Funded by

European Union Humanitarian Aid

and Civil Protection

PREVENTION ACTION INCREASES

LARGE FIRE RESPONSE PREPAREDNESS

WP2 – Deliverable 2.3

Report on wildfire suppression cost analysis

Project name: Prevention Action Increases Large Fire Response Preparedness (PREVAIL)

Financed by: DG ECHO 2018 Call for projects on prevention and preparedness in civil protection and marine pollution

Website: http://prevailforestfires.eu/

Partnership: Università degli Studi della Tuscia - UNITUS (Coord.), Università degli Studi di Napoli Federico II – UNINA, Centre de Ciència i Tecnologia Forestal de Catalunya - CTFC, Ellinikos Georgikos Organismos - DIMITRA, Instituto Superior de Agronomia – ISA

Duration: 2019 – 2021

Data of deliverable: Deliverable D2.3 – Report on wildfire suppression cost analysis, Task 2.2: Cost analysis, Work Package (WP) 2. Review and analysis of existing large wildfires prevention measures and preparedness actions

Date of deliverable: 31/01/2020

Lead partner of task: Università degli Studi della Tuscia - UNITUS

Summary

Executive summary

The present deliverable reports an operational review with practical examples for direct and indirect estimation of the cost of wildfire suppression, with specific reference to large fires (burned area > 500 ha or 5 km^2). Empirical data on fire cost categories associated to large fires occurred in Mediterranean European countries, are used to apply state-of-the-art theoretical approaches to estimate direct fire suppression costs. Three main estimation methods are presented, each characterized by different needs in terms of data input on fire suppression costs and, consequently, by different precision in the resulting estimates. From the results of this exercise, and more generally, from the apparent divergence between the theoretical needs and the current availability of information on fire suppression costs from official data sources, the conclusions of this work highlight the operational difficulties in the systematic calculation of the total cost of wildfire suppression, on both aggregate and disaggregate spatial and temporal scales. These conclusions also allow to identify different options for improving the data collection chain associated to single fire events, in the field or ex-post, that would enable a substantial increase in the level of precision of the fire suppression cost estimates compared to the current situation.

1. Estimation of wildfire suppression costs: definitions and methods

1.1. Introduction

The forest has always been an essential component of the economy of rural and non-rural populations. Today, forest resources play a deeply renewed role, due to their prevalent ecological and environmental significance. Forest fire regimes have been changing in Europe during the last 30 years, showing an increase in the length of the fire season, with extreme fire events also occurring in June and October, at the edge of the historical fire season (San-Miguel-Ayanz et al., 2018). In addition, the vulnerability of forest ecosystem services to fire disturbance have been increasing due to the expansion of the wildland-urban interface, new needs such as carbon sequestration, protection, tourism, and climate change related stresses (Moreira et al., 2020). Consequently, the social, ecological and economic impacts of wildfires have been increasing over the last decades, because of the unanticipated consequences of historical forest and fire management, a rapidly changing climate, and an increasingly populated wildland-urban interface (Ellison et al., 2015).

The costs of suppressing large fires that affect thousands of hectares of wooded and non-wooded lands every year in Mediterranean countries are known to be manifestly significant. The quantification of suppression costs is also one of the essential aspects for the realization of a refined environmental accounting system, at both national and regional levels, that is capable of providing updated information for policy design and implementation.

In this perspective, this first section of the deliverable offers a review of background literature, in order to introduce key terms, cost categories and methods currently available for the evaluation of wildfire suppression costs. Then, in Section 2, practical examples of estimation of fire suppression costs are given, based on elementary and aggregated data publicly available, at regional or National level, in PREVAIL partner countries. Building on existing examples of data availability in Italy, Greece, Portugal and Spain, this exercise helps to draw some conclusions in Section 3 on common minimum standards of data collection to be adopted, in order to improve the current quality of estimates of wildfire suppression costs.

1.1.1. Wildfire suppression: definition

Suppression is defined as: "**All work involved in controlling and extinguishing a wildfire**" (Mefisto project, https://www.mefistoforestfires.eu/content/common-terminology-and-good-practices). The purpose of fire suppression is to put the fire out in a safe, effective, and efficient manner, with the primary responsibility to protect lives, property, and strategic assets and resources, as example, wildfires that threaten homes or other infrastructure are attacked aggressively. When the management goal is full suppression, aggressive initial attack is the most common method to ensure the safety of firefighters and the public, and to limit suppression costs. Successful initial attack relies on speed and appropriate force: planning, organizing, and implementing fire suppression operations should always meet the objective of directly, quickly, and economically contributing to the suppression effort.

Very recently Simpson et al. (2019) devised a conceptual map of "suppression" grounded on 20 distinct suppression tasks, resulting from operational activities which can be grouped into five stages (Figure 1): defensive suppression: the fire behavior is beyond the control capacity of the suppression resources; 2. offensive suppression: suppression resources are making 'gains' on the fire. Plans are emerging and being executed; 3. containment achieved: a control line has been established along the entirety of the sector or division, and subsequent mop-up activities are expected to hold the fire at this perimeter; 4. mop-up: while mop-up activities occur to some degree in stages 2-5, complete mop-up of some depth (typically a 30 m perimeter) is the focus of this stage; 5. Patrol and Rehabilitation: the fire is still smoldering in the interior or in isolated hotspots on the perimeter. Perimeter mop-up is almost complete, and resources can be freed up for rehabilitation or demobilization.

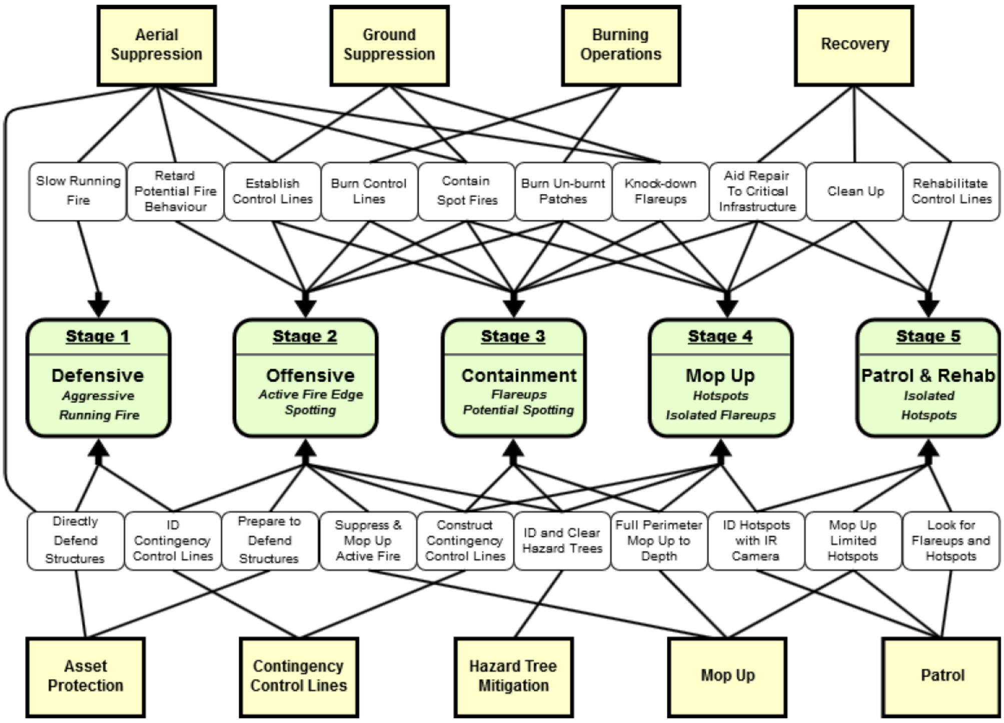


Figure 1. Suppression stages (in green), activities (in yellow) and tasks (in white) (source: Simpson et al., 2019).

Based on this premise, in this deliverable the terms “fire suppression”, “active fire-fighting”, and “fire extinguishing” have the same meaning and are used as synonyms.

1.1.2. Wildfire suppression costs

Studies carried out since now widely differ in how wildfire impacts on costs are defined, delineated and calculated. Most studies divide wildfire impacts into direct costs and indirect losses, or some variation of this. Direct costs associated with wildfires are usually the most visible and generally refer to fire-fighting and immediate damages costs (e.g. damages to private property and assets, including timber loss, any evacuation and medical costs, public and commercial disruptions such as the closing of schools and transport networks, restoration costs). Indirect costs are more challenging to measure as they include a broad range of environmental, social, and economic losses that persist after the wildfire has been put out (Caohuu et al., 2015). In line with this approach, several authors argue that suppression costs alone are too often incorrectly referred to as the cost of wildfire: suppression cost figures capture only the immediate costs for persons, houses and the wildfire itself, while wildfire costs can generally be considered within the context of impact duration, such as an immediate consequence to homes and properties or a long-term effect on community resources. In this regard, Zybach et al. (2009) compiled a comprehensive and exhaustive overview of the cost categories associated to wildfires (Table 1), broken down into direct, indirect, and post-fire costs.

Table 1. Overall fire cost categories from Zybach et al., 2009. In this deliverable we adopt the definition of direct suppression costs highlighted in orange.

Fire Cost Categories	**Direct**	**Indirect**	**Post-fire**
1. Suppression costs	wages, transportation, equipment, services, supplies, depreciation, interruption of business, evacuations	preparedness, equipment maintenance	repairs, restocking, medical treatment for responders
2. Property	structures, communications and transportation networks, timber, and agricultural products	insurance, building/landscape maintenance	repairs, replacement, real estate/sales tax impacts
3. Public health	injuries, fatalities, hospitalizations, evacuations, medical equipment	health insurance, training	health effects, costs of care
4. Vegetation	timber, forage, agriculture, habitat	growing stock	future harvests, replanting
5. Wildlife	habitat	pre-fire population enhancement	restoration, population effects
6. Water	suppression, system shutdowns	system investments	repairs, impacts on supply
7. Air and atmospheric effects	pollution, visibility	public health effects, property damage	carbon mitigation
8. Soil-related effects	erosion	pre-fire investments	erosion, rehabilitation decreased productivity,
9. Recreation and aesthetics	closures, damaged assets	pre-fire investments	restoration, degraded assets
10. Energy	grid damage and shutdowns	pre-fire investments, planning costs	repairs, sales reductions
11. Heritage	cultural/historical sites, supporting businesses	pre-fire investments	repairs, loss of sites

In light of the above, this deliverable focuses on **the estimation of the direct suppression costs,** i.e. the direct costs incurred to contain and extinguish a fire. This cost category includes costs covering contracted services, fire fighter salaries, wages, transportation, equipment, administrative personnel, procured assets, supplies and services needed to manage a wildfire.

1.2 Suppression costs estimation: empirical approach

Much of the available literature examines suppression cost using individual wildfire events or wildfire regions as observational units, as opposed to the national-level trend models, based on relationships between surface burned (on x axis) and suppression cost (on y axis).

Estimation of suppression costs for medium-large wildfires **relies on models when accurate, continuous and homogenous data over a long time period (30-50 years) are available**. This is the case for North American countries where a huge amount of studies analysed, in the last 30 years, the relationship between suppression costs and other predictive variables (e.g. fire behavior, fire weather, fuels and environmental characteristics, values at risk, etc.).

Conversely, in countries of Mediterranean Europe, complete information on direct wildfire suppression cost categories is, in most cases, missing at the level of single wildfire events. Further, available data come from multiple sources, and are poorly aggregated and/or inconsistently coded or miscoded. This makes accurate economic assessments of suppression costs about individual wildfire events or whole wildfire seasons/years highly problematic or, sometimes, impossible.

For this reason, in this deliverable an **empirical estimation methodology** of suppression costs is applied, according to a **modular approach moving from high-to-low levels of data availability on direct wildfire suppression costs**.

The presentation is divided into (i) **an exploratory framework** (§ 1.2), which illustrates the general methods of organizing the estimates (the reference estimation criterion, assumptions, simplifications, limits and factors of uncertainty in the application of the methods); and (ii) **a practical exercise** of cost estimation in different environmental conditions, in which the information sources are presented and, where available, also the data and technical parameters that can be used in the application of the proposed methods (§ 2).

In general, based on the background described on § 1.1, the estimation of suppression costs can be accomplished through procedures that differ in terms of input data requirements. Based on the completeness of the available information three main approaches are applicable (Figure 2):

1. in severe cases, where firefighting involves equipment and extraordinary personnel, an analytical approach can be used, based on the collection and reprocessing of accounting data, relating to time, costs and the type of equipment and staff employed.

2. Where available and updated, for interventions of a certain relevance and complexity, reference can be made to estimates of the actual times of use of the various vehicles and personnel, and these can be attributed the unit cost data obtained from predefined prices.

3. Ordinarily, it is possible to proceed with synthetic approaches based on the use of standard costs and modelling, although lacking specific information, using statistical techniques.

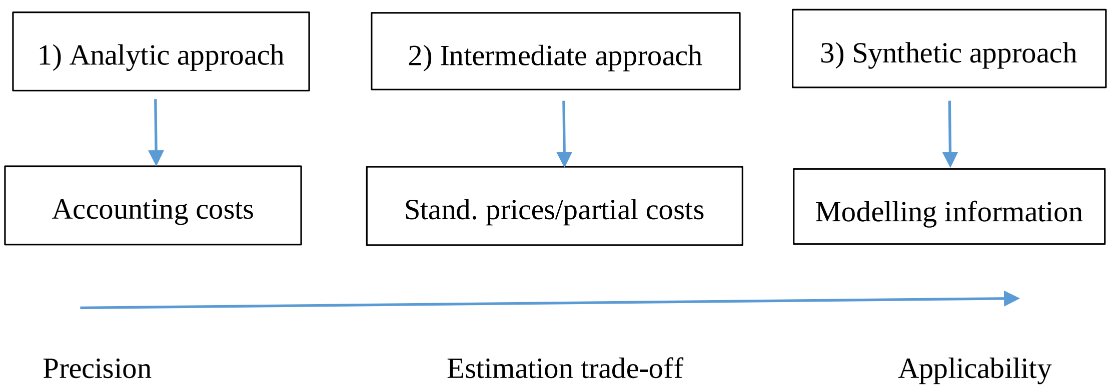


Figure 2. Estimation of suppression costs for wildfires.

These three approaches are characterized each by different levels of trade-offs between data input requirements, therefore applicability, and precision of the derived estimates.

1.2.1. Analytical approach: cost accounting

For wildfire incidents where the deployment of aerial resources was significant and where the need for a high level of precision in the economic estimate of the suppression cost is presumed, it is necessary to reconstruct the constituent parts of the costs accounted for, during ground and aerial fire suppression (i.e. teams and equipment involved in ground operations; number and type of aircrafts) based on a precise accounting of the time/duration of fire-fighting operations.

In general, this procedure may lead to a substantial improvement in the accuracy of the estimate, obtaining less uncertain and questionable data. However, the reconstruction of cost can be somewhat laborious when fire suppression operations involved several autonomous accounting organizations (State Forestry Corps, Civil Protection, Fire Brigade, Local Police, Voluntary Associations, etc.), in the absence of a central system of integrated accounting and harmonized data collection. The procedure is particularly appropriate in the case of big fires where the air component of suppression costs is dominant.

1.2.2. Intermediate approach: standard costs and the use of price lists

For medium-large wildfires incidents where suppression operations involved primarily ground personnel and equipment, it is possible to refer to two different methodological approaches: the first is based on the standard costs of the personnel employed in the extinguishing operations, the second on the standard costs of different types of intervention teams. This procedure assumes that the people that intervene at the scene of a wildfire will remain there for the whole duration of the incident. The duration of wildfire suppression operations is calculated accordingly, including also the time necessary for the transfer of the fire suppression personnel to the operating area (D).

The cost of extinction (C_{e_sp}) can be estimated by knowing the average hourly cost of the personnel (C_{mo}), the number of people attending (N_{tot}), possibly divided into the two categories of paid and unpaid personnel (N_{nr}), and the duration of the extinction operations (D), to which the costs of the equipment used are to be added. These, in an approximate way, can be assumed as equal to the total cost of the personnel intervened. It is clear that, in the case of intervention by unpaid personnel, this must not be counted for the calculation of personnel costs, but should be included in the calculation of the cost of equipment. The estimate can, therefore, be made based on the following equation:

$$C_{e_{sp}} = \big((N_{tot} * 2) - N_{nr}\big) * D * C_{mo}$$

where:

C_{e_sp} = extinction cost based on standard personnel costs (€);

N_{tot} = total number of people involved in the extinction activities;

N_{nr} = total number of unpaid people involved in the extinction activities;

D = duration of the intervention, including the time required for the transfer to the operating area (hours);

C_{mo} = average paid hourly personal cost (€/hour).

The number of hours spent in extinguishing interventions (D) can be derived from wildfire statistics, provided that the start and end of the intervention is reported for each event. The personnel employed in the interventions (N_{tot} and N_{nr}) are reported, e.g. in summaries of wildfire incident technical reports, where resources (personnel, equipment) mobilized to a wildfire incident are usually registered. As an indication, the average hourly cost of paid staff (C_{mo}) can be assumed according to price lists.

The costs of means and equipment used in the extinction for each operator can be considered equal to the cost of the personnel themselves. This figure can be estimated based on the sum of the hourly cost of the manual and motorized equipment normally supplied to firefighters vehicles and the average hourly cost of three light vehicles fitted and one medium-heavy vehicle fitted (refueling tanker for light vehicles), compared to the number of members of the intervention team (usually three people).

If aerial operations were necessary to suppress the wildfire, these costs are to be added to the costs of the ground crews. It is clear that this approach is a simplification of more precise and analytical accounting systems. Although being rather imprecise, this estimation can provide a general order of measure in the suppression cost of a specific fire when other, more precise and analytical information are not available.

The extinction costs can be also estimated by referring to average hourly costs by type of team (C_{sq}), multiplied by the number of intervention hours (D). To these standard costs of use of the different types of machines, the costs of earthmoving machines and those relating to air vehicles (C_m) should be added, based on the data reported in the related fire sheet. The formula that can be used is the following:

$$C_{e\_ss} = C_m + \sum_{1}^{ns} D_{sq} * C_{sq}$$

Where:

C_{e_ss} = extinction cost based on standard team costs (€);

D_{sq} = duration of the team's intervention (hours), including time for transfer to the operating area;

C_{sq} = average hourly cost of the team (€/hour);

C_m = cost of earthmoving machines and air vehicles (€);

ns = number of teams involved.

A possible classification of the main team types is based on two criteria: the type of equipment and the staff employed. Regarding the two criteria, the following team classification system is suggested (Table 2) (Ciancio et al., 2007):

- type A: light team with undeveloped vehicle (without extinguisher); these are extinguishing teams equipped with light tools (manual or motorized) to support those of the other types; they consist of the team leader with 3-4 people;

- type B: team with light set up vehicle (with extinguisher); it consists of the foreman with 2 people on a vehicle equipped with load ≤ 3.5 t;

- type C: team with heavy-duty vehicle (with extinguisher); it is made up of the foreman with 3-4 people on a vehicle equipped with load > 3.5 t;

- type D: heavy team with undeveloped vehicle; these are teams equipped with portable pumps for the construction of hose lines; it is made up of the foreman with 3-4 people who move with a motor vehicle equipped with motor pumps, hoses and mobile tanks;

- type E: light airborne team; it is a team made up of the team leader with 3-4 people equipped with manual or motorized tools (chainsaws, blowers, etc.);

- type F: helicopter team with fire-fighting form; is a team made up of the team leader with 3-4 people equipped with manual or motorized tools and equipped with complete tools.

Table 2. Examples of average cost of teams for fire-fighting interventions.

Typology	Average cost (€/hour)
Type A - light team with unequipped vehicle	130
Type B - team with light equipped vehicle	100
Type C - team with heavy equipped vehicle	180
Type D - heavy team with unequipped vehicle	150
Type E - helicopter transported light team	90*
Type F - helicopter transported team with fire-fighting module	105*

(*) transport helicopter cost not included; source: Ciancio et al. (2007).

Table 3 proposes indicative hour costs for the use of the teams (C_{sq}) which can be used in estimating the cost of extinction and can be considered indicative for a Mediterranean socioeconomic context (Ciancio et al., 2007; Marchi et al., 2017). Greater detail and precision can be achieved if the individual countries, regions, or other competent public administrations, make available average cost data calculated locally. In the case of air vehicle use, these will be added to the costs of ground crews. The data shown in Table 3 are examples that can be used to estimate air intervention costs providing an order of measure of the related monetary amounts.

Table 3. Examples of cost of air transport means for fire-fighting interventions.

Typology	Mean	Average cost* (€/hour)	Average fuel consumption** (lt./hour)
Airplane	Canadair	8000	1200
Helicopter	NH 500	700	100
Helicopter	AB 412	2500	500
Helicopter	S64 F	3600	2000

(*) costs including depreciation, insurance, maintenance, consumables (excluding fuel) and spare parts, personnel (with the only reference to mission expenses and overtime)

(**) source: Ciancio et al. (2007), Marchi et al. (2017).

According to a consolidated administrative practice, price lists have been prepared for estimating the unit costs of using specific equipment (and personnel) in fire-fighting interventions. The price lists have different purposes, including the estimation of costs for statistical purposes, the internal accounting analysis of the administrations, the eventual reimbursement of suppliers and voluntary staff. This can be useful information for the formulation and revision of fire-fighting regional plans. Price lists are based on the calculation of the operating cost of the machines, a method of common application in many sectors for planning and control. The cost can be determined "on estimate", "on final balance" or during the life of the machine. In the first case, the calculation is based on data estimated or suggested by experience; in the second it is based on real data (which must, however, be regularly recorded during the life of the machine); in the third case, it is based on both real and estimated data. The processing of the price lists can be addressed to the determination of the operating costs by macro-categories. A price list of approximate operating costs for macro-categories of equipment used in extinguishing operations is shown in Table 4[1].

[1] In the application of standard costs and price list's methodologies - especially when estimating operational costs by macro-categories, certain aspects that make many parameters used in the calculation procedures extremely variable, and therefore difficult to identify, must be taken into consideration. A first aspect is linked to the particular characteristics of the extinction activities which differ considerably from those of other sectors, such as the agricultural-forestry sector, where the various operations are planned and involve the use of a limited number of machines with well-known characteristics. Many different means, both land and air, intervene on a single fire. For example, the fitted vehicles have very different characteristics by type of vehicle (there are numerous models of off-road and non-off-road vehicles that are used in forest fire-fighting), by type of preparation (there are arrangements of various sizes and with variable components, both industrial or artisanal production, both self-assembled by end-users) and for the vehicle-set-up combination methods (fixed set-ups, demountable set-ups, with pumps driven by autonomous engine or vehicle engine, etc.). A further aspect is linked to the type of use of equipment and vehicles which are not always for the exclusive use of forest fire-fighting: often fire-fighting fittings are dismantled at the end of the "fire season" and the vehicle is used for civil protection activities (voluntary activities, bodies operating in the civil protection sector, etc.) or for the transport of materials in agricultural works or forestry (mountain communities, provinces, etc.). All that has a considerable influence on the calculation of the cost of the equipment of the vehicles, even if with similar characteristics. Furthermore, some parameters of extreme importance for the estimate of the operating cost may undergo considerable fluctuations depending on the structure that uses the equipment (for exclusive use in the sector or also for agricultural-forestry or civil protection activities) or for the frequency and characteristics of the fires that occur. Price lists should, therefore, be applied and used with caution.

Table 4 – Examples of operating costs for macro-categories of equipment used in extinguishing operations (Ciancio et al., 2007).

Equipment	Operating cost (€/hour)
Chainsaw	3,5 – 6
Motor brush cutter	2 - 4,5
Blower atomizer	3,5 - 4,5
Shoulder pump	45 – 80
Fire-fighting modules (off-road set up vehicles)	100 – 150
Tankers	30 – 150
Earth-moving machineries	50 – 150

1.2.3. Synthetic approach: estimate and modelling of suppression costs under (partially) lacking information

When the input data required for the application of the intermediate estimate approach are not available for all fire events occurred in a specific territory (country/region) and year, but only for a representative sample of fires, the estimation of fire suppression cost have to be necessarily based on an approximation. Statistical regression models, namely, can be used to determine whether is possible to estimate a theoretical cost model in conditions of partial unavailability of data: e.g. partially lacking information on the air/land means intervened on a fire scene or, even worse, availability of only the indicator of the fire duration or the extent of the burned area.

The multiple linear regression theory, namely, responds to the objective of studying the dependence of a quantitative variable Y (in this case a proxy relevant for fire analysis) on a set of quantitative explanatory variables (the number of vehicles and operators on the ground, the number of helicopters intervened, the duration, etc.), called regressors, using a mathematical model. Considering the number of explanatory variables that influence suppression costs, to make the mathematical function of the regressive model more interpretable, in addition to improving its performance in terms of representativeness of the real phenomenon, specific methodologies allowing for an automatic selection of relevant regressors can be implemented, aiming to select the combination of regressors with the best performance. In this way, a small group of variables can be selected, whose influence is predominant in determining the characteristics of the fire and the related estimated costs in a given area/exercise. This comparison can be made through an iterative stepwise regression process, a system applied to multiple regression methodologies.

Such a modeling approach would provide the total cost of fire suppression activities for all fires that occurred in the specific year, based on a restricted amount of information. Because of lacking information, the precision of the estimates is relatively low. In particular, Marchi et al. (2017) suggested that the following variables could help defining suitable "standard" costs per event, being intended as possible predictors of fire suppression costs:

- *Fire duration*.

- *Burned area*. This parameter could be a simple parameter to define standard costs for surface classes. These surface classes could be those commonly considered for statistical purposes at the regional level. The possible use of this parameter and the division into classes must be supported by a careful analysis of the results obtained with the intermediate approach.

- *Length of the perimeter of the area burnt*. This parameter could represent a valid alternative to the surface value since it represents the length of the front where the extinction, remediation and surveillance activities were carried out, in particular in the last hours of the event.

- *Accessibility of the affected area*. This factor affects the efficiency and effectiveness of extinction and can favor the request for intervention by aerial resources. Unfortunately, parameters for defining this factor are rarely available in the fire sheet.

- *Presence of urban-forest interface elements*. In fires involving interface areas, extinction management can be strongly influenced by the need to protect the safety of people and infrastructure. For such events, other things being equal, the costs can, therefore, be considerably higher.

2. A practical exercise with mixed data

This chapter presents a specific exercise for estimating the cost of suppressing forest fires, using the approaches illustrated and discussed in the previous section. Elementary and aggregated data collected in different operational contexts in Italy, Greece, Portugal, and Spain are used. The relatively wide amount of information was used with the aim to describe the different operational contexts, and the related weak points associated with each context. More specifically:

(i) the **analytical approach** was used to quantify the extinguishing costs of a large fire that occurred in 2018 in Central Italy;

(ii) the **intermediate approach** was used to estimate the extinguishing costs of 4 other large fires developed in Italy in recent years;

(iii) a **synthetic approach** was applied to a database containing some detailed information for a collection of forest fires in Greece, making some assumptions that limit the precision of the estimate. These assumptions, however, allow for the provision of aggregate information on a known time scale, giving an order of measure of suppression costs for large fires on a given spatial scale (e.g. individual fire, an administrative region, the whole of a country). In this case, statistical models were also used to estimate missing information and enabled the synthetic approach also in other contexts with a more significant lack of relevant data.

None of the above methods of cost estimation can be currently applied in Portugal and in Spain.

Publicly available information on fire suppression operations, which can be derived from fire statistics and wildfire incident technical reports in Portugal and in Spain, does not contain sufficient data for the application of any of the three estimation approaches. Therefore, this exercise proved useful also to throw light on measures to be taken to improve data collection on individual fires in the field, to allow the costs of wildfire suppression be estimated.

2.1. Using the analytic approach to estimate suppression costs in Calci, Tuscany

A large fire (1,069 hectares) developed on Monte Serra on the evening of Monday 24th September 2018 (Figure 3), in the Calci area (province of Pisa, central Italy). Based on the data provided by the operating room of the Tuscany region, which coordinated the intervention with the contribution of the Italian national civil protection, it was possible to estimate the entire cost of suppression of the event starting from particularly detailed information that we will briefly describe below. The operations specifically concerned 1,628 interventions by ground crews and 146 interventions by air units.

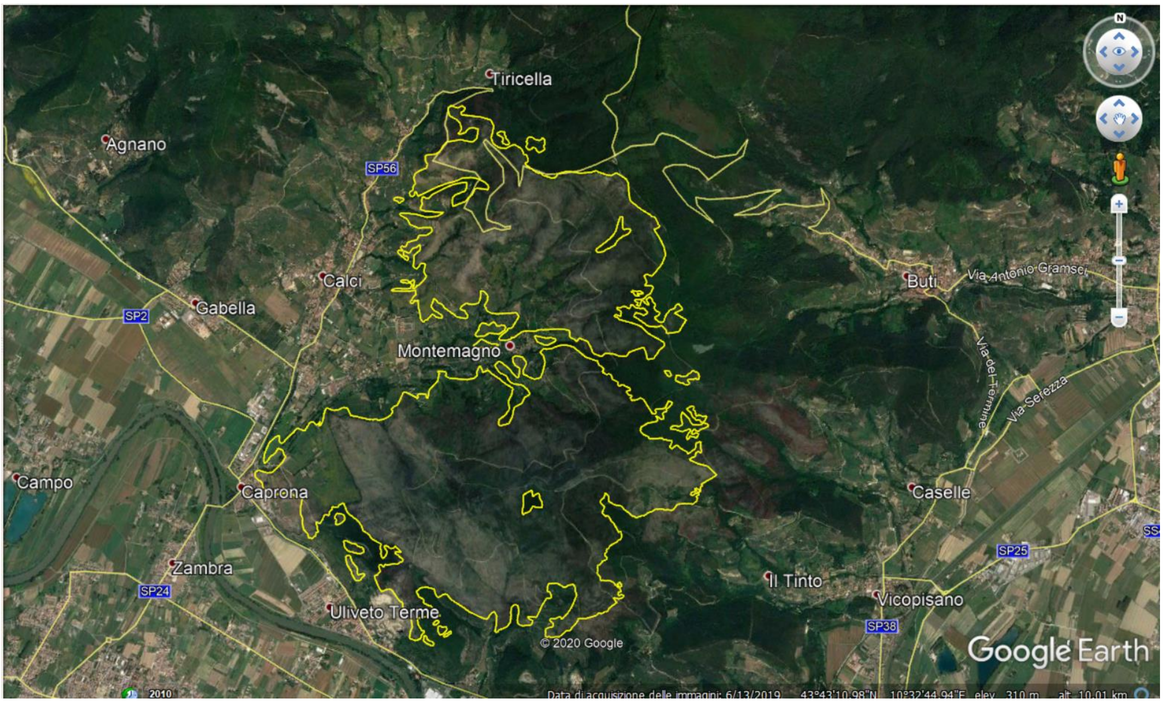


Figure 3. Fire perimeter (in yellow) of the Calci wildfire (Pisa, Tuscany).

The aircrafts involved, both helicopters and Canadair, were active for most of the day on September 25th and, more marginally, on the following three days, from September 26th to September 28th, 2018. A total of 6 helicopters from the Tuscany region intervened on the burning area. A total of 11 aircrafts made available by the national civil protection emergency room also intervened. A total of 80 flight hours of the vehicles provided by the Tuscany region and 156 flight hours of the national civil protection vehicles were carried out. A total of 1,249 operators organized in 530 field actions were deployed to face the fire front for a total of 6 working days, from 25th September to 30th September.

At the end of the operation, the total extent of the fire was quantified in 1,069 hectares. The extinguishing operations involved two operating rooms, one regional, which coordinated the interventions of men on the ground and of regional air vehicles (helicopters) and one national (Italian civil protection emergency room), which coordinated the air vehicles (mainly Canadair), which contributed significantly to the extinguishing of the fire, classified as being particularly dangerous due to its proximity to the town of Calci and other peri-urban settlements in the Pisa metropolitan area.

The total cost of the personnel involved in all the extinguishing activities amounted to **324,652 euros**. The cost of the operation room activities, including the activities of both the regional operation room and the national civil protection emergency operation room, was estimated at **1,868 euros**. The total cost of air vehicles was estimated at **1,166,956.76 euros**, of which the cost of the air means made available by the national civil protection was equal to ***896,494.09 euros***. The remaining cost was incurred by the regional civil protection of the Tuscany region. Based on the analytical approach, the total cost of extinguishing the Calci fire was quantified in **1,493,476.44 euros**, equivalent to **1,397 euros per hectare**.

As regards the cost structure, it was observed that aerial resources represent the great majority of total costs (78.2%). The cost of personnel and ground crews slightly exceeds 20%. The cost of coordination is clearly modest. The cost of air operations supported by the National Civil Protection Coordination Center is 76.8% of the total cost of air operations.

2.2. Using the analytic approach with partial information to estimate suppression costs in four large fires in Italy

An additional exercise was developed through the analytical costs approach, evaluating the expenditure of aerial means of a sample of four large fires that have occurred in Italy in recent years. The fires considered in this exercise cover, together with the Calci fire described above, a wide spectrum of events, representing both summer and winter fires, in various biogeographical regions of Italy, from North to South, with variable dimensions (events from about 5 km^2 to more than 100 km^2 of the burnt area). Based on these premises, the fires considered here had various origins and causes, with very different economic implications and human losses present in some cases (see table 5). This analysis, although partial, offers a greater generalization of the results compared with the previous exercise.

Table 5. Synthetic overview of the selected fires, Italy.

Fire	Date	Time of fire start	Cause	Casualties	Burned area (ha)
Calci	24/09/2018	22:00	Anthropic (arson)	0	1,069
Vesuvio	11/07/2017	10:00	Anthropic (arson)	0	3,198
Val Susa	22/10/2017	10:00	Anthropic (doubt)	0	4,054
Ozieri	23/07/2009	4:58	Anthropic (arson)	2	10,359
Gargano	24/07/2007	9:20	Anthropic (arson)	2	528

2.2.1. A brief description of the four wildfires

The fires considered here occurred on Mt. Vesuvio, Campania (11th July 2017, for a total of 3,198 hectares of burnt area), in the Val Susa, Piedmont (22th October 2017, for a total of 4054 ha), Ozieri-Torralba in Sardinia (23th July 2009, for a total of 10,359 ha), and Gargano in Puglia (24th July 2007, for a total of 528 ha).

Vesuvio fire, July 11th, 2017

During the summer of 2017, the area of the Vesuvio National Park was hit by a fire of very large dimensions which caused significant damage to the forest heritage on all sides of the volcano (Figure 4). Besides, large quantities of ash from the combustion of dozens of hectares of Mediterranean pines and scrub were dispersed in the environment and, as can be seen in the ESA Sentinel 2B satellite image of 12th July (Figure 5), the fire caused extensive coulters of smoke that affected a very large area including inhabited areas.

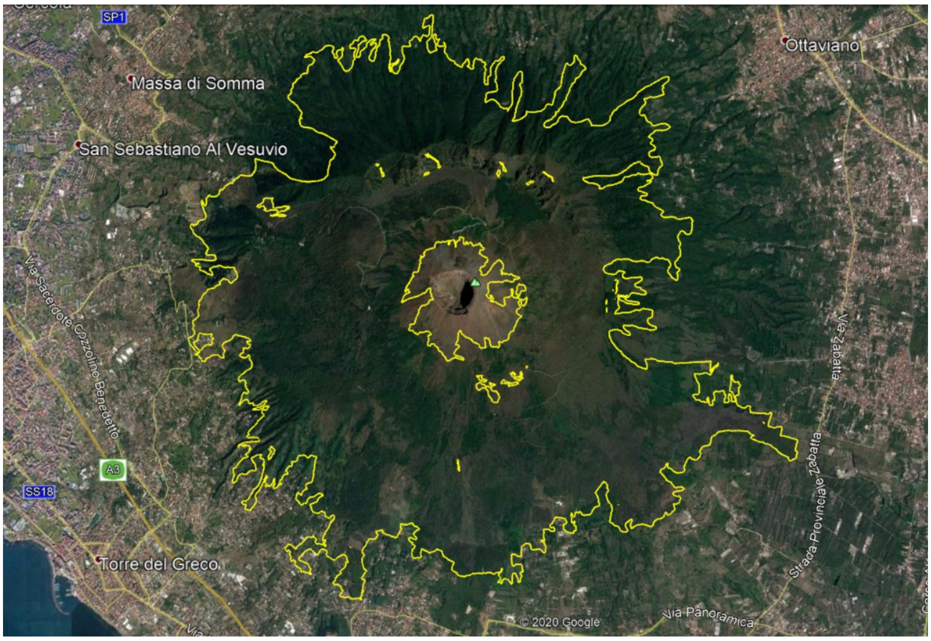


Figure 4. Fire perimeter (in yellow) of the Vesuvio wildfire (Naples, Campania).

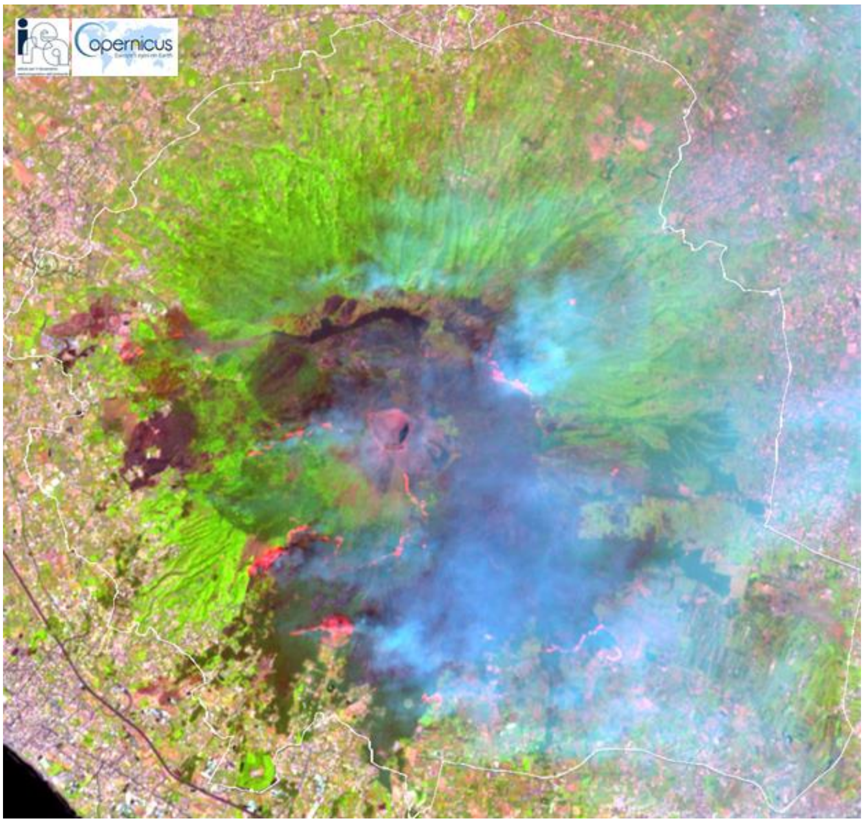


Figure 5. ESA Sentinel 2B satellite image of 12th July of the Vesuvio fire.

The means used in the extinguishing work were significant; over 60 people in action in the Vesuvio area included regional employees, SMA staff (systems for meteorology and the environment) Campania and volunteers, as well as the use of national air vehicles: one S64 and two Canadair.

Val di Susa, October 22th, 2017

On 22th October 2017, in the Susa Valley, in the Turin area, a fire started out from the Bussoleno Municiplaity, where the flames quickly reached 1,900 meters above sea level, immediately wiping out hundreds of hectares of broadleave and conifer forests, shrublands and pastures (for a total of 4,054 ha), expanding in the first hours to the locations of Caprie and Rubiana. Two Canadair and some helicopters were used immediately in the area, but this was not enough to contain the flames that continued to spread for many days, hitting the entire Val Susa mainly due to the wind. On October 30th, more than a week after the start, Swiss Canadair went into operation, while hundreds of firefighters were working day and night. Figure 6 shows the mountains burnt by the fire.

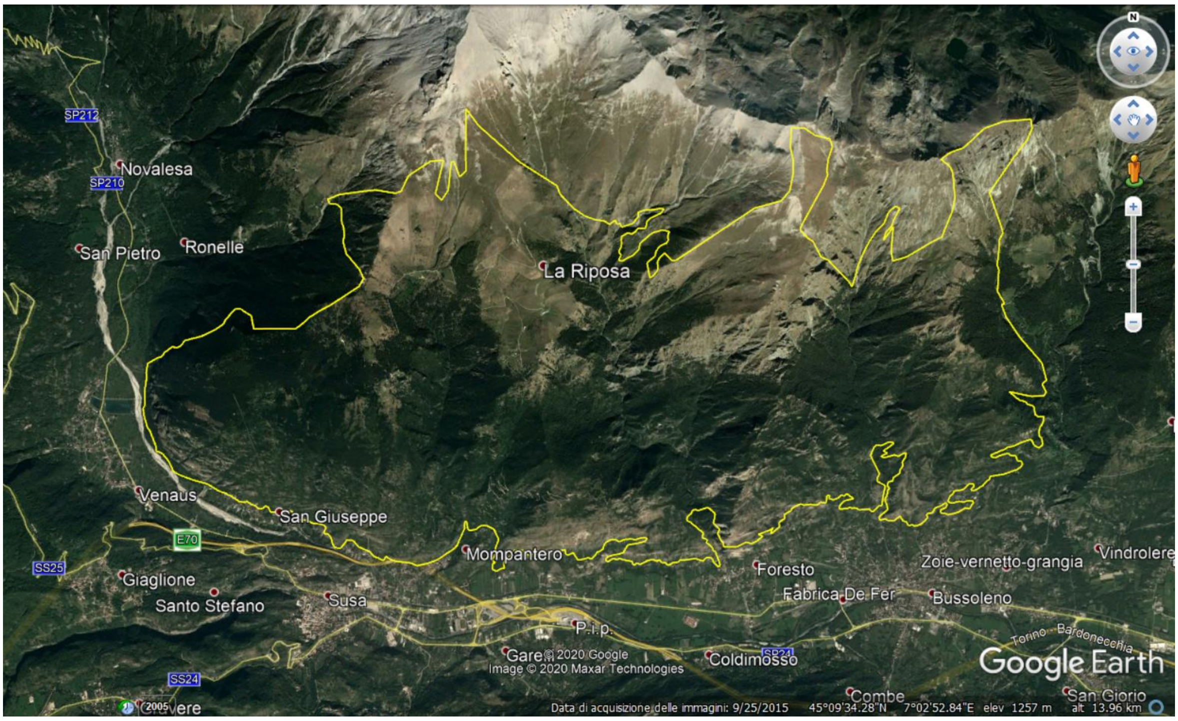


Figure 6. Fire perimeter (in yellow) of the Susa wildfire (Turin).

Ozieri-Terralba (Sassari- Sardinia), July 23th, 2009

In July 2009, the Ozieri-Terralba fire was favored by the high temperatures (peaks of 46 degrees in Valledoria, in the province of Sassari). The fire hit the inhabited center of Ittireddu, where most of the houses were evacuated. The same fate occurred for several inhabitants of Ozieri and Nughedu San Nicolò. There were two victims in this vast fire (Figure 7 and 8).

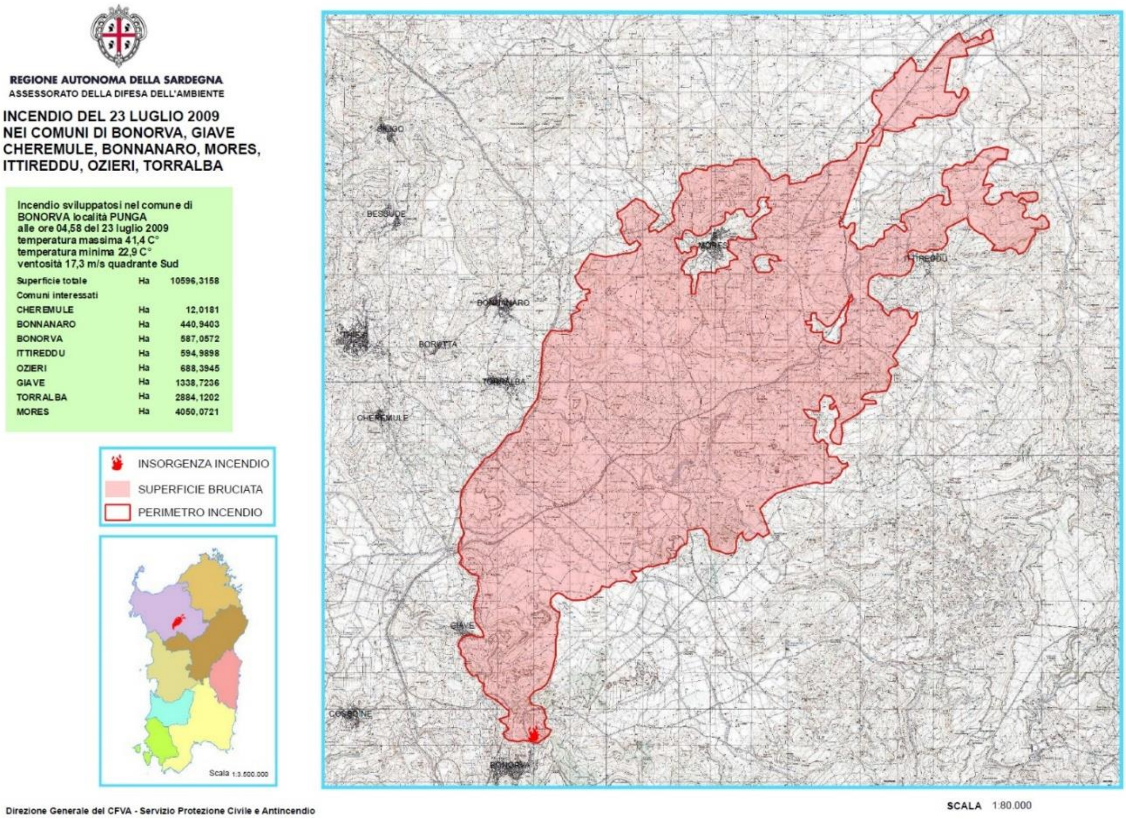


Figure 7. A map of the Ozieri-Terralba fire.

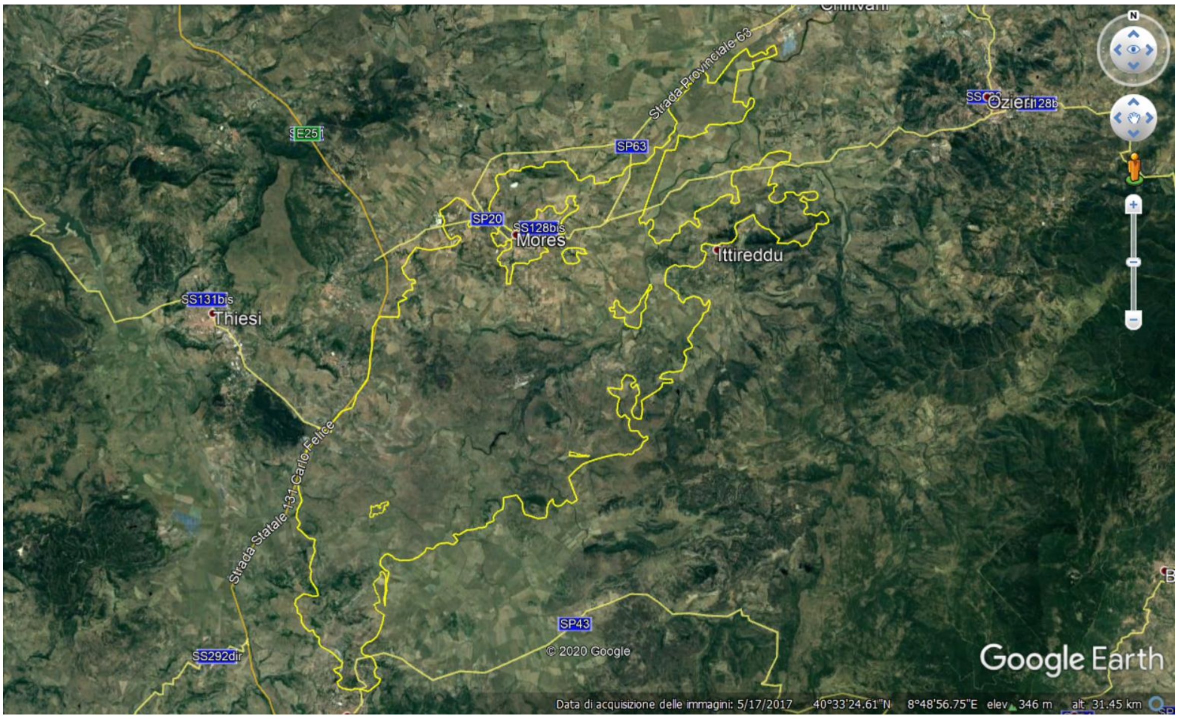


Figure 8. Fire perimeter (in yellow) of the Ozieri wildfire (Sassari, Sardinia).

Peschici (Gargano) July 24th, 2007

On July 24th, 2007 in Peschici, a big fire started close to some very famous touristic beaches, with two people killed, 300 injured among tourists and locals, extensive damage to camping sites and tourist villages, hundreds of hectares of the Gargano forests destroyed (Figure 9). Overall, about 3,000 people were evacuated from the area.

Figure 9. Fire perimeter (in yellow) of the Gargano wildfire (Foggia, Puglia).

2.2.2. Cost estimation

The main evidence of the empirical analysis for the 4 events considered and the relative comparative data for the Calci fire have been summarized in the table below (Table 6).

Table 6. Cost estimates for aerial resources in selected fires, in Italy. Only costs of Italian Civil Protection Agency aircrafts involved in aerial operations are considered [2].

Fire	Canadair (h)	Helicopter (h)	Costs (euros)	Costs/ha (euros)
Vesuvio	218	50	1,210,150	378
Val Susa	78	5	345,434	85
Ozieri	14	0	58,305	6
Gargano	3	41	410,313	777
Calci	119	37	896,494	778

[2] For the calculation of costs incurred by the civil protection we have used actual hourly costs provided by Italian National Civil Protection and not standard data from literature.

The analytical data were collected at the Italian national Civil Protection operations room, through comparative procedures and integration of different data sources. The data collected relate exclusively to a specific component of the fire suppression operations, i.e. the costs of flight operations supported by national civil protection. These costs appear particularly significant and representative of the overall cost structure in large fires where the national structure is called upon to intervene, in support of the regional structures. The costs proposed in this table, therefore, exclude the costs of ground personnel and the costs of air operations incurred directly by the individual regions. Considering the cost structure observed for the Calci fire, these costs are considered rather high, at least for the largest fires in Italy.

However, the exact accounting of flight hours in the four fires studied in this exercise may benefit from a refined analysis of the cost structure, providing approximate indications on the overall size of the interventions (Table 6).

The comparison of estimated costs of national air operations for the 5 events (including Calci) highlighted a particularly heterogeneous picture, which can be generalized to all large events. Unit costs fluctuate widely, from almost 800 euros per hectare in the case of Calci to just under 400 euros per hectare in the case of Vesuvio, and only 6 euros per hectare in the case of a particularly large fire such as that of Sardinia (2009). Therefore, the cost structure depends on vastly different variables, which cannot be inferred directly based on just a few events, although representative of a wider context. At the same time, the data provided some specific information, which can lead to formulating broader considerations, valid for the cost estimations at an aggregate level. The Ozieri-Terralba fire, in particular, can be considered as an example of events that occurred in rural areas with medium-low biomass (fuel) presence, in a Mediterranean summer-dry climate context. Although the fire covered an extensive area, the number of air vehicles involved was relatively small, at least for the national component. The cost per unit area was therefore relatively low. However, the estimated expenditure of 6 euros per hectare appears particularly significant, if generalized to all the medium-large events that occurred in Italy in that period. At the same time, spending increased greatly in peri-urban or high natural contexts (Calci, Vesuvio, Val Susa) or where victims were involved (Gargano). Compared to the fire in Sardinia, these events can be considered less frequent. However, despite the rarity of these events, the associated expenditure, considering only the national component, seems to be extremely high.

2.3. Using the synthetic approach to estimate suppression costs in selected fires of Greece

In this exercise, the synthetic approach using standard costs was applied to a dataset containing all the fires occurred in Greece from 2000 to 2018 provided by the Hellenic Fire Brigade according to the national Greek Law no. 4305/2014 redefining the open availability and re-use of public sector documents, information and data, by adapting national legislation to the provisions of Directive 2013/37/EU of the European Parliament to further enhance transparency. Pursuant to the above law, the Fire Department routinely provided these data based on a standardized spreadsheet scheme, and freely disseminated them through the official website of the service. More specifically, the database provided summary indications for all forest fires (small, medium and large) that required intervention by the firefighters. From 2000 to 2010 the available information was the extent of the fire, a very rough geo-location, the start and end date of the extinguishing operations and the main uses of the land burnt, with a summary quantification of the surface areas affected by fire. Starting from 2011, the quality of the data has visibly increased, and summary information on the personnel involved as well as equipment (land and air means) have been collected for the whole of events. The only variable available for the quantification of the duration of the interventions was based on an estimate calculation, derived from the records of the date and time of the start and end of the fire. However, these two figures were found, in some cases, unreliable because of evident recording errors.

During the latest observation period (2011-2018), a total of 46 large events (> 5 km^2) occurred. The most critical year was 2012 with 13 large fires. The years with the least critical events were 2014 and 2018 (3 events each).

Costs were quantified following the specific assumptions grounded on the work of Ciancio et al. (2007), based specifically on the elementary data provided in the Fire Department dataset described above. For prudential purposes, and based on the insufficient information made available, the lowest standard costs of the category were adopted (e.g. team with light equipped vehicle) as reported by Ciancio et al. (2007). Furthermore, these costs - which refer to various contexts in Mediterranean Europe - were not discounted for price inflation. In fact, it is assumed that the cost structure, with particular reference to personnel costs, remained substantially unchanged, or modestly increased, in the period following the economic crisis. On the other hand, errors in the estimate of personnel costs can be considered much less relevant than errors in the estimate of the costs of air vehicles. In this sense, estimates of personnel costs are to be considered prudent and minimal. Concerning airplane operations - considering the importance of these missions in the overall cost structure - the duration of the operations was preliminarily estimated starting from the only indication available, the total duration of the fire. This duration was estimated in hours and minutes. For short-duration fires of less than 24 hours, the flight time of each aircraft was estimated based on the duration of the fire in daylight hours, with a maximum hourly amount of 12 hours. For each aerial mean, the flight minute was further divided by 2, considering an average half-life of the daily intervention based on the effective operation of the mean (Marchi et al. 2017). For fires of daily duration or longer, a maximum of 12 hours per day was considered as operating time. The flight time was also divided in this case by 2 for prudential purposes. Also, in this case, the lower standard cost for intervention foreseen by Ciancio et al. (2007), considered the minimum cost for all components. The estimate is considered prudential and, although evaluating all the available information, it must be considered affected by important errors. It can be considered indicative of a coarse unit of measurement, also indicating the strong cost variability between year and year.

Based on the above considerations, the estimate of the total costs of extinguishing by fire and by year is shown in the figure below. **The costs of fire extinguishing are quite variable over time and do not seem correlated with the density of large fires.** The fires that occurred in 2018 were those estimated with the highest unit cost. Even in the years 2012, 2013 and 2016, the unit cost appeared rather high, while the other years witnessed fewer significant costs for fire suppression. The year 2011 had the lowest average fire costs of the entire time series. On average, considering the past 8 years, the average cost of a large fire in Greece has been estimated at just under € 1,000,000. This cost appears in line with - or slightly lower than - the estimates previously discussed for the Italian case studies. However, these values must be treated with extreme caution and can only be considered indicative of aggregate trends on a large scale, considering the significant limitations of analysis that we have presented above (Figure 10).

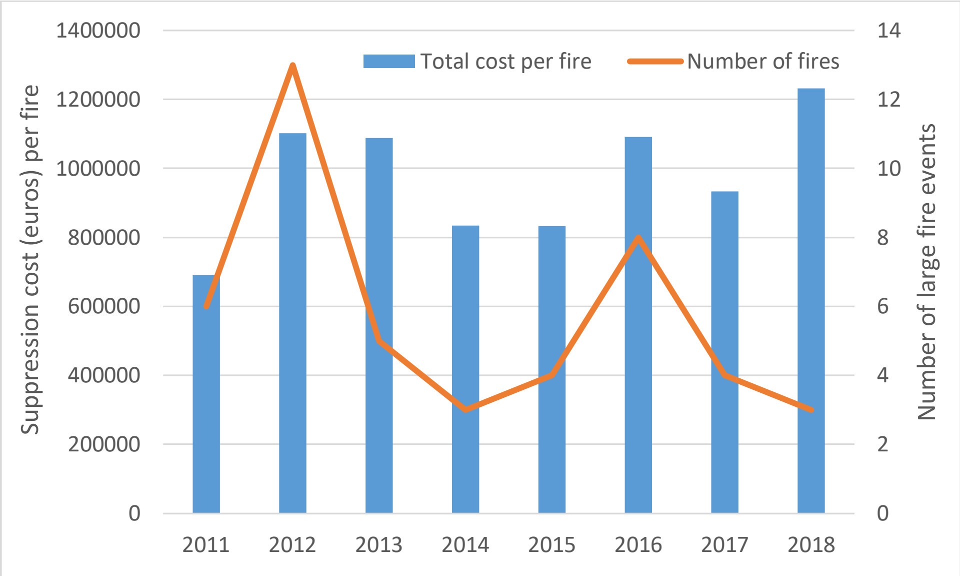


Figure 10. Average cost estimates for fire suppression, Greece.

2.3.1. Using the synthetic approach with lacking data to estimate suppression costs in selected fires

The database provided by the firefighters that include all the fires from 2000 to 2018 in Greece enabled to estimate a theoretical cost model in conditions of partial unavailability of data on fire suppression operations. Based on the information on the means used to extinguish fires available between 2011 and 2018, it was possible to develop - through multivariate and inferential (regressive) exploratory statistical methodologies - the estimation models of the ground and air vehicles used in each fire based on variables, observed ex-post, such as the extent of the burnt area and the overall duration of the fire. These variables are more frequently available in fire registers in almost all European countries and, therefore, the greater availability of elementary data allows for the estimation of costs - even if highly partial and indicative - on a wider set of events. In Appendix 1 the main results of the quantitative analysis based on a large dataset of context variables were reported. The empirical analysis revealed **a significant correlation between the overall duration of the fire and the means used for extinguishing**. This correlation, tested on the events observed between 2011 and 2018 in Greece, appears rather stable and statistically robust. In other words, from the overall duration of a large fire, it is possible, under specific assumptions and in a defined socioeconomic context, to roughly estimate the amount of ground and air forces, thus providing an indirect quantification of the total cost of each intervention shutdown by adopting specific standard costs. This method appears to be of interest in all cases in which the information available, even if concerning the single event, is partial, as it lacks significant variables in the cost estimate.

Regarding the routine detection of large fires in Portugal, despite the large amount of information about the use of burnt soil and some categories of means involved in extinguishing (Table 7), the scarce (or missing) information on the duration of the interventions (overall or by individual means) does not allow for the ordinary application of the synthetic costs method through price lists.

Table 7. Variables included in the fire registers in Portugal and Catalonia (x = data present in the database; n/a = data not present or incomplete in the database).

VARIABLE	PORTUGAL	CATALONIA
ID	x	X
COUNTRY	x	X
ADMINISTRATIVE REGION	x	X
LATITUDE	x	X
LONGITUDE	x	X
YEAR	x	X
DATE	x	X
TIME OF FIRE START	x	n/a
TIME OF FIRST INTERVENTION	x	n/a
BURNEDFOREST	x	X
BURNEDAREA	x	X
NUMBER OF FIRE FIGHTERS	x	n/a
NUMBER OF OTHER CONTRIBUTORS	x	n/a
NUMBER OF FIRE TRUCKS	x	n/a
NUMBER OF HEAVY MACHINES	x	n/a
NUMBER OF AIRPLANES	x	n/a
NUMBER OF AMPHIBIAN MEANS	x	n/a
NUMBER OF HELICOPTERS	x	n/a

In Catalonia, the variables of Table 7 are registered officially by the Fire Service for an internal use, but it is not edited for public access, for instance in Fire Service website or Fire Statistics.

The analysis of the fire register and the analytical files relating to the fire-fighting activity by the competent authority available on-line do not follow a quality standard in data collection, nor a uniformity of contents, for both the characteristics of the fires and the means used, and **above all, the relative costs, or at least, the time of use of individual means**. Sometimes the analyzed reports have proposed monetary values of overall fire damage, without adding more precise information regarding the means used or the methodology adopted.

Therefore, **to be able to carry out the methodologies described in this deliverable full access to official and formally validated data on fire suppression logistic should be necessary**.

3. Conclusions

A correct practice in the systematic estimate of a widely diversified typology of suppression costs for wildfires can only be based on the logic of continuous improvement of the methodologies. The lack of information is an obstacle for investment decisions to be made, so that adequate prevention and control measures may be adopted, and subsequently, sufficient resources may be allocated. The practical exercises proposed in this deliverable suggest that technical and organizational knowledge is not always easy to translate into economic assessments. When fires occur, the Authorities responsible for assessing suppression costs are subject to various operational and administrative tasks, which usually lead to only partial recording of the necessary information. The exercise developed in this deliverable allows us to identify **the optimal information** for the analytical estimate of the costs of suppressing large fires and also to identify **sub-optimal operating situations**, where an approximate estimate of the costs is however possible.

3.1. The optimal context

The first exercise proposed in this deliverable (the example of Calci fire in Italy) shows an example of optimal availability of information for an analytical estimate of fire suppression costs, as particularly detailed information was collected both for ground and air fire suppression operations. This was possible because data from multiple sources concerning wildfire suppression operations (e.g. Tuscany region Wildfire Department and national civil protection) was collected by the Tuscany Region control room (i.e. the facility from which resources are directly assigned to wildfire incidents) and processed into an effective data format to allow subsequent estimation of fire suppression costs. An analytical quantification of the elementary costs (per person, by air, per minute of activity) was finally developed. Based on these premises, the Calci experience indicates the **best data collection model** based on the following record structure (Figure 11 and Figure 12). **Each crew was asked to collect the relevant data** and the control room improved the quantification based on additional data, when available.

Name crew
ID radio
Function
No. Persons
Activation date
Deactivation date
Starting mission date
Arrival on the field date
Coming back date
Number and type of equipment and vehicles for wildfire suppression
Operation time (hours, min)
Operation type (e.g. regular suppression, mop-up)

Figure 11. The optimal data structure for analytical estimation of suppression costs in Southern Europe (ground suppression operations).

ID
Air vehicle
Starting operation
date and hour
ending operation
date and hour
Operation time (hours and min)
Operation type (e.g. extinction, surveillance, helitransport of brigades)

Figure 12. The optimal data structure for analytical estimation of suppression costs in Southern Europe (aerial means).

As regards air operations, the optimal information to be collected is evidenced in the structure of the Figure 12. Each air operation should be recorded based on the start and end date and time, the air vehicle involved and the total cost of the individual mission. In this way, it is possible to analytically quantify the cost of flight operations, containing the estimate errors as much as possible. The precise quantification of the flight time (hours and minutes) also makes it possible to minimize the error in the use of fuel.

Standardization of the information collected according to a single scheme (like the information reported in Figures 11-12) appears mandatory for all European countries. The data collection format reported in Figures 11-12 should be ideally collected by an agency operating at a national level for each European country, using a common template that covers all fires that have required aerial intervention. This solution would allow for an analytical, low-error estimate of the suppression costs to be devised on a national scale, and be disaggregated over time and space, according to policy requirements.

3.2. Sub-optimal solutions: a brief reflection

While the structure of the data collected in Calci appears to be the best for quantifying the total costs of fire suppression with the least possible error, this data structure is not routinely available for all events, not even for larger events. Therefore, the application of the analytical estimation method can only be carried out in specific situations. Many factors cause **a significant increase** in the error of estimation of the overall costs, requiring the use of indirect and approximate methodologies, as follows:

(i) the fragmentation of the interventions in several control rooms,

(ii) the use of personnel and air vehicles from different organizations,

(iii) the partial accounting of flight hours or the failure to record flight hours for each mission.

In most situations, the data collection effort does not appear compatible, without major logistical and monetary investments in the processes of recording and collecting information, with the analytical estimate of costs. Particular attention must be given to the accounting of air means, representing the most significant component of the total cost structure.

In these regards, the second exercise in this deliverable that estimates the cost of the aerial component for selected fires in Italy nonetheless highlights the importance of **estimating the costs of aerial operations**. In this sense, the analytical accounting of the individual operations, with the exact recording of the time of actual use (e.g. flight) for each vehicle involved, appears indispensable. We have shown how air freight costs can reach 80% of total direct suppression costs. In suboptimal contexts, detailed information on this cost component could significantly help reduce the imprecision in the estimate of total costs.

The third exercise proposed in this deliverable highlight **critical points and limitations of databases of an administrative nature**, regularly compiled by the competent authority in compliance with specific provisions of national laws (e.g. fire register), for the estimate of the suppression costs. These databases, as available to date, are not directly usable either for analytical estimates or for partial or intermediate approaches, aimed at producing **aggregate estimates of suppression costs with acceptable and documented errors**. Despite a fair amount of information, at least in some cases, the information collected is partial and scarcely usable, and the quality of the information collected is highly questionable. There are systematic errors for some variables, missing data with high frequency for other variables. These shortcomings seldom allow for the accurate application of synthetic methods through price lists. There is also a lack of typological information on both teams and air vehicles. In this case, the specific information on the flight hours of the individual aircraft appears to be particularly scant. The absence of this information is quite limiting, given that the cost of air interventions represents the most important cost component for extinguishing fires.

The results of this deliverable clearly outline that greater detail and precision in suppression cost estimates can be achieved only if the individual authorities involved in fire suppression operations (e.g. Forest services, fire brigades, Civil Protection agencies) record and make available average cost data determined locally (i.e. at each event), estimating the hourly and/or kilometric cost of vehicles, special equipment, modular fire-fighting systems, manual and mechanical equipment. **In a scenario of low monetary resources**, scarce or ineffective coordination among the organizations involved in wildfire suppression, the indirect estimate of variables relevant to the application of the synthetic cost method appears to be a possible approach for the approximate quantification of the costs of extinguishing at regional, national or supranational levels. It is widely demonstrated, however, how this approach may cause significant errors in the estimate of aggregate suppression costs for individual events, regions and whole countries in a defined year or time scale.

To conclude, a precise estimation of wildfire suppression costs is the necessary prerequisite to balance against one another the economic dimensions of fire prevention and suppression. For example, the total cost of suppression operations of the single large fire event of Calci (Pisa province, Italy; burned area around 1,000 ha) amounts to 1,397 euros ha^{-1} and largely exceeds the expenditure per hectare of forest land relating to measure 2.2.6 (prevention of forest fires) of the 2007-2013 Rural Development Program, corresponding to 63, 76 and 642 euros ha^{-1} respectively in Italy, in the province of Pisa and in the municipality of Calci.

It can be seen how the costs of extinguishing a single fire of large dimensions are significantly higher than the amount invested on fire prevention on all possible intervention scales (national, regional, local). In this sense, the savings deriving from more effective fire risk prevention are particularly significant for public finances. Nevertheless, it should be assumed that the benefits related to the avoided costs of the prevented fires arise only when a fire event occurs, which has normally a random distribution. This and other methodological considerations regarding the cost-benefit assessment of prevention-suppression scenarios are developed in Plana and Font (2015). A specific research comparing fuel management scenarios versus lack of management in the Mediterranean conditions (Plana 2010) shows how maintaining, increasing and optimizing the funds related to the prevention of forest fires in the rural development plans is a pertinent strategy with the reduction of the suppression costs, and cascading costs due to fire impacts on ecosystem services.

Appendix 1

This section presents the results of a statistical analysis which intends to develop a model for estimating the means involved in extinguishing a fire (distinguishing ground and air vehicles) starting from intrinsic information of each fire (duration, size, location, environmental context, and reference area, etc.). The statistical analysis was carried out on all large events (> 500 ha) recorded in Greece between 2011 and 2018. The analysis involved a phase of control and correction of the original data on an elementary scale (fire by fire) also acquiring, where possible, ancillary information from other sources, including reliable information on the web. A second phase aimed to build a matrix of relevant variables through integration with ancillary data sources. A third phase developed descriptive and inferential statistical methodologies for the analysis of the information content of this data matrix. Finally, a subsequent phase allowed for the development of interpretative models through factorial analysis and regressive models. These models developed an indirect estimate of the means in the field (land and air) based on significant and intrinsic variables for each fire, easily measurable and generally measured in any reporting operation.

A total of 5 indicators evaluating fire phenology, frequency, intensity, and severity were derived from an elaboration on elementary records of wildfires in the national archive of the Greek Firefighters, along with other 6 environmental indicators. Moreover, to provide a relevant information base for the characterization of efforts involved in the fire suppression, a total of 6 indicators, comprising both land and aerial means, were considered. The full list of considered variables is reported in Table 1.

Table 1. Definition of the involved variables.

Indicator dimension	Acronym	Description
Wildfires' profile	DOY	Day of the year with starting fire
	HOU	Hour of the day with starting fire
	SPE	Log-ratio of the area burnt (ha) and the time length of the fire (min)
	LEN	Log-time length of the fire (min)
	FIR	Log of the number of fires
Environment	URB	Urban prefecture (dummy)
	FOR	Ratio of burnt forests in total burnt land area per fire
	CRO	Ratio of burnt cropland in total burnt land area per fire
	HOR	Ratio of burnt horticulture in total burnt land area per fire
	PAS	Ratio of burnt pastures in total burnt land area per fire
	WOO	Ratio of burnt woodland in total burnt land area per fire
Fire suppression	EFF	Total number of persons and land/air means involved in fire suppression (log)
	HEL	Ratio of helicopters in total aerial means involved in fire suppression
	TAN	Ratio of tankers in total tracks involved in fire suppression
	MEN	Ratio of specialized firemen in total persons involved in fire suppression
	TRA	Log-number of land means involved in fire suppression
	AIR	Log-number of aerial means involved in fire suppression

When multiple variables have to be analyzed simultaneously, a multivariate statistical approach is a useful tool to characterize their multidimensional behavior. Therefore, to explore how variables relate to each other, a Spearman nonparametric correlation analysis has been computed for both medium and large fire (MLF) events. Figure 1 summarizes the strength of the relationships between each pair of response variables together with the significance at the 0.05 level.

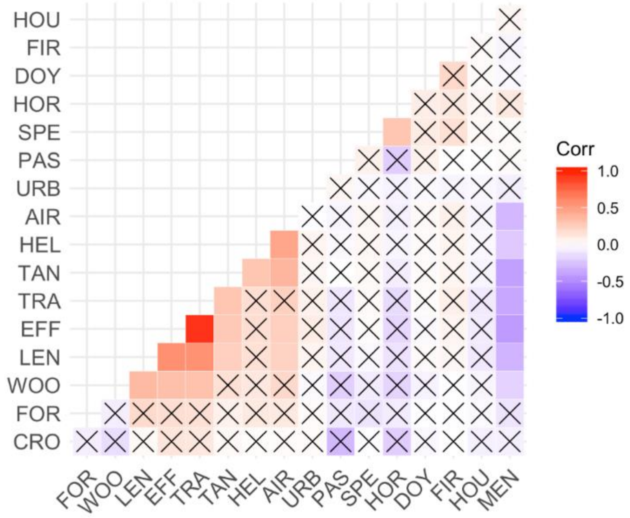
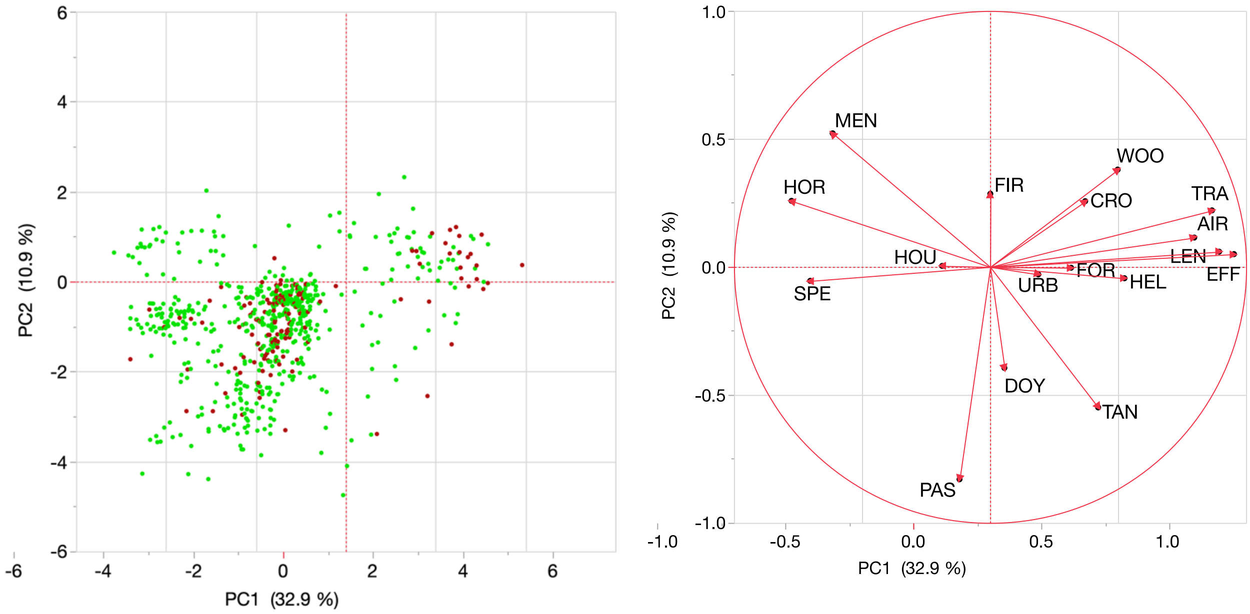


Figure 1. Nonparametric correlation matrix. The no significant coefficients are crossed out. Variable names follow Table 2.

Principal Component Analysis (PCA) was applied to the considered variables for MLFs (Figure 2). Essentially, PCA explores multiple correlations among variables and contributes to reducing redundancy, prioritizing variables likely relating to MLF regimes.



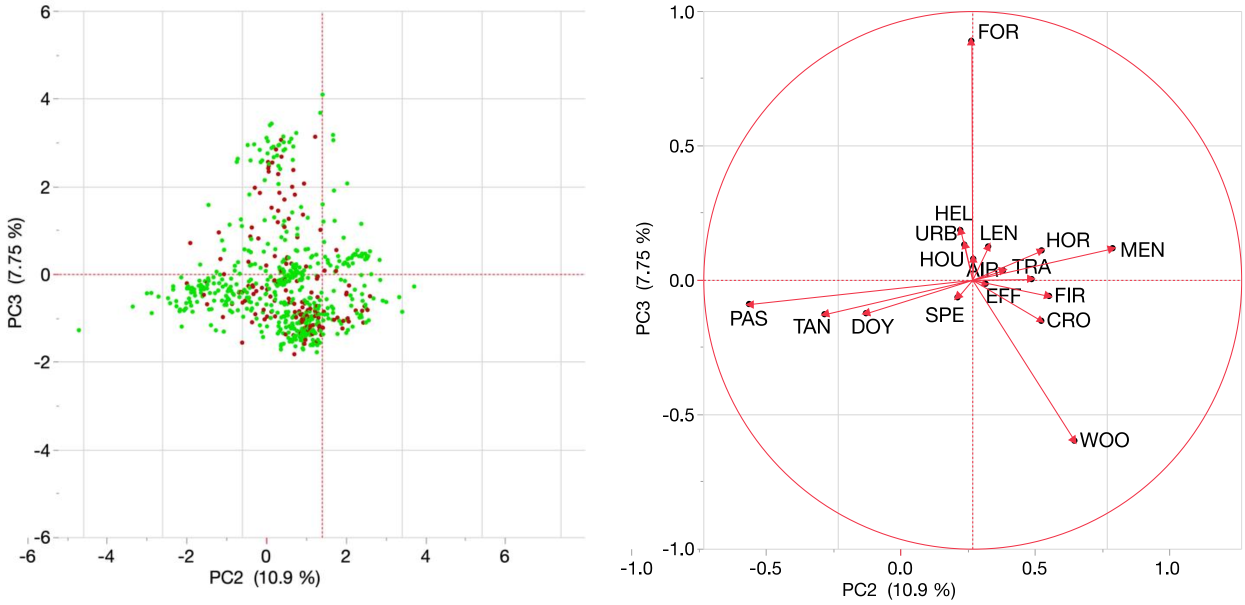


Figure 2. Principal Component Analysis eigenvalues, loading and score plots (green: medium fires; red: large fires). Variable names follow Table 2.

PCA is a useful exploratory technique to derive a restricted number of new orthogonal variables (principal components) of a set of key variables explaining as much of the variability in the original variables as possible. The PCA extracted 3 relevant axes accounting for almost 40% of the cumulated variance. PCA discriminates wildfires and suppression indicators (Component 1 and 2) from fire and wood cover indicators (Component 3). Component 1 was correlated positively with the time length of MLFs and negatively with the fire speed (Table 2). Component 2 was positively correlated with the ratio of specialized firemen in total persons involved in fire suppression and, and negatively with pastures and the ratio of tankers in total tracks involved in fire suppression; while Component 3 was mainly related to wood and forest areas.

To derive the contribution of the involved land and aerial means in fire suppression, a modelling approach has been carried out. In particular, multiple linear regression models were performed to predict the fire time length in relation to both land and aerial means involved in fire suppression (Figure 3).

Table 2. Variable's loadings by Principal Components (darker colors indicate an increasing large distance of the absolute loading value from zero).

Variable	**PC1**	**PC2**	**PC3**
URB	0.18845	-0.02950	0.13091
DOY	0.05610	-0.39481	-0.12397
HOU	-0.18689	0.00370	0.07823
SPE	-0.70219	-0.05469	-0.06493
LEN	0.89474	0.05925	0.12399
FIR	0.00125	0.28542	-0.05995
FOR	0.31651	-0.00348	0.88858
CRO	0.37166	0.25658	-0.15220
HOR	-0.77532	0.25777	0.10952
PAS	-0.11927	-0.82976	-0.09005
WOO	0.49844	0.37973	-0.59808
EFF	0.95285	0.04971	-0.01438
HEL	0.52489	-0.04450	0.18522

TAN	0.42228	-0.54908	-0.12764
MEN	-0.61460	0.52156	0.11760
TRA	0.86686	0.22048	0.00281
AIR	0.79772	0.11443	0.03544

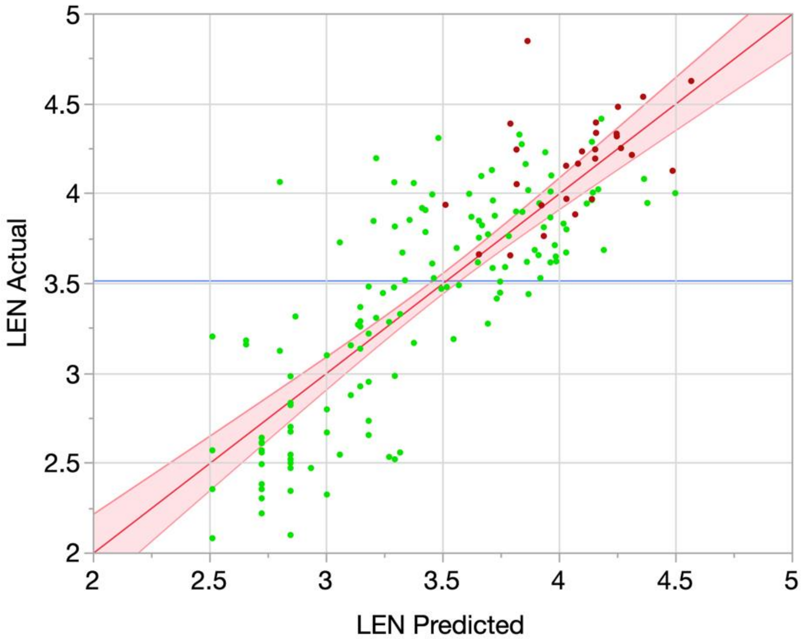


Figure 3. Actual by Predicted plot for medium (green) and large (red) fires.

Stepwise regression is a method of selecting independent variables to select a set of regressors that have the best relationship with the dependent variable through two variable selection strategies. The forward method starts with a "null" model in which no variable among the predictors is selected; in the first step, the variable with the most significant association on a statistical level is added. At each subsequent step, the variable with the highest statistically significant association among those not yet included in the model is added, and the process continues until there is no more variable with a statistically significant association with the dependent variable. The backward method begins with a model that includes all the variables and proceeds, step by step, to eliminate the variables starting from the one with the association with the least significant dependent variable on the statistical level. The stepwise process used has explored the two strategies, adding and removing the variables that, in the various adjustments of the model (with the addition or re-insertion of a variable) gain or lose in terms of significance.

From the multiple linear regression analysis, the model suggests that both land and aerial means are significant predictors for fire time length (Table 3 and Table 4), so the total amount of land and aerial means can be estimated from the time length of wildfire extinction with a confidence of 67%.

Tables 5 and 6 depict the model summary statistics together with the parameter estimates, over the 2011-2018 time period. The only significant predictor is the fire time length.

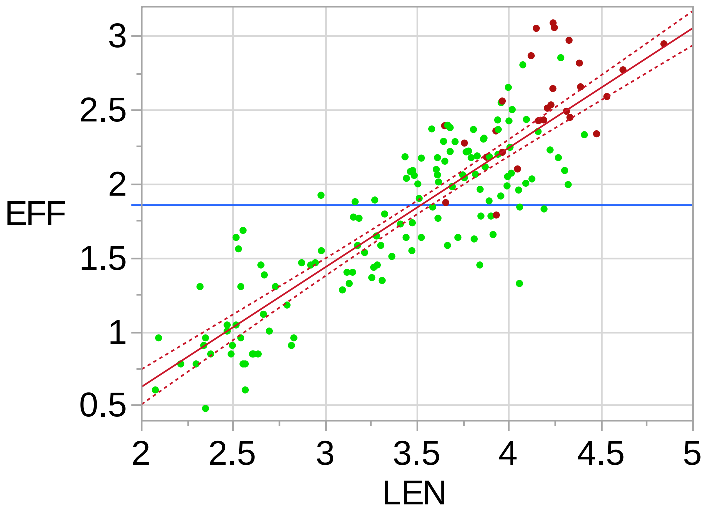


Figure 3. Regression of EFF by LEN for medium (green) and large (red) fires.

Table 3. Parameter Estimates.

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**	**VIF**
Intercept	2.51	0.07	35.66	<.0001*	.
TRA	0.70	0.07	9.90	<.0001*	1.67
AIR	0.48	0.09	5.25	<.0001*	1.67

Table 4. Model summary.

RSquare	0.67
RSquare Adj	0.67
Root Mean Square Error	0.36
PValue	<0.0001*
Observations	159

Table 5. Model summary.

RSquare	0.76
RSquare Adj	0.76
Root Mean Square Error	0.29
PValue	<0.0001*
Observations	159

Table 6. Parameter Estimates.

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	-0.988506	0.130448	-7.58	<.0001*
LEN	0.8090598	0.036507	22.16	<.0001*

References

Caohuu D.-T., Gadgil G., Jamnejad Y., McBride V., 2015. Fueling resilience. Climate and Wildfire Risk in the United States. Johns Hopkins University, School of Advanced International Studies, Energy Resources and Environment Student Practicum. Swiss Reinsurance Company Ltd, Zurich, Switzerland. 40 pp.

Ciancio O., Corona P., Marinelli M., Pettenella D. 2007. Valutazione dei Danni da incendi boschivi. Accademia Italiana di Science Forestali, Firenze.

Ellison A., Moseley C., Bixler R.P., 2015. Drivers of wildfire suppression costs. Literature review and annotated bibliography. Ecosystem Workforce Program. Working Paper 53. University of Oregon.

Mefisto (n.d.). Mediterranean Forest Fire Fighting Training Standardization. Common terminology and good practices. Forest fire multilingual glossary. English general reference; https://www.mefistoforestfires.eu/content/common-terminology-and-good-practices.

Marchi E., Fagarazzi C., Sacchelli S., Foderi C., 2017. Proposta metodologica per la valutazione dei costi di estinzione per gli incendi boschivi in Toscana. Regione Toscana, Firenze.

Moreira F., Ascoli D., Safford H., Adams M.A., Moreno J.M., Pereira J.M.C., Catry F.X., Armesto J., Bond W., González M.E., Curt T., Koutsias N., McCaw L., Price O., Pausas J.G., Rigolot E., Stephens S., Tavsanoglu C., Vallejo V.R., Van Wilgen B.W., Xanthopoulos G., Fernandes P.M., 2020. Wildfire management in Mediterranean-type regions: paradigm change needed. Environmental Research Letters, 15(1), 011001.

Plana E., Font M., 2015. Cost effective assessment of wildfire risk mitigation strategies. In Plana, E., Font, M., Green, T. (Ed.). Operational tools and guidelines for improving efficiency in wildfire risk reduction in EU landscapes. FIREfficient Project. CTFC Editions. Pp: 26-30.

Plana E. 2010. Gestione forestale e prevenzione degli incendi. Analisi economica a scala di paesaggio. Sherwood 166:11-16.

San-Miguel-Ayanz J., Durrant T., Boca R., Libertà G., Branco A., de Rigo D., Ferrari D., Maianti P., Artés Vivancos T., Costa H., Lana F., Löffler P., Nuijten D., Ahlgren A.C., Leray T., Benchikha A., Abbas M., Humer F., Baetens J., Konstantinov V., Pešut I., Petkoviček S., Papageorgiou K., Toumasis I., Pecl J., Valgepea M., Kõiv K., Ruuska R., Timovska M., Michaut P., Joannelle P., Lachmann M., TheodoridouC., Debreceni, P., Nagy D., Nugent C., Zaken A.., Fonzo M., Sciunnach R., Leisavnieks E., Jaunķiķis Z., Mitri G., Repšien S., Assali F., Alaoui H.M.H.A.R.Z.I., Botnen D., Piwnicki J., Szczygie R., Almeida R., Pereira T., Cruz M., Sbirnea R., Mara S., Eritsov A., Longauerov V., Jakša J., Enriquez E., Lopez A., Sandahl L., Reinhard M., Conedera M., Pezzatti B., Dursun K.T., Baltaci U., Moffat A., 2018. Forest fires in Europe, Middle East and North Africa 2017. Publications Office of the European Union. Luxembourg. ISBN: 978-92-79-92831-4, https://doi.org/10.2760/663443.

Simpson H., Bradstock R., Price O., 2019. A temporal framework of large wildfire suppression in practice, a qualitative descriptive study. Forests 2019, 10: 884.

Zybach B., Dubrasich M., Brenner G., Marker J., 2009. US wildfire cost-plus-loss economics project: The ‘One-Pager’ checklist (p. 20). Tucson, AZ: Wildland Fire Lessons Learned Center.