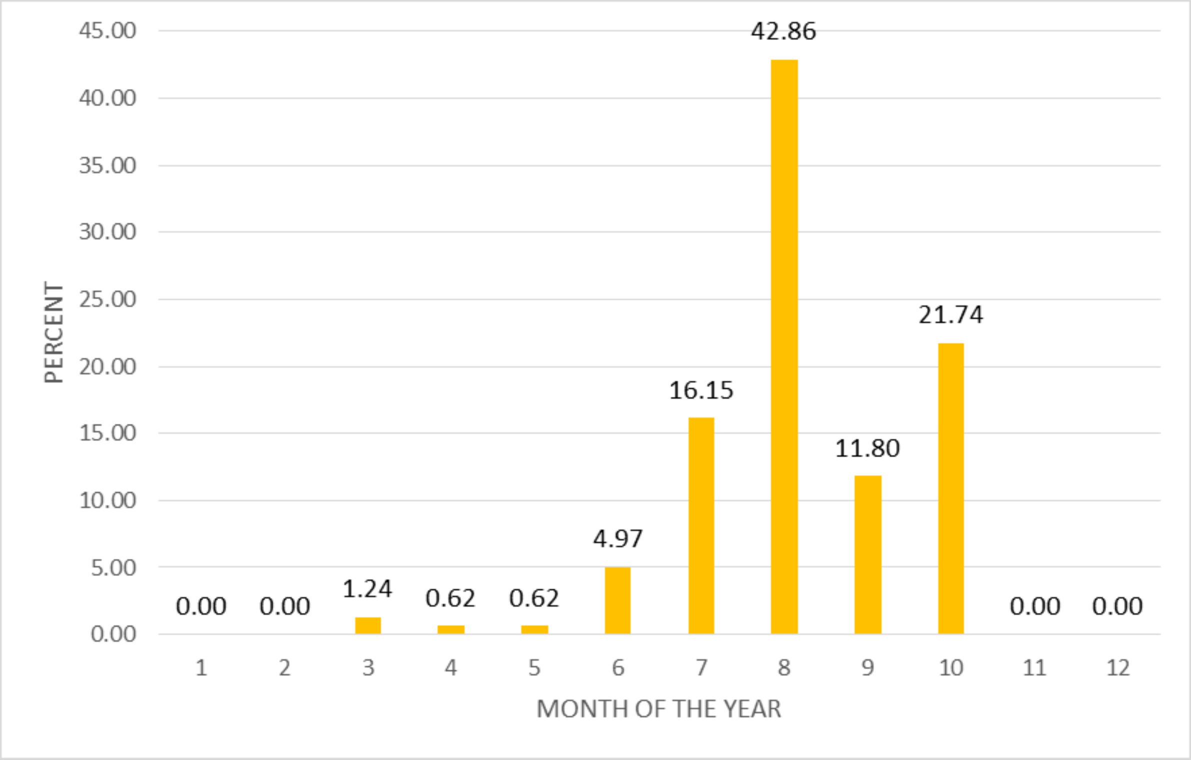
Where do large fires occur in Portugal?

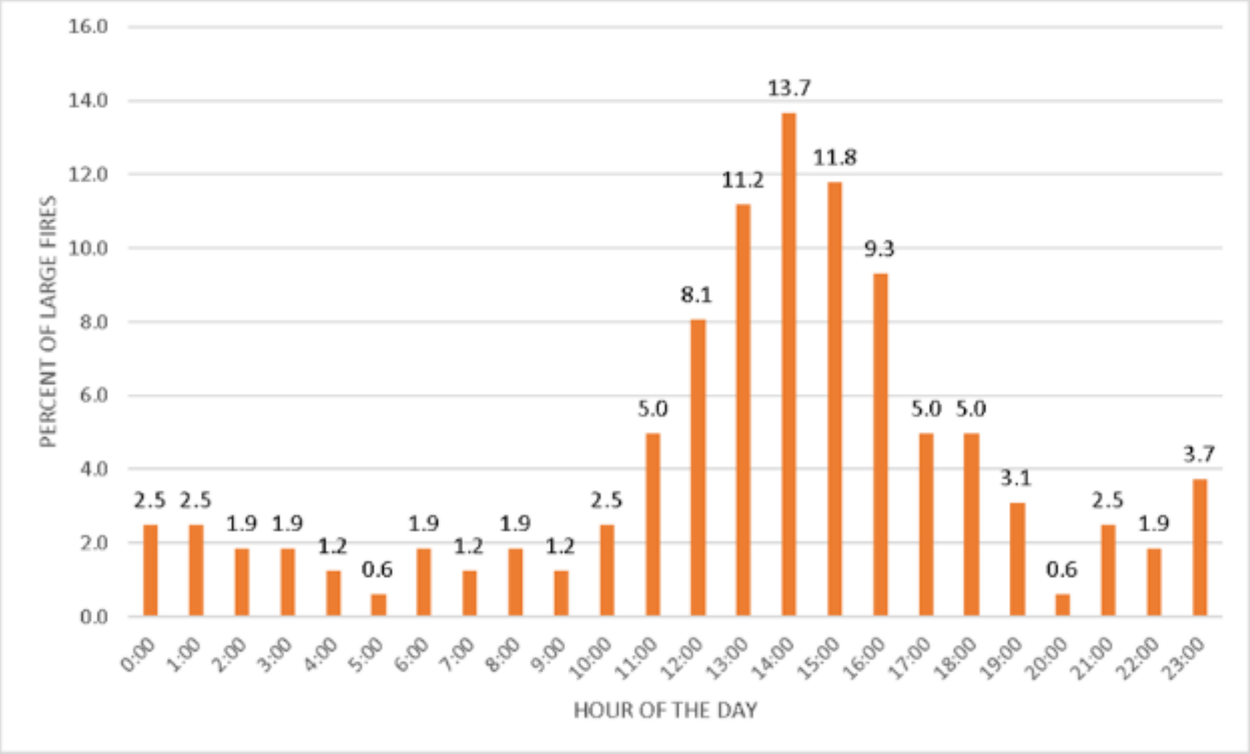




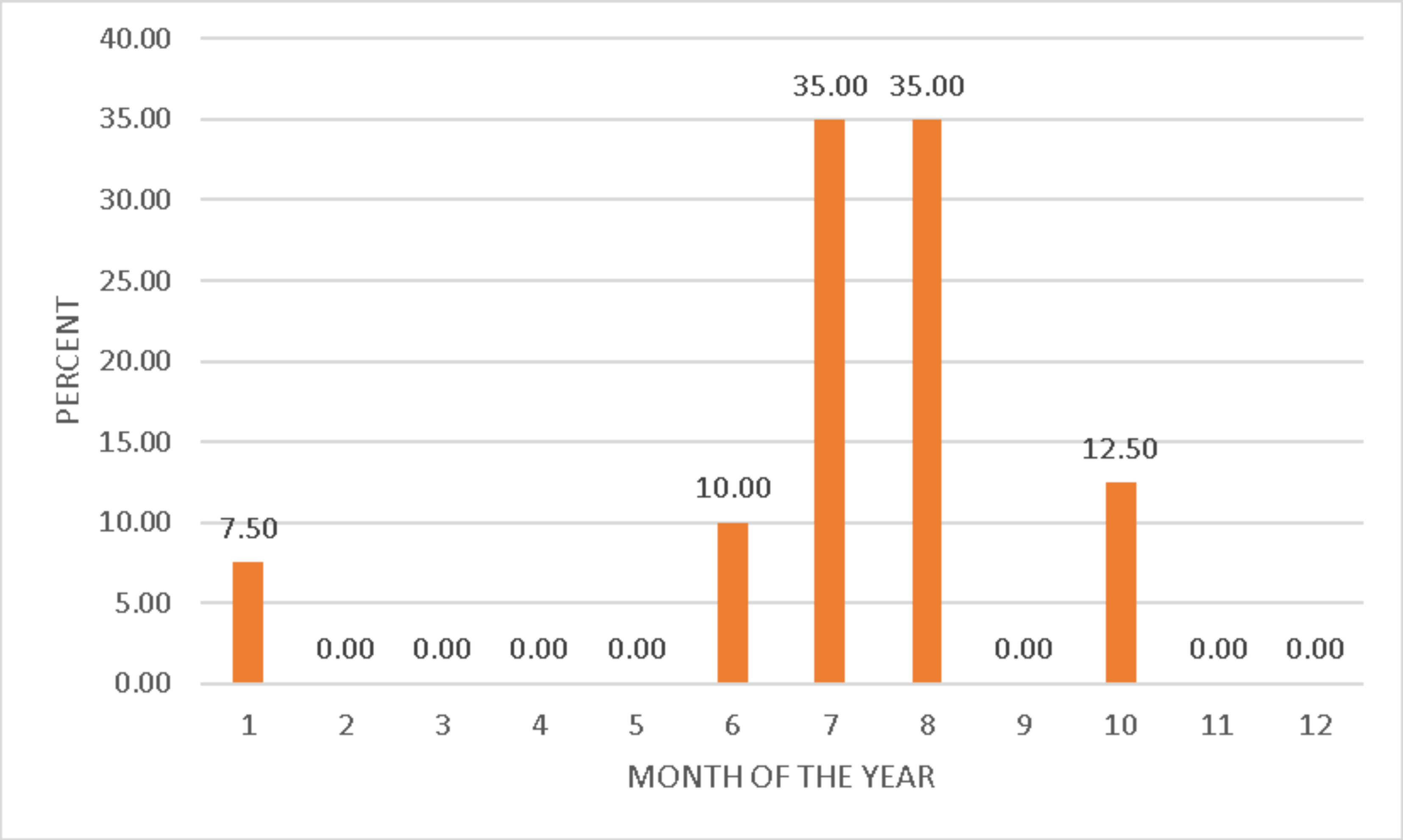


When do large fires occur in Portugal?



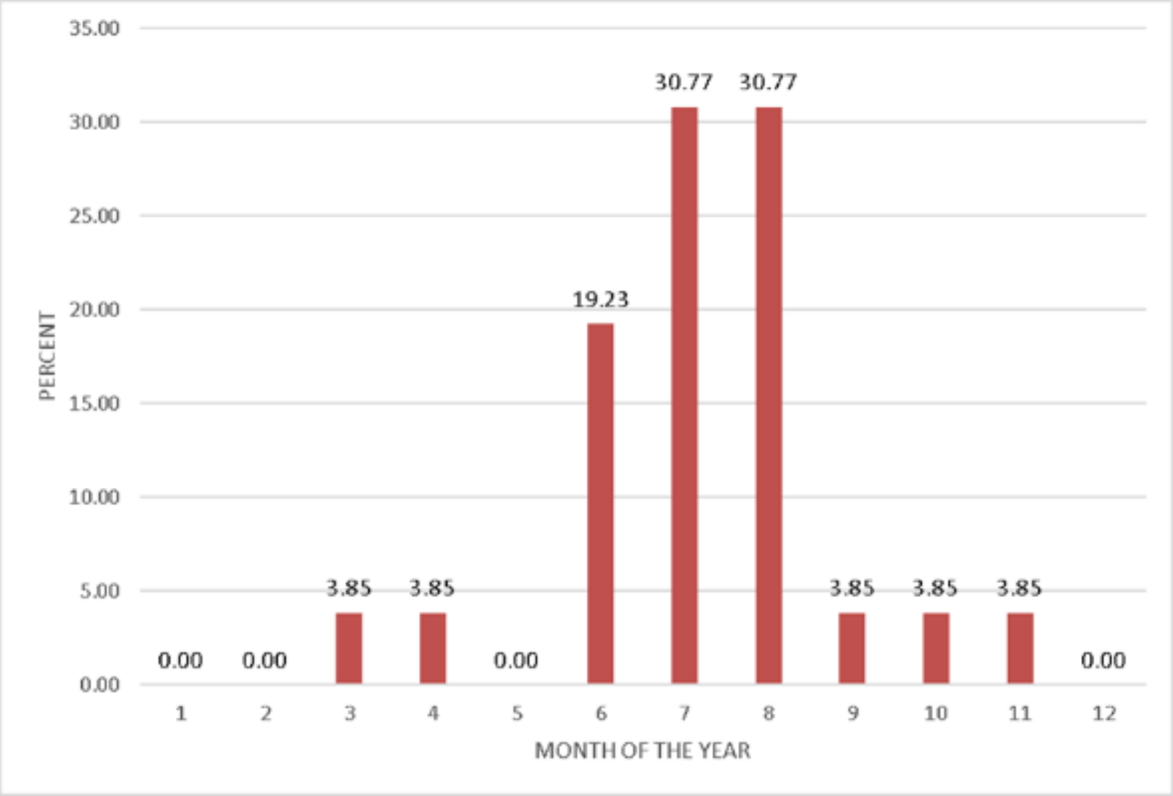


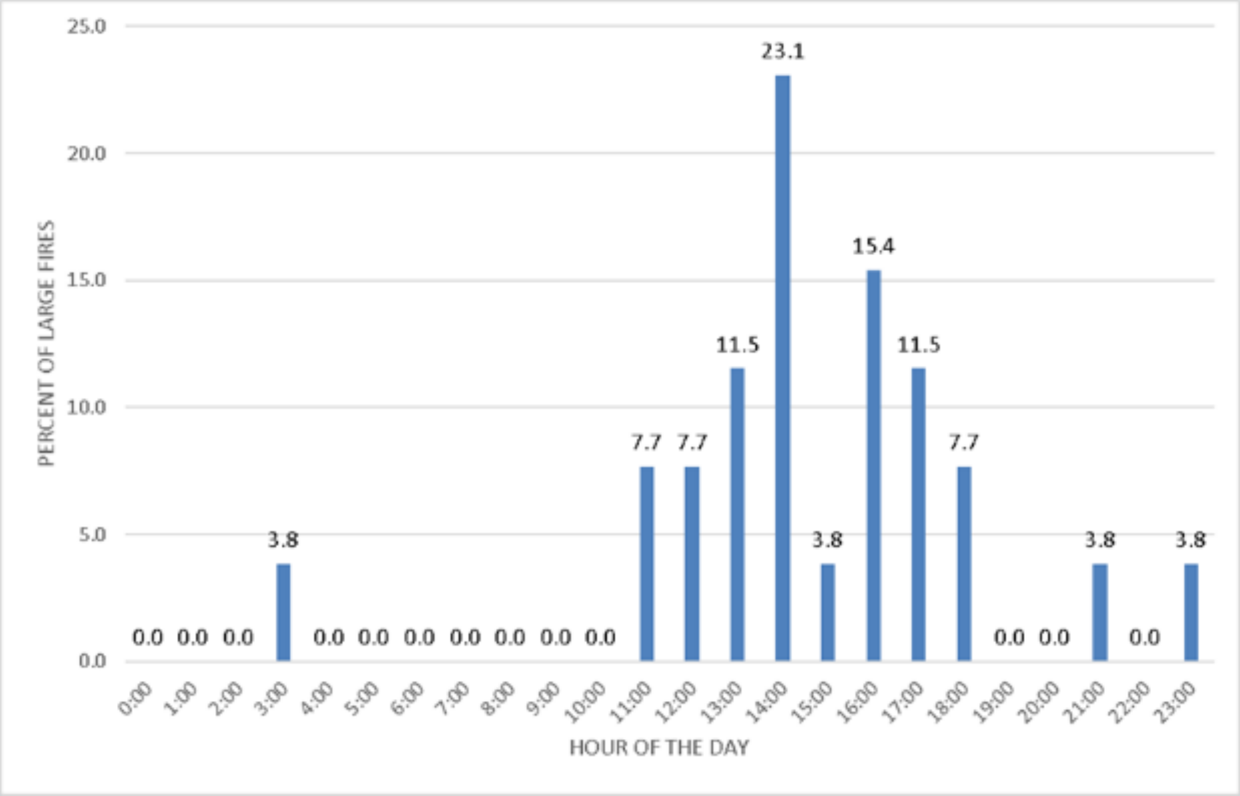
When do large fires occur in Italy?



Note: 40 large fires that occurred in 2017

When do large fires occur in Catalonia, Spain?

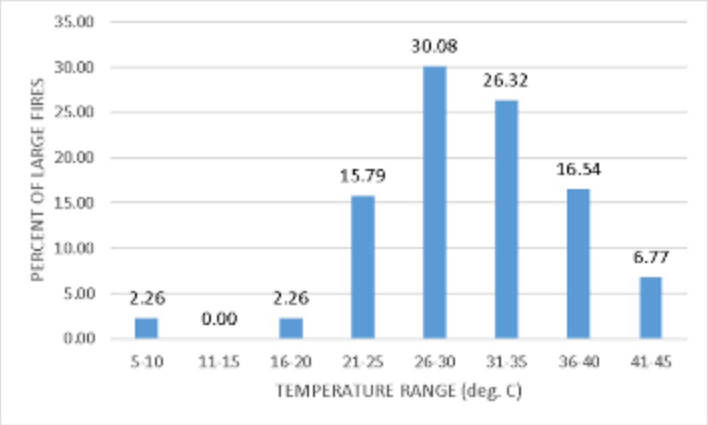


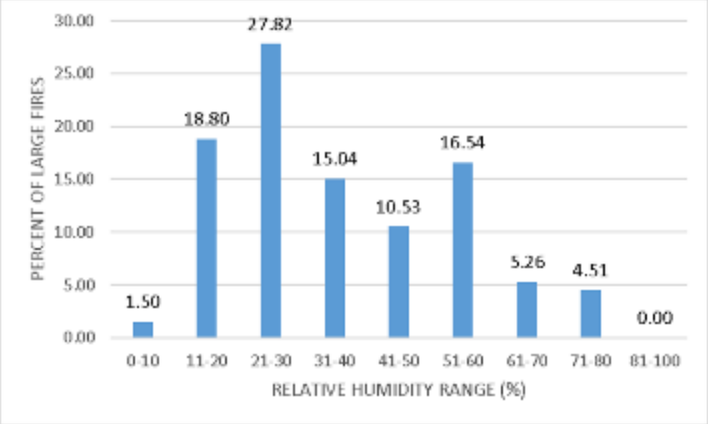


Frequency of occurrence as a function of …

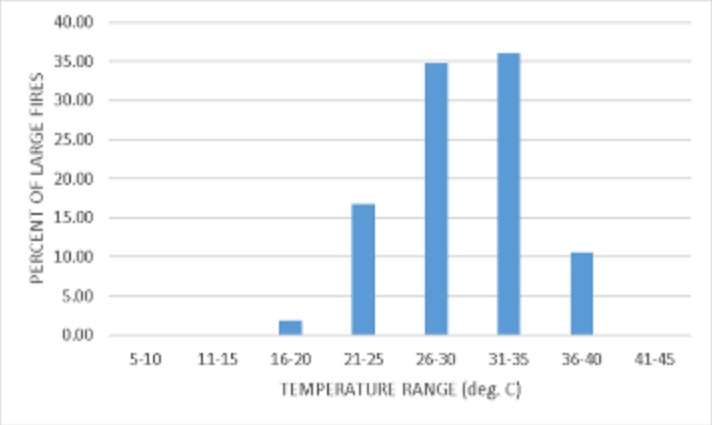
Analysis of the frequency of occurrence of LF as a function of most of the independent variables showed the lack of linear or even monotonous trends:

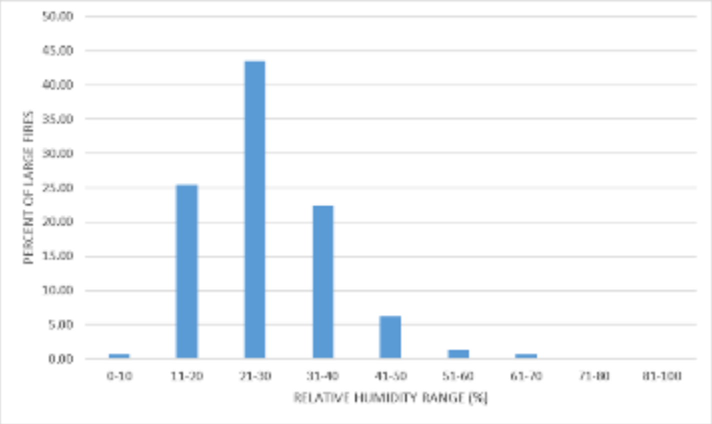
Greece



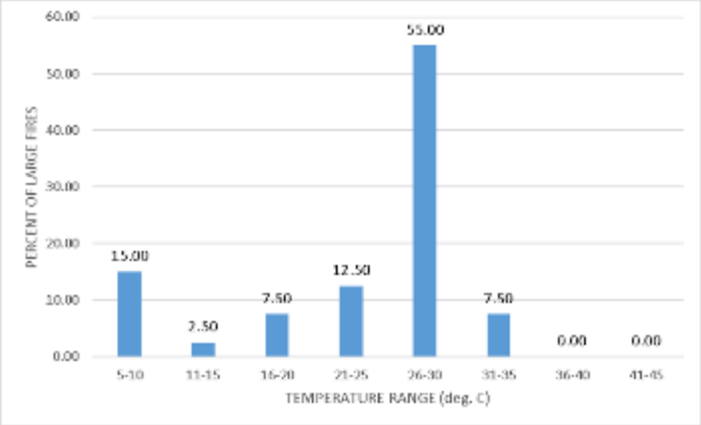


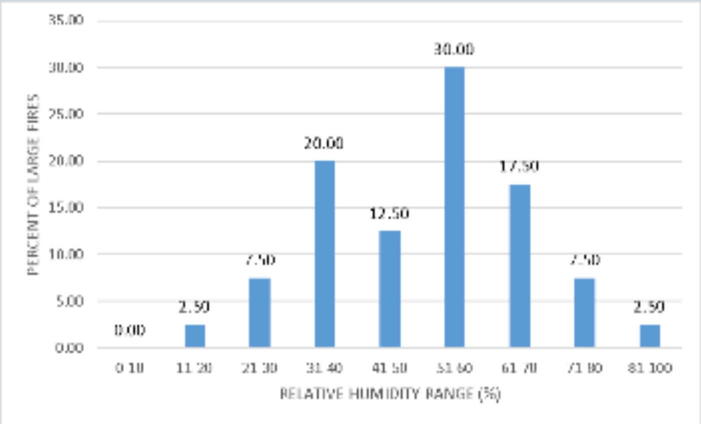
Portugal



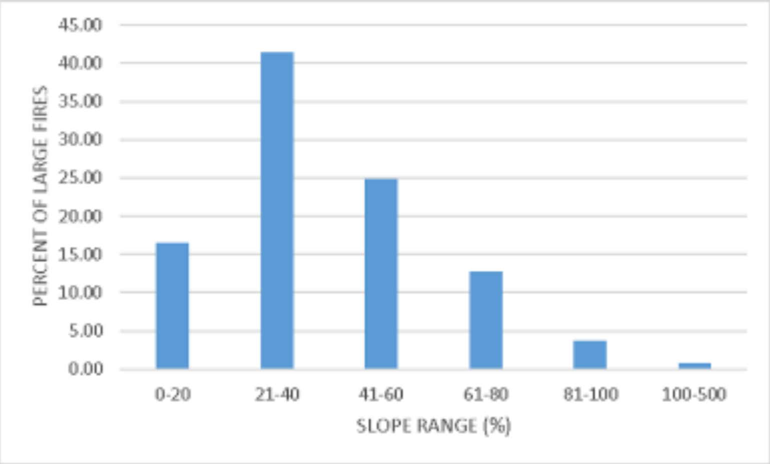


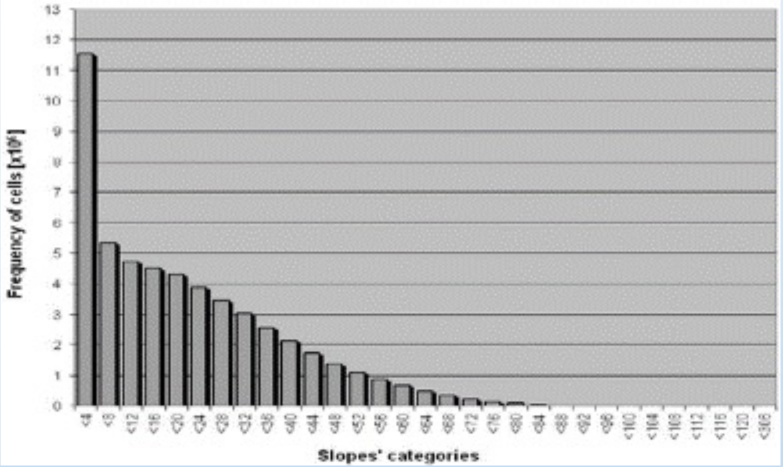
Italy





Explanation of the non-monotonous trends with an example from Greece

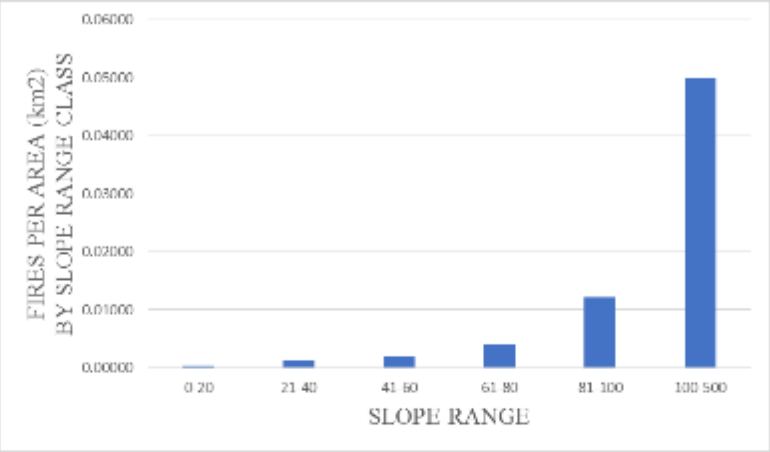




Slope distribution histogram for Greece based on cells of 0.25 ha (source: Darra et al. 2010)

Calculation of the number of large fires per km^2 in Greece

Slope range (%)	Number of large fires	Distribution of the number of fires by slope range class (%)	Approximate area occupied in Greece by slope range class (km^2)	Fires per km^2 in each slope range class (fires/km^2)
0-20	22	16.54	71116	0.00031
21-40	55	41.35	39104	0.00141
41-60	33	24.81	16944	0.00195
61-80	17	12.78	4364	0.00390
81-100	5	3.76	409	0.01222
100-500	1	0.75	20	0.05000
	133	100	131957	

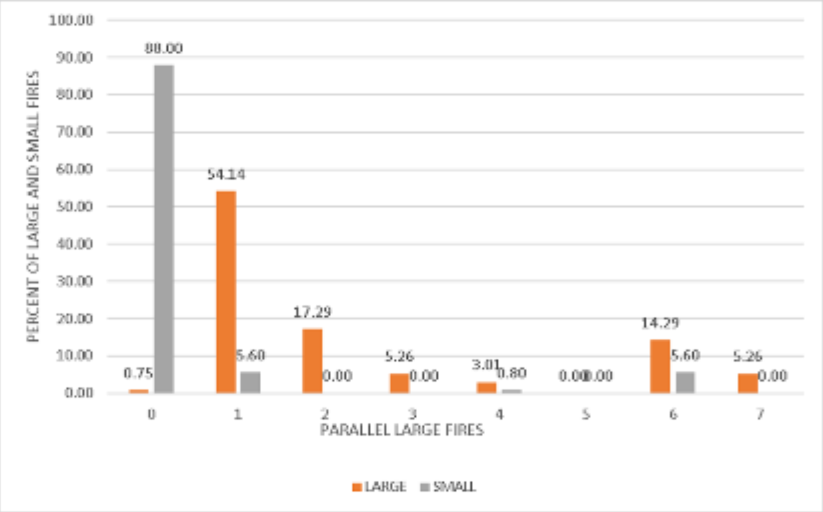


Frequency of occurrence of large fires at six ranges of slope after accounting for the area occupied (km^2) by each slope range

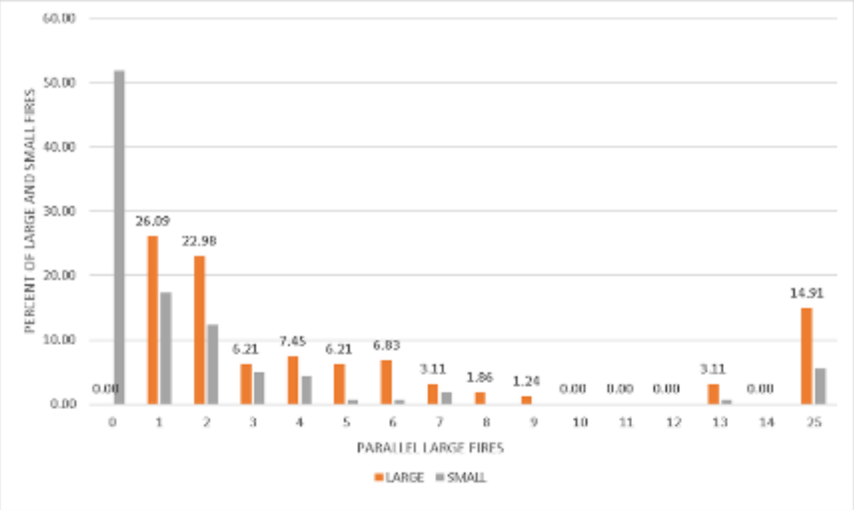
Parallel large fires

Although large fires (>500 ha) are relatively uncommon, taking into consideration the example of frequency of LF with slope, in general the evolution of a fire to become large growth seems to be influenced by the existence of other simultaneous large fires. Note the difference in the distribution of the subsample of randomly selected small fires.

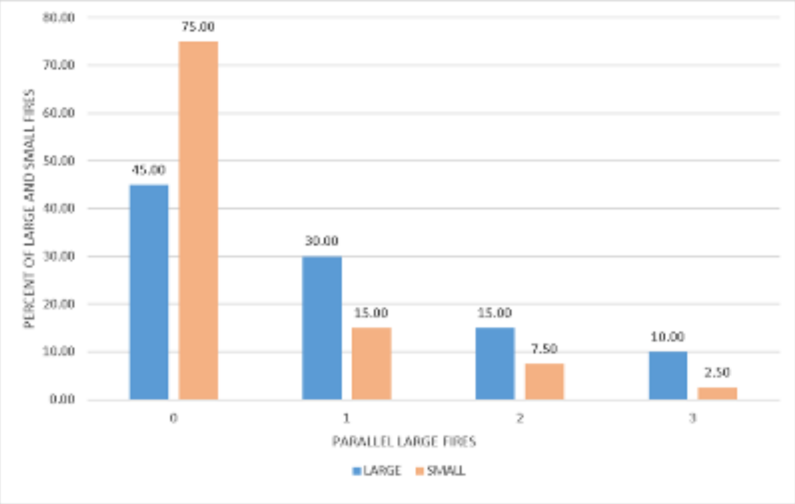
Greece



Portugal



Italy



Prediction of the probability of a fire to become large in Greece

- Binary logistic regression analysis was used to derive an equation able to provide an estimate of the probability of a fire to become large.

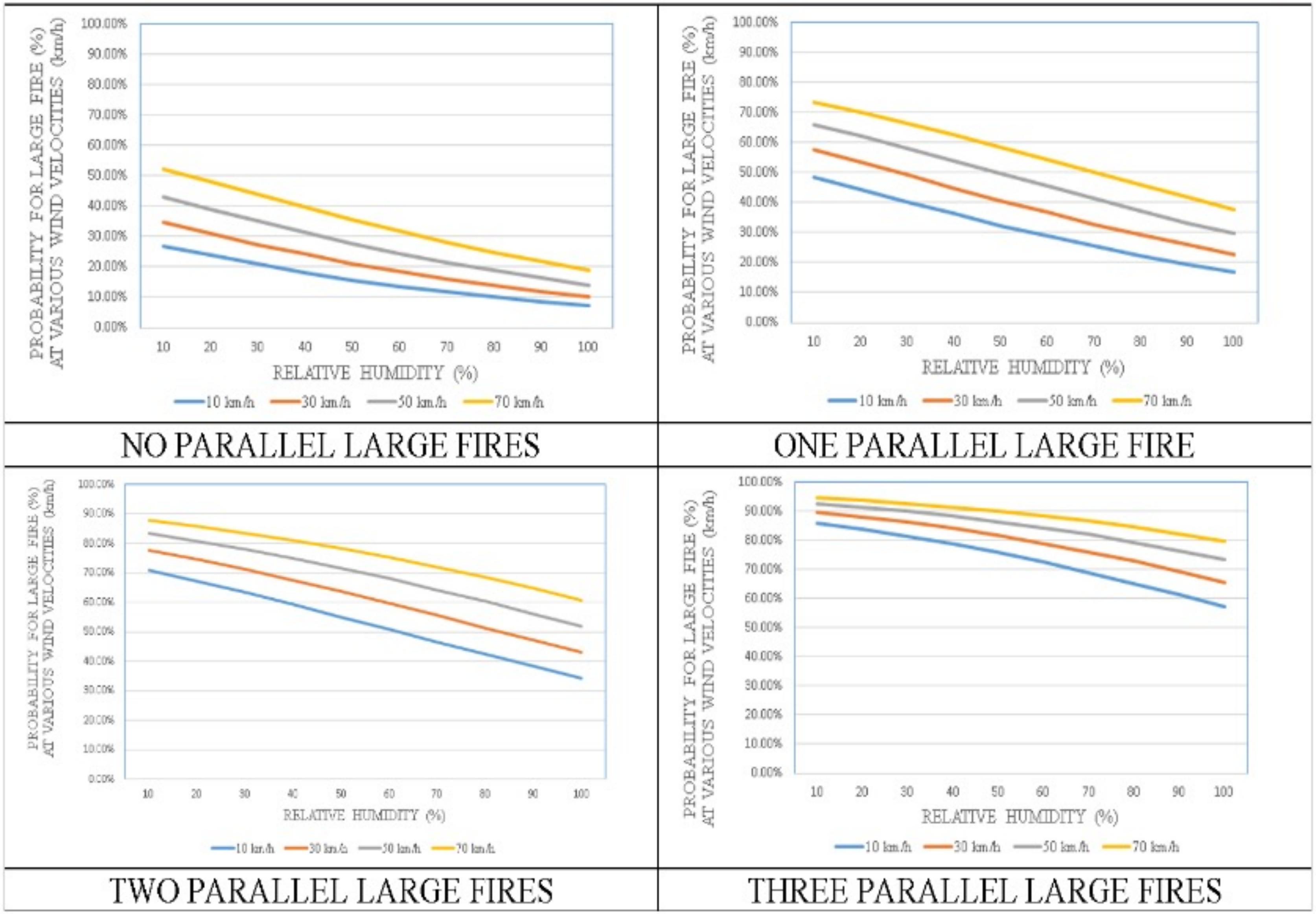
$$Ln(P_{LARGE}/1-P_{LARGE}) = -\ 1{,}002 - 0.017\ RH + 0.018\ WIND + 0.938\ PAR\_LFIRES$$

(0.057) (0.053) (0.028) (0.000)

Where:

RH:	Relative humidity (%)
WIND:	Wind speed (km h^{-1})
PAR_LFIRES:	Number of large fires (>500 ha) that were burning or started on that day
N=258	Nagelkerke R2= 0.399 Model significance: p-value = 0.000

$$P_{LARGE} = 1/[1+EXP(-(-\ 1.002 - 0.017\ RH + 0.018\ WIND + 0.938\ PAR\_LFIRES))]$$



Comparison of the probability (%) of a fire to become large (>500 ha) if it escapes initial attack as a function of relative humidity (%) and wind velocity (km/h), and the number of simultaneous large fires, in Greece.

Prediction of the probability of a fire to become large in Portugal

$$Ln(P_{LARGE}/1-P_{LARGE}) = 1,363 - 0.064\ RH + 0.063\ WIND + 0.024\ PAR\_LFIRES$$

(0.000) (0.000) (0.000) (0.260)

Where:

RH:	Relative humidity (%)
WIND:	Wind speed (km h^{-1})
PAR_LFIRES:	Number of large fires (>500 ha) that were burning or started on that day
N=323	Nagelkerke R^2= 0.342 Model significance: p-value = 0.000

$$P_{LARGE} = 1/[1+EXP(-(1.363 - 0.064\ RH + 0.063\ WIND + 0.024\ PAR\_LFIRES))]$$

Prediction of the probability of a fire to become large in Greece, Portugal, and Italy

$$Ln(P_{LARGE}/1-P_{LARGE}) = 1.238 - 0.030\ RH - 0.028\ WATERDISTANCE$$

(0.003) (0.000) (0.000)

$$+ 1.034\ PAR\_LFIRES$$

(0.000)

N=499 Nagelkerke R^2= 0.510 Model significance: p-value = 0.000

$$P_{LARGE} = 1/[1+EXP(-(1.238 - 0.030\ RH - 0.028\ WATERDISTANCE + 1.034\ PAR\_LFIRES))]$$

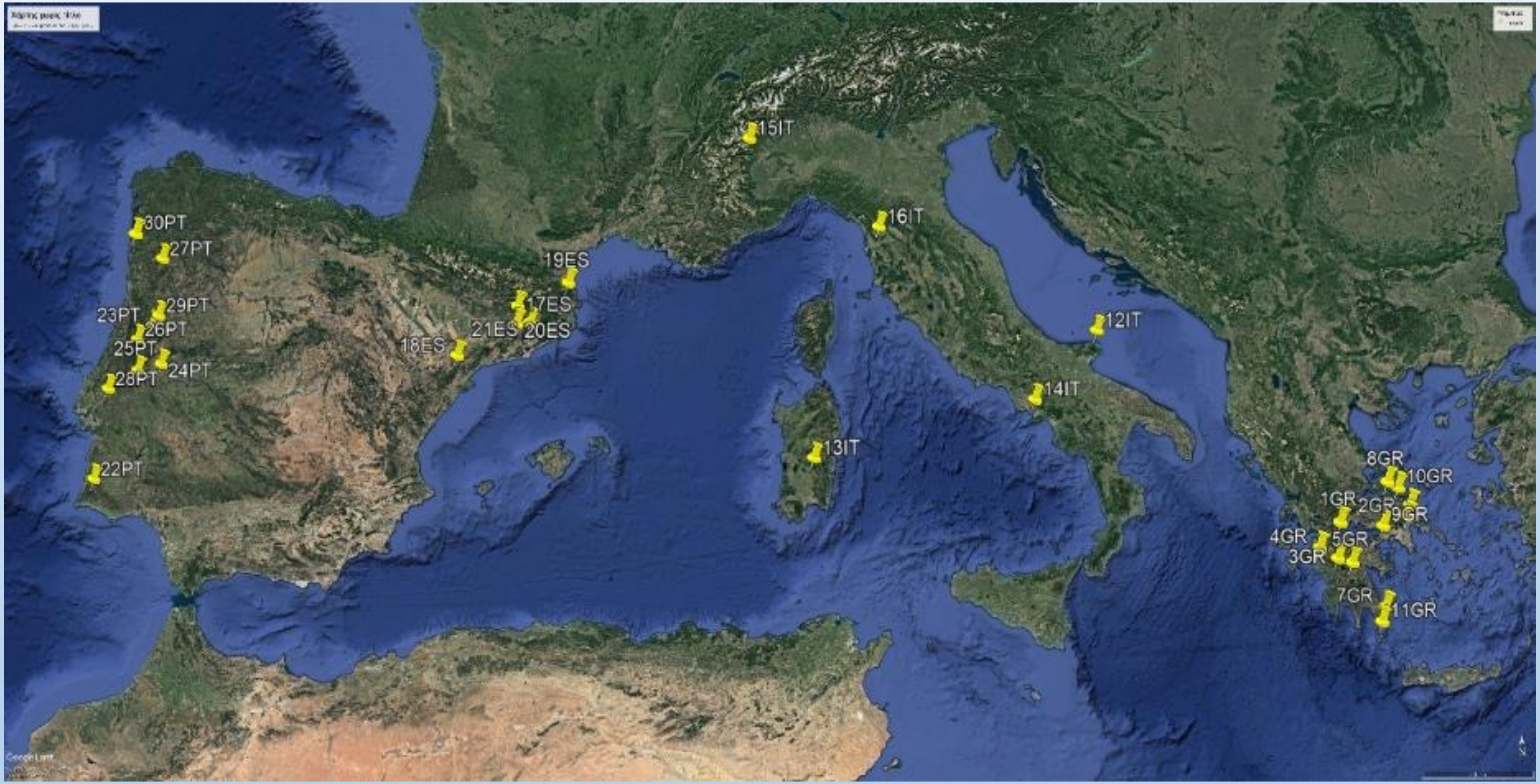
Conclusions of large fire statistics analysis

- Equations for BURNEDAREA prediction are weak (poor data quality, missing data, a data value representing the duration of days of burning, non-monotonous relationships, etc.).
- Data are not readily available.
- PAR_LFIRES is an important variable for the prediction of BURNEDAREA in Greece and Portugal
- The binary logistic equations for the prediction of the likelihood of a starting fire to become large in Greece and Portugal, include the same independent variables (RH, WIND and PAR_LFIRES) and can be useful.
- BURNEDAREA models with “firefighting resources” as independent variables are stronger but cannot be used for prediction. They can probably have some value for cost estimation.

Conclusions of large fire statistics analysis (2)

- Finally, in spite of all the limitations of the complete database and based on a sample size of N=499 cases from Greece Portugal and Italy, the general binary logistic regression equation with RH, WATERDISTANCE and PAR_LFIRES, with Nagelkerke R^2 =0.510, is a relatively strong model.
- Non-inclusion of WIND is most likely due to poor quality of data for this variable (highly variable along the duration of a fire, recorded in broad classes in Greece, obtained from models in Italy,…)

Detailed analysis of 30 very large fires (VLFs)



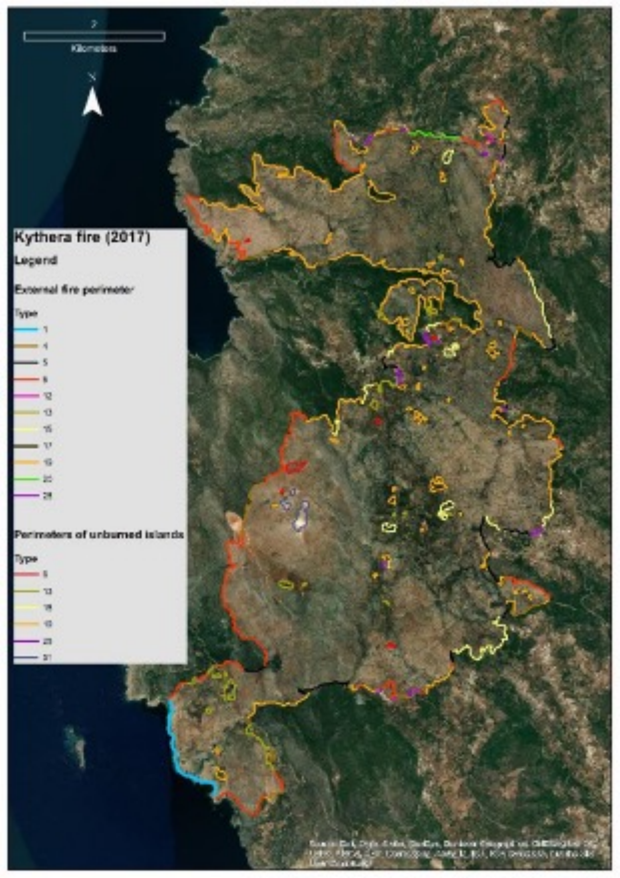
The external perimeter, as well as the perimeter of the unburned islands within the burned area of each of these VLFs were digitized

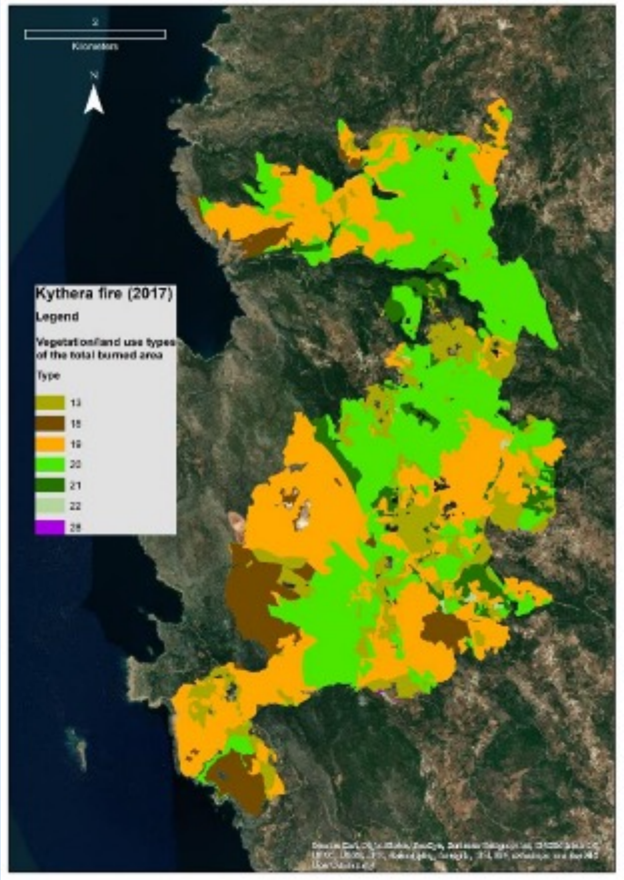
An example of the August 4, 2017 fire on the island of Kythera in Greece

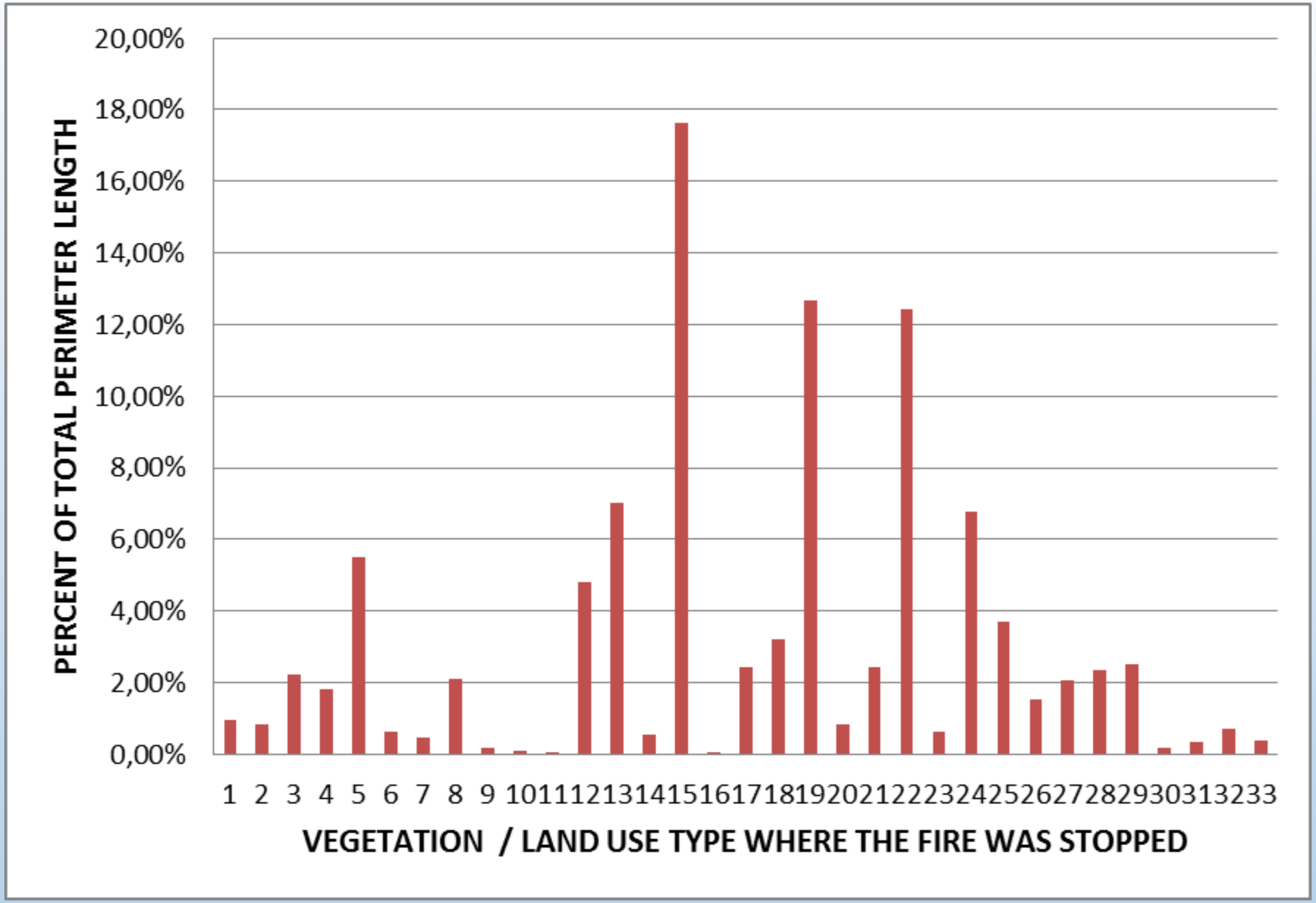
Vegetation/land use types along the final (external) fire perimeter

Number	Vegetation/land use type	Length (m)	Number	Vegetation/land use type	Length (m)
1	Sea		18	Phrygana/Scrub	
2	Lake / pond		19	Low shrubs (<70 cm)	
3	River		20	Medium shrubs (<150 cm)	
4	Unpaved narrow Road		21	Tall shrubs (150 cm< h <400 cm)	
5	Paved road (two lane)		22	Pine forest	
6	Wide road (more than two lanes)		23	Tall conifer forest (other than pine)	
7	Railway lines		24	Oak forest	
8	Bare ground		25	Eucalypt forest	
9	Firebreak (linear)		26	Other broadleaved tall forest	
10	Fuelbreak or managed fuels (incl. prescribed burned)		27	WUI area (interspersed)	
11	Green belt (football field, golf course, etc.)		28	Settlement/Village	
12	Tree orchard (other than olive)		29	Town/City	
13	Olive grove		30	Industrial area	
14	Vineyard		31	Quarry	
15	Annual agricultural cultivation (wheat etc)		32	Recently burned area (3 years or less)	
16	Greenhouse		33	Mixed broadleaved & coniferous forest	
17	Grassland				

Total fire perimeter length = …………m







Percent distribution of the total perimeter (4,453,803 m) of N=30 Very Large Fires by vegetation/land use type

- 15: Annual agricultural cultivation (wheat etc.)
- 19: Low shrubs (<70 cm)
- 22: Pine forest

Contribution of linear features to the control of the N=29 VLFs

Extinction perimeter type	Length (m)	Percent
Perimeter stopped on linear features	649,993	10.01%
Perimeter stopped in spatial features	5,840,520	89.99%
Total perimeter (external plus unburned islands)	6,490,513	100.00%

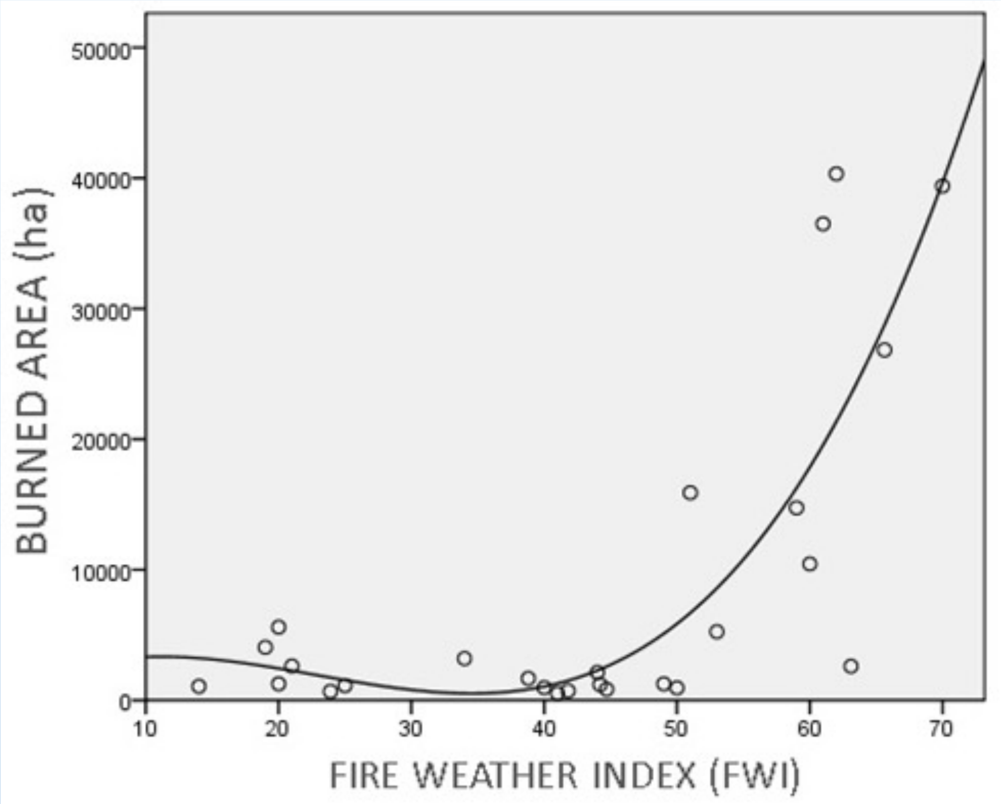
Assessment of the contribution of each vegetation/land cover type in stopping the VLFs after normalization by the area they occupy

External perimeter length, unburned island perimeter length and their sum (m) by vegetation/ land cover type, the area of that type contributing to the burned area (ha), and the total perimeter to area ratio (km/ha).

	Vegetation/land use type	External perimeter length (m)	Unburned island perimeter	Total perimeter length (m)	Area (ha)	Ratio (km/ha)
29	Town/City	111160	42949	154109	51	3.01973
16	Greenhouse	410	0	410	0	2.15677
2	Lake/pond	37272	563	37835	26	1.45520
30	Industrial area	7834	304	8138	43	0.19022
28	Settlement/Village	106894	85546	192440	1089	0.17671
9	Firebreak (linear)	7570	111	7681	48	0.15926
14	Vineyard	23145	9248	32393	230	0.14103
	….					
	Total	4388390	2102123	6490513	228062	

	Vegetation/land use type	Ratio (km/ha)
29	Town/City	3.01973
16	Greenhouse	2.15677
2	Lake/pond	1.45520
30	Industrial area	0.19022
28	Settlement/Village	0.17671
9	Firebreak (linear)	0.15926
14	Vineyard	0.14103
12	Tree orchard (other than olive)	0.13945
31	Quarry	0.12619
11	Green belt (football field, golf course, etc.)	0.11411
8	Bare ground	0.07060
27	WUI area (interspersed)	0.06917
15	Annual agricultural cultivation (wheat etc.)	0.05057
26	Other broadleaved tall forest	0.03704
10	Fuelbreak/managed understory fuels	0.03255
19	Low shrubs (h<70 cm)	0.03084
17	Grassland	0.02272
23	Tall conifer forest (other than pine)	0.02218
24	Oak forest	0.02166
25	Eucalypt forest	0.02124
32	Recent burn	0.01863
18	Phrygana/Scrub	0.01665
13	Olive grove	0.01626
21	Tall shrubs (150 cm< h < 400 cm)	0.01505
22	Pine forest	0.01065
20	Medium shrubs (70<h<150 cm)	0.00623
33	Mixed broadleaved & coniferous forest	0.00579
1	Sea	0.00000
3	River	0.00000
4	Unpaved narrow road	0.00000
5	Paved road (two lane)	0.00000
6	Wide road (more than two lanes)	0.00000
7	Railway lines	0.00000
	Total	

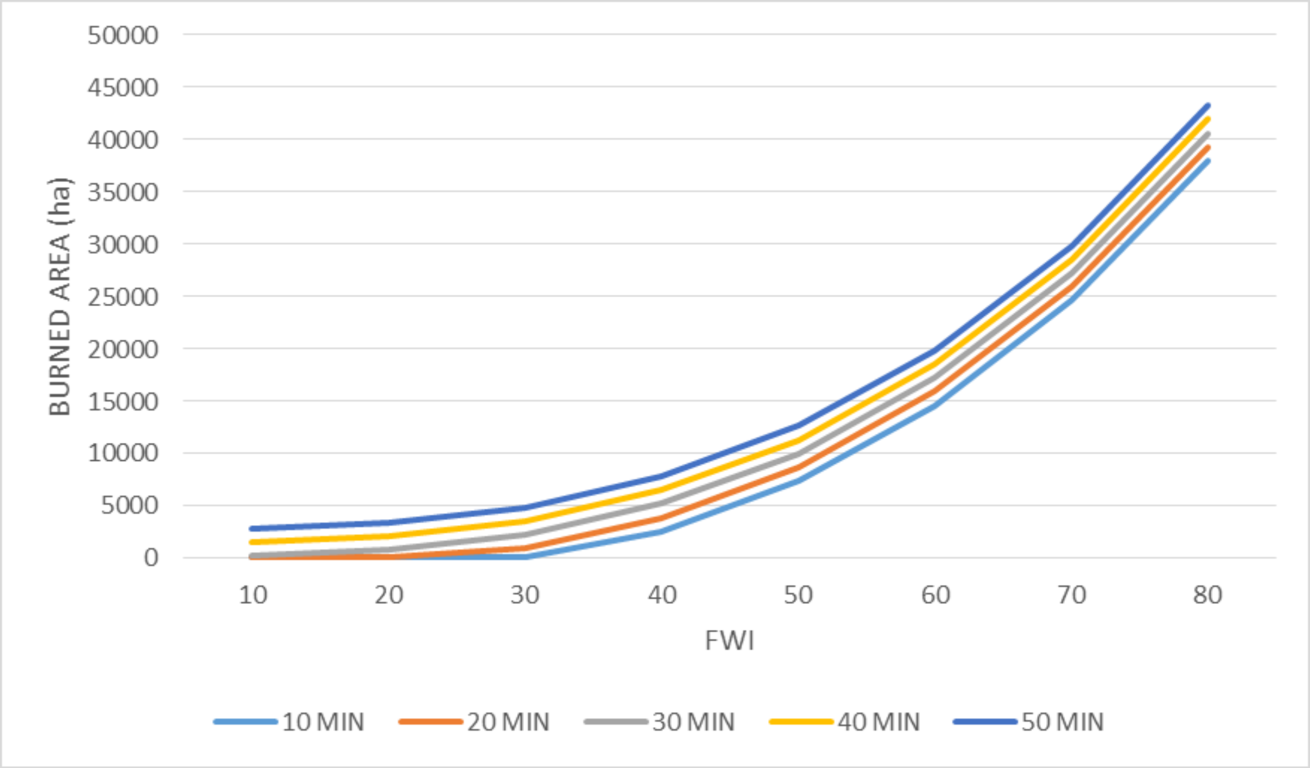
Large fires and the Canadian Fire Weather Index



BURNED_AREA =793.722 + 510.854 FWI - 30.269 FWI^2 +0.442 FWI^3

N=26 Adj. R^2= 0.675 Equation significance: p-value = 0.000

BURNED_AREA area prediction



Where FIRSTINT is the time to first intervention in minutes

$$BURNED\_AREA = -3833.192 + 130.2708\ FIRSTINT + 0.07916\ FWI^3$$

(0.148) (0.010) (0.000)

N=22 Adj. R^2= 0.691 Equation significance: p-value = 0.000

Burned Area Growth Rate (BAGR)

BAGR is calculated as a ratio, with BURNED_AREA (ha) as the numerator and DURATION (min) as the denominator

$$BAGR = -14.594 + 1.8655\ FIRSTINT + 0.00063\ FWI^3$$

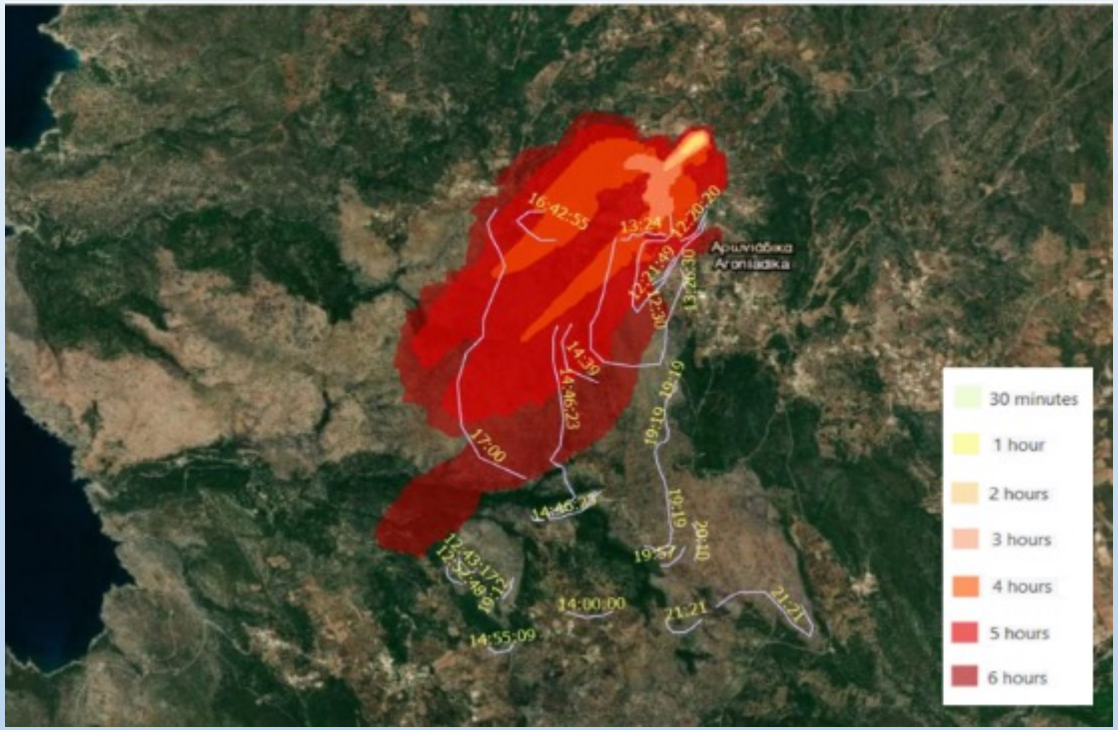
(0.535) (0.000) (0.002)

N=23 Adj. R^2= 0.750 Equation significance: p-value = 0.000

Simulation of the results of fuel management

- There are many studies in international literature on the effect of fuel treatments on expected fire behavior. Some of them utilize real world measurements, while most of them are based on fire simulations using available fire simulation systems.
- These studies have shown that, as a rule, fire behavior becomes less intense, although in some cases fine fuels increase, resulting in faster rate of spread.
- In PREVAIL, we documented in detail a 2,621 ha fire on Kythera island in Greece on August 4-6, 2017.
- We then used the GFMIS simulation system, a detailed forest fuel map and data on the meteorological conditions to simulate the spread of that fire.
- Satisfied with its performance, we then tested four fuel treatment scenarios through additional GFMIS simulations.

Simulation of the results of fuel management: Fuel treatment scenarios on Kythera island



Kythera fire (August 4, 2017)

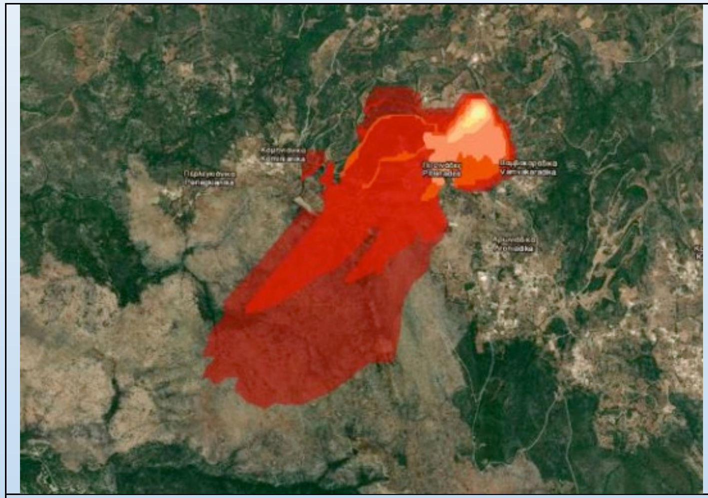
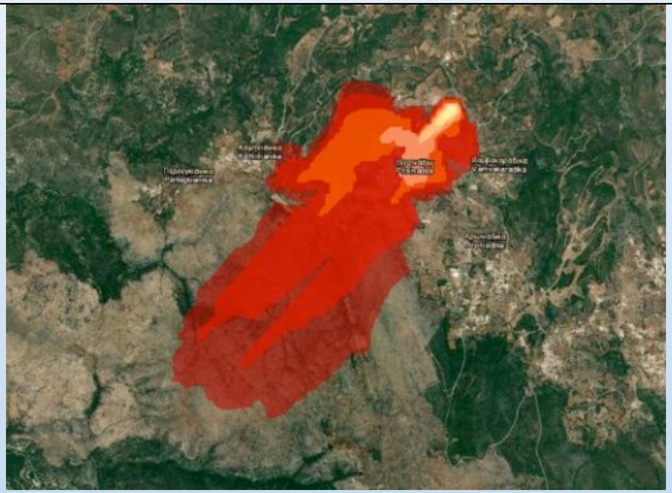
Detailed documentation for PREVAIL

Observed fire perimeter and simulation using the actual fuels map

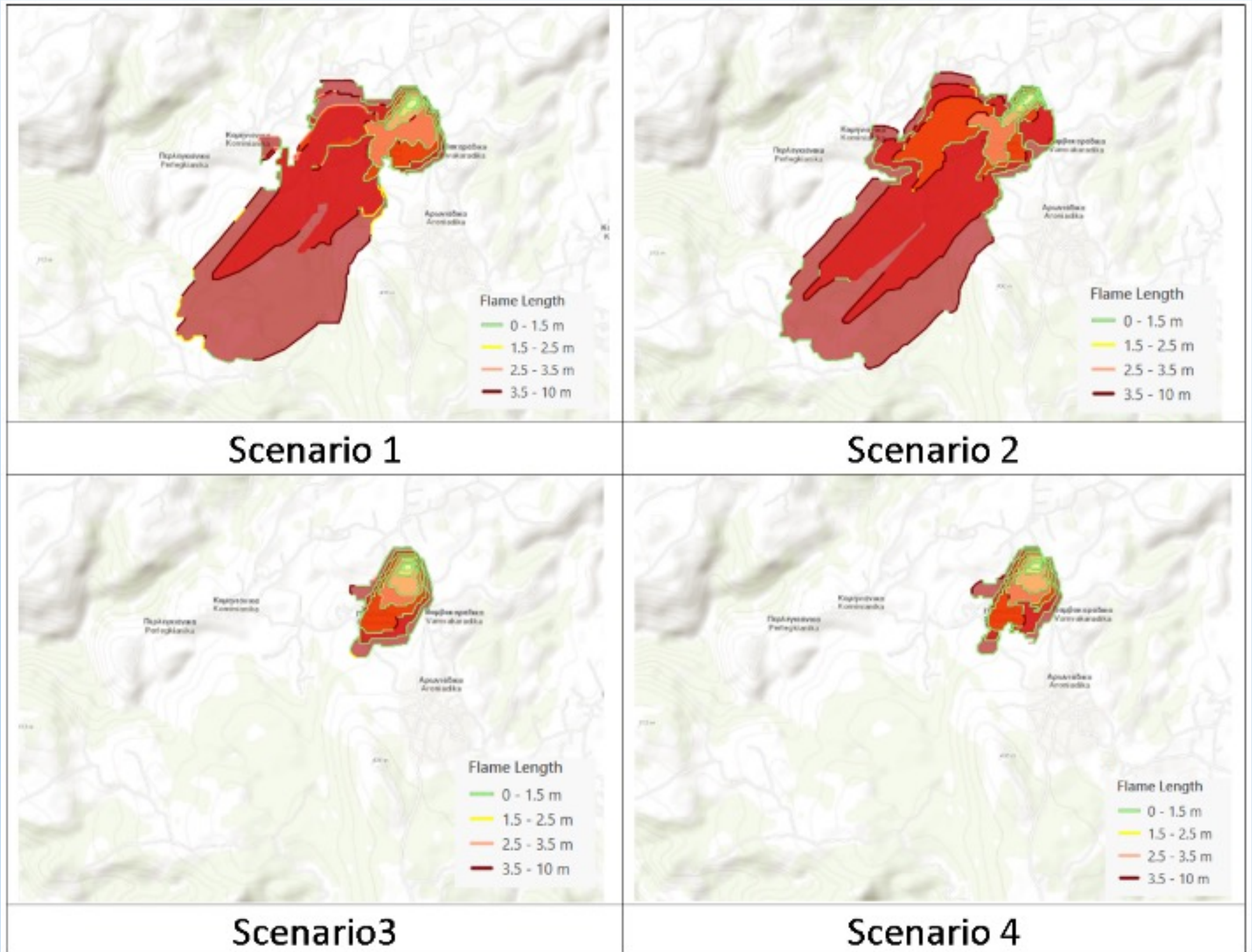
- Start time 10:55 am
- Simulation step: 1 hour
- Fire simulation duration: 6 hours

- **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)

Influence of 4 scenarios of fuel treatment on fire rate of spread (simulation of 6 hours)

	
Scenario 1	Scenario 2
	
Scenario3	Scenario 4

Influence of 4 fuel treatment scenarios on flame length (simulation of 6 hours)



Assessment of the effect of the fuel treatment scenarios on the required firefighting effort

- We used a published formula for calculating the length of the flank of a fire that can be extinguished by a firetruck with a capacity of 2500 l, as a function of flame length (Simos and Xanthopoulos 2014)
- This allows to estimate perimeter extinction (m) per truckload (2,500 l)
- We traced the fire perimeter of the simulated fires under the four scenarios for each time step and calculated the perimeter length for each of five classes of flame length (m):
  - a) 0-1.5 (1.2), b) 1.5-2.5 (2.2), c) 2.5-3.5 (3.5) d) (3.5-10) (10.0) e) >10 (20.0)
  - Class e) was not present

Required number of firetrucks estimation

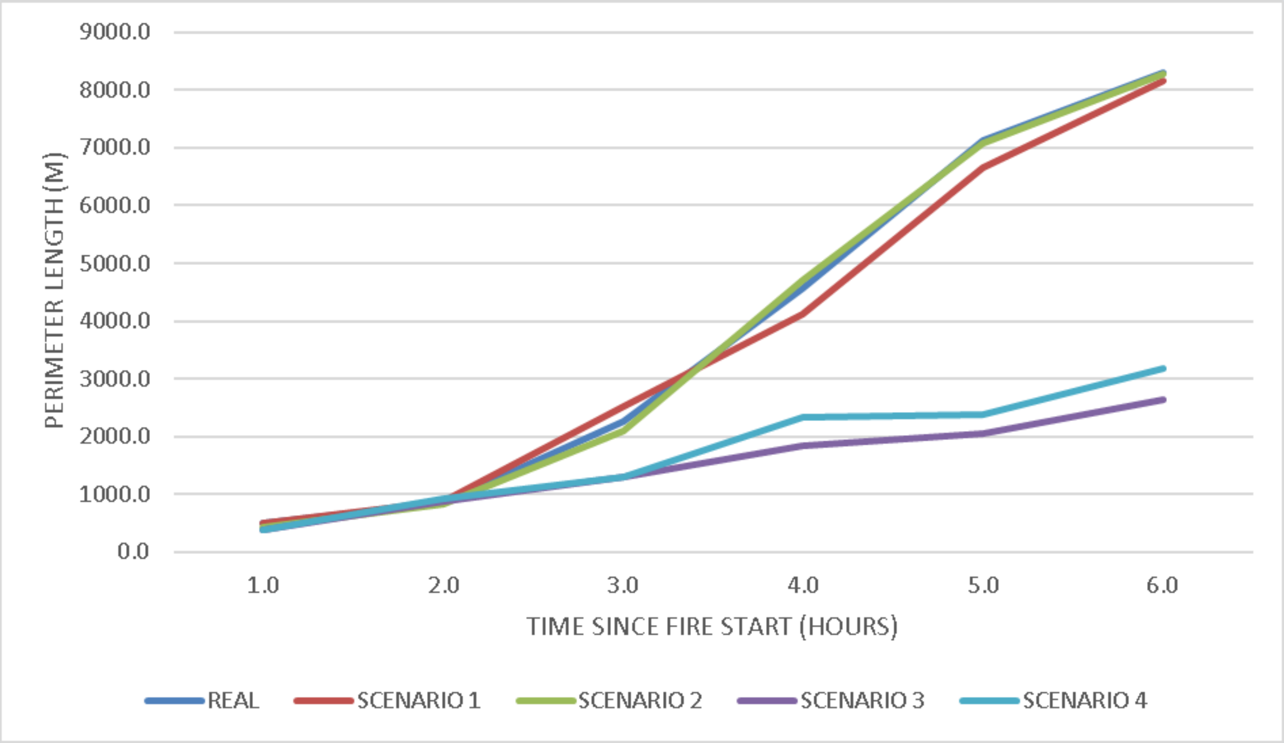
- We then used a set of plausible values for the time needed (in Kythera) for the firetrucks to refill:

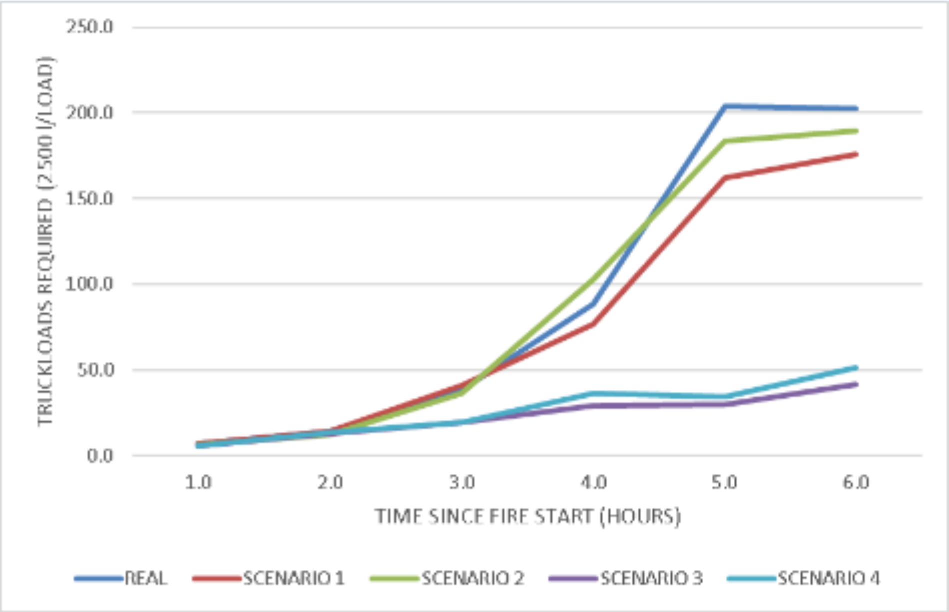
Flame length class	FL value used in simulation	Extinction of perimeter (m) per firetruck load
1: up to 1.5 m	1.2	68.7
2: up to 2.5 m	2.2	46.9
3. up to 3.5 m	3.5	37.2
4. up to 10 m	10.0	26.5
5. more than 10m	20.0	23.6

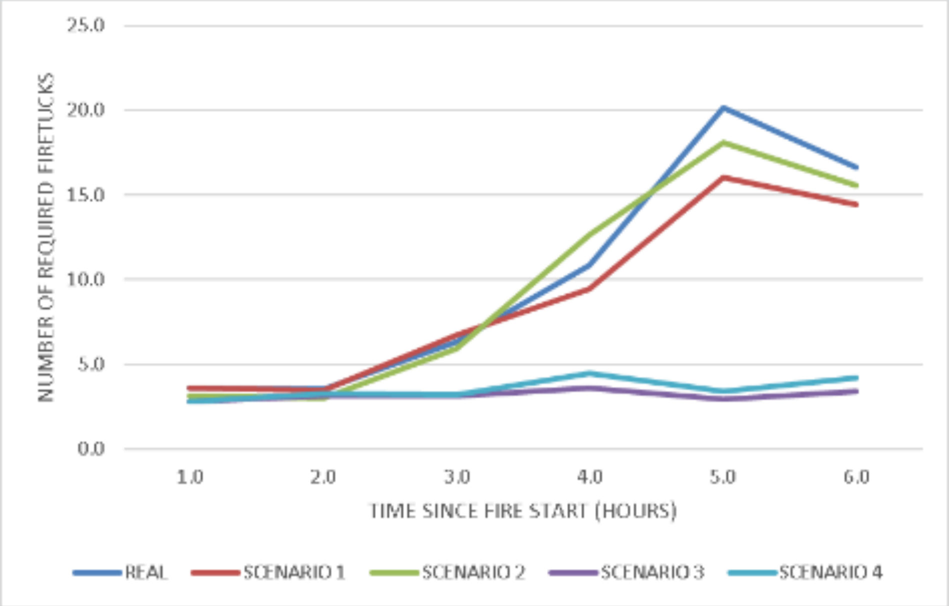
Average distance (km)	4
Firetruck speed (km/h)	50
Water loading time with delays	5
Travel time (min)	14.6
Time for using-up one water load (min)	15
Total time required per truckload for each round (min)	29.6
Fight & reload rounds per hour (LOADS_PER_HOUR)	**2.0**

- Thus, based on the water demand (i.e. firetruck loads as the fire progresses and the need to refill) we estimated:
    - Truckloads required to extinguish the perimeter at each step (considering different flame lengths)
    - Loads that can be achieved by a firetruck in this step's hours
    - Number of firetrucks that can achieve the required truckloads
- This value can be compared to the number of available firetrucks (13)

Modelling perimeter growth & firefighting demand for 6 hours







Conclusions

- Scenarios 1 an 3 (treatments only in agricultural areas) do not affect the length of fire perimeter but reduce the required firefighting effort through the reduction of flame length along many parts of the perimeter. The capacity of the available firetrucks on the island (13) is exceeded after roughly 4 hours. It is unlikely that reinforcements will arrive by boat by that time (as it happened in 2017).
- Scenarios 3 and 4 reduce both perimeter growth rate and flame length, thus reducing the needed firefighting effort. The number of firetrucks on the island is not exceeded.
- Broadcast fuel treatment through grazing over all of the land is much more effective (and cost free, actually producing income) than scenarios 1 & 2.

Thank you for your attention