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Summary

The Tuscan Region spends about 12 million euro every year in the prevention and suppression of forest fires. In this context, this study aims to verify the economic and environmental benefits derived from the activities of the prevention and suppression of fires.
Starting from a case study of a real fire event in Tuscany, we have simulated three hypothetical scenarios (with different fire durations) without fire extinction activities planned. These hypothetical scenarios have been obtained using the open source software FARSITE, and georeferred data concerning meteorological data, territory and forest characteristics were used to run the three simulations.
A monetary approach to the quantification of avoided damage thanks to fire extinction activities has been applied. Quantification of the economic avoided damage has been calculated through the estimation of the total economic value of forest destroyed by fire. Total economic value is represented by the value of economic and environmental benefits provided by the forest (ecosystem services).
Total economic values of forest surfaces burned by real event and simulated fire have been calculated: the difference between these values represent the avoided damages (from an environmental point of view) thanks to fire extinction activities. The completely avoided damage was calculated in a second phase by considering the real estate values of buildings that the extinction activities had protected and safeguarded. The results achieved confirm how forest fire services and forest management are important from both economic and environmental points of view.

Keywords: fire damage; farsite; total economic value; fire simulation; gis

JEL codes:Q51, Q57,R14

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1. INTRODUCTION

In recent decades, changes in land use and society have led to a significant increase in the number of fires. This phenomenon has become an important socio-economic and environmental problem that requires greater attention, especially in terms of prevention (FAO, 2011).

Hilly and mountainous areas, the development of urbanized areas and viability are the mean factors of this phenomenon. Indeed, as argued by Martinez et al. (2009) the trigger point of numerous fires appears to be near the edge of roads and highways.

Despite the increase in the number of fires, the surfaces covered by fire are progressively decreasing in extent. In Italy, in fact, in the decade 1995-2005, 1,185,000 hectares (ha) of surface burned, while in the decade 2005-2015, 765,000 ha were destroyed by fire, a reduction of 35% of the surface. The reduction in the area covered by fires in recent years is above all the consequence of an improvement in firefighting organization at regional and national level. In the case of Tuscany, from 2010 to 2015 the number of forest fires indeed increased, but the wooded area covered by the fire has significantly decreased. During this period, the number of forest fires rose from 243 per year to 303, while the average area of individual events went from 1.56 ha to 0.75 ha.

In the case of significant investments in forest fire prevention and repression, which in the case of the Tuscany Region amount to almost 12 million euro a year, the extent both of the damage caused to goods and the extent of the damage avoided thanks to prevention and repression activities are still unclear. Knowing the magnitude of such effects would allow better efficiency and effectiveness of investment planning policies. There are several studies in existing literature which aim to assessing the damage caused to agroforestry areas by fires (Arca et al., 2009, Bovio et al., 2001, Di Renzo et al., 2012): these works provide a quantification of damages of fire, but do not, however, consider their relation to the cost of fire extinction activities.

To overcome this limitation, the aim of the study is to propose a methodology for defining the potential evolution of fires in the absence of anthropogenic extinction and to evaluate the avoided damages thanks to these actions. Starting from a case study taken from a real event located in Tuscany, three hypotheses of simulated fire were carried out, which not consider fire extinction activities. These simulations were implemented in a Geographical Information Systems (GIS) program, the open source software FIRESITE (Finney and Ryan, 1995, Finney and Andrews, 1999).

Avoided damages are related to forests and their ecosystem services, including benefits such as recreation and tourist functions, biodiversity conservation, timber production, carbon storage, hydrogeological conservation, and so on. These benefits represent the Total Economic Value (TEV) of the forest and take into account both private and public environmental functions. Many works in literature have quantified these functions (Marinelli and Marone, 2013, Tempesta and Marangon, 2004, Tao et al., 2012,

Bottalico et al., 2016). In this study, we have calculated the TEV of the burned surface in a real event and the TEV of destroyed surface by simulated fires: fire extinction activities are planned only in the real event, so the difference between the TEV of the real event and the TEV of simulated events represent the avoided damages thanks to fire extinction activities.

The paper is organized as follows: section 2 describes the materials and method, section 3 gives the results and section 4 presents the conclusions and final remarks.

2. MATERIAL AND METHODS

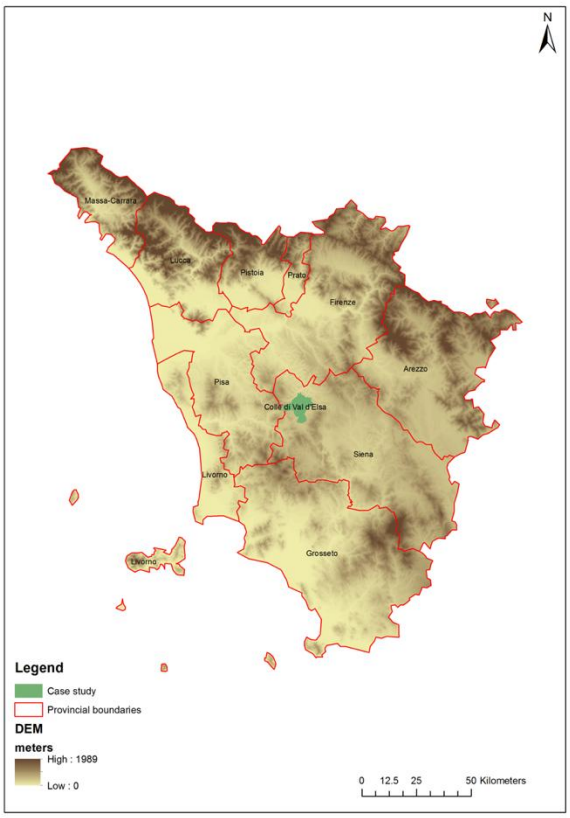
2.1 Case study

The fire examined occurred in Italy, Tuscany, in Verniano, Colle di Val d'Elsa (Siena) during the period between 11 July 11 and 3 August, 2012. The area affected was 308.12 ha. This territory is mostly hilly (66.5%), with some plains (about 8.4% of the territory) and major mountain ranges (25.1% of the region), and with annual rainfalls of around 600-700 mm.

The origin of this fire was surely malicious because of pruning residues burned in a farm near the area concerned. The deployment of intervention forces was difficult, due to adverse weather conditions that required complex intervention plans and the intervention of three Canadair firefighting aircraft for four days.

The area affected by the fire includes areas covered by mixed forests of conifers and broad-leaved trees, with a prevalence of Mediterranean pines and cypresses (domestic pine, maritime pine, Aleppo pine).

Figure 1: Case study.



The real event damage estimated is based on the perimeter detected by firefighters. For determining the costs of extinction or specific costs of the fight, reference was made to studies conducted by the Italian Academy of Forest Sciences in 2007 (Ciancio et al., 2007). In this an intermediate approach was applied, based on the detailed definition of unit costs of personnel and equipment, in relation to the National Collective Labour Contracts of the various operators involved (State Forestry Corps, National Fire Corps, etc.) and the hourly costs of the equipment that can be deduced from service contracts, Confindustria construction tables and sector bibliography, technical data sheets. The total cost of fire extinction activities was over 1,222,900 euros.

2.2 Simulations of fire

The simulations of fire were performed using FARSITE (Fire Area Simulator) software. FARSITE, developed by Finney and Ryan (1995), was integrated using a vector propagation technique for fire perimeter expansion that controls for both space and time resolution of fire growth over the landscape (Finney and Andrews, 1999). The model produces vector fire perimeters at specified time intervals; the vertices of these polygons contain information, which are interpolated to produce raster maps of fire behaviour.

The FARSITE model is inspired by the simple ellipse model (Van Wagner, 1977), fire behaviour model (Catchpole et al., 1982) and fire model evolution in relation the field conditions (Anderson, 1982, Peet, 1967).

The vector modelling approach proved to be a practical technique for incorporating separate models for surface fire, crown fire, acceleration, spotting and fuel moisture. The model integration was relatively straightforward because the one-dimensional calculations for each model apply directly to the vertices on the fire front.

The semi-empirical propagation model of Rothermel's grazing fire is based on statistical observations of the fire phenomenon under controlled conditions combined with physical considerations of the combustion event (Bovio et al., 2007). It derives from the correction of the Frandsen equation of 1971 (Sugihara et al., 2006) and is characterized by the numerator being the value of the amount of heat received from the vegetable fuel, while the denominator is the amount of heat necessary to bring the fuel to the ignition temperature (Equation 1).

$$R = \frac{I_{xig} + \int_{-\infty}^{0} \left(\frac{\partial Z_c}{\partial Z}\right)_{Z_c} dx}{\rho_{be} Q_{ig}} \qquad [1]$$

Where:
R = quasi–steady state rate of spread
I_{xig} = horizontal propagating heat flux
$\left(\frac{\partial Z_c}{\partial Z}\right)_{Z_c}$ = gradient of the vertical intensity flux
P_{be} = effective bulk density
Q_{ig} = heat of pre-ignition

The FARSITE simulation outputs illustrate the strict spatial consequences to fire behaviour of incorporating the models into a two-dimensional simulation. Simplified test conditions show that surface fire growth and intensity conform to idealized patterns. Similarities also exist between simulated crown fires and

observed patterns of extreme wind-driven fires. As argued by Finney and Andrews (1999), the model generates complex patterns of fire growth and behaviour from spatial and temporal dependencies.

The FARSITE model needs to have uniform conditions when factors affecting fire (fuels, weather, and topography) are spatially and temporally constant, although these conditions rarely exist in nature.

It is possible to divide the input raster data of the model into three macro-categories: (i) landscape data, (ii) weather files data and (iii) fuel files data.

Landscape data represent the general characteristics of territory such as digital elevation model, slope, canopy cover and fuel type.

In order to guarantee a good representation of the FARSITE model compared to the Italian context, it was necessary to define the fire growth for individual fuel types. Fuel type is a reclassification of land uses in fuel type code that indicates which land uses are more susceptible to burning than others. The 1972 Rothermel model was then modified from the Soil Corine Land Cover (CLC) 2012 level V, Version 18.5.1, defining a "matching" between CLC and Rothermel Fuel Model classes (Rothermel, 1972 and 1991).

Weather data are represented by climatic data[1] (e.g., start-end precipitation, temperature min/max, humidity min/max, etc.) and data of the event (such as ignition point, direction, speed of wind, etc). Each parameter was georeferenced using a pixel resolution of 10 metres.

Finally, fuel files data are related to characteristics of land use interested by fire such as crown bulk density, crown base height, foliar moisture content, stand height, etc.

Combing the above-mentioned data in FARSITE, three hypotheses (simulations) of were performed, without fire extinction activities.

- Simulation 0 = same duration of real event in Verniano
- Simulation 1 = 7 days more than duration of real event
- Simulation 2 = 14 days more than duration of real event

2.3 Evaluation of Total Economic Value of forest

Forest produces both private goods (timber production, no-wood products) and public utility services (recreational activities, hydrogeological function, biodiversity protection, CO2 storage, etc.). Considering fire damages, the multifunctional role of forest introduces a significant problem related to the compensation of two subjects involved: private owners for damage suffered by their incomes and public owners for damage to ecosystem services. We computed the avoided damage thanks to fire extinction activities by quantifying the ecosystem services provided by forest. These benefits represent the Total Economic Value (TEV) of the forest considering both private and public environmental functions.

Regarding the degree of damage and the intensity of the event, the proposed approach requires the definition of some initial hypotheses. First, it is hypothesized that the damage that involves the forest is total, not partial; second, moreover, it is hypothesized that the effects on private and public functions are temporary and therefore all functions can be restored after a recovery time.

[1] Available at http://www.lamma.rete.toscana.it/clima-e-energia/climatologia/report-mensili-toscana [last access June 20, 2018].

Some authors in existing literature relate damages to forest and its TEV. Di Renzo et al. (2012) underline that the determination of the damage and its compensation cannot disregard the various components that contribute to the total economic value of the forest area. Carbone (2005) defines the damage as the sum of the damages of private interest and those of public interest. Specifically, he defines the damages of private interest such as those ascribable to the forest topsoil, to the structures and infrastructures, while those of public interest are represented by damages to all those goods and resources that, following the passage of fire, have compromised their ability to provide services of public interest.

A wide literature provides a schematic classification of TEV. Pearce (2001), Silvestri (2005), and Polelli (2006) divide TEV into two macro-categories (Use Value and Non-Use Value). Moreover, they are subdivided into Direct Value, Indirect Value, Option value, Existence Value and Bequest Value categories.

For the estimation of TEV in our case study, the approach proposed by Bernetti et al. (2011), Bernetti et al. (2013) and Marinelli and Marone (2013) has been used. The authors have provided a quantification of TEV (values were calculated in euros per year) by using a territorial approach where the TEV value of all forests in Tuscany have been georeferred.

The following functions have been considered: (i) tourist-recreational function, (ii) naturalistic function, (iii) hydrological function, (iv) drinking water service, (v) timber production, (vi) carbon sequestration.

The recreational tourist function is given by the sum of recreational tourism activity, hunting activity and mushroom picking activity. The first activity was estimated by referring to Travel Cost Method (TCM) with specific logit models for naturalistic areas (Ferrini, 2002). In this case the variation of the consumer surplus was evaluated following an increase of 10% of the surface for 19 natural parks in Tuscany. Hunting evaluation was the result of a study on the willingness to pay hunters made by Marinelli and Romano (1997). The result, updated, has been correlated with the number of hunters active in Tuscany. Finally, the recreational function linked to the collection of mushrooms was calculated based on the maximum prices set by the regional regulations for collection authorizations.

The naturalistic function was estimated through a literature review on the willingness to pay (in euros per year) for the preservation of the biodiversity of the regional forest ecosystems (Randall and Stoll, 1982, Freeman, 1993, Ten Brink et al., 2000, De Groot et al., 2012, Gaodi X. et al., 2010, Pak et al., 2010).

The evaluation of service for water flow control was estimated based on the subrogation cost calculated in relation to the refurbishment works that would be necessary to guarantee the maximum flow rates in the absence of the forest. For each basin, a maximum sizing of the expansion tank system was therefore necessary to guarantee the disposal of the increase in flow due to the absence of wood and calculate the total annualized cost of the system of boxes. Finally, this subrogation cost was attributed to each "pixel" of the basins in proportion to the quantity of water governed by the presence of the forest.

The drinking water service was assessed by hypothesizing that the best alternative to groundwater is represented by the water reserves stored in the artificial basins and the consequent contribution of forest soils to the production of drinking water calculated using the water balance method. In this case, the values of water storage in the watersheds in Tuscany were defined on the basis of the studies carried out by Civita et al. (1999), Pettenella and Secco (2006) and CISPEL (2008).

The wood production function has been calculated by annualizing the capital value of the forest surplus obtained on the basis of the Faustman formula.

Finally, the climate change mitigation service was quantified through the activity of carbon stored in the trees and therefore not released into the atmosphere. This quantification is related to the average increase of the different forest species, the biomass allocation factor and carbon credits.

2.4 Evaluation of avoided damage

Quantification of the economic avoided damage thanks to fire extinction activities was analysed by using the above-mentioned TEV.

TEV was calculated both for the real event and simulations through a raster dataset where each functions examined was associated to specific burned surface (Equation 2).

$$TEV_{ik} = \sum_{j=1}^{N} F_{jk} \qquad [2]$$

Where:
TEV_{ik} = TEV of i-th event (real event (r) or simulated fire (s)) of k-th burned surface
F_{jk} = value of j-th function belonging to the k-th burned surface;
N = total number of functions examined.

The avoided damage (AD) is represented by the value of the only surfaces preserved by fire thanks to the action of extinction. For this reason, the fire growth simulation model has been activated for a duration equal to that of the real fire (recorded in the intervention sheet) in order to verify which surfaces have been saved thanks to the extinction intervention. Then, assuming that in nature the fire could last longer than the actual duration, prolonged fire durations of one and two weeks were hypothesized.

So, the avoided damage thanks to the fire extinction activities (Equation 3) is represented by the difference between the TEV of the real event (where fire extinction activities were planned) and the TEV of the simulated fire (where fire extinction activities were not planned).

$$AD_k = TEV_{rk} - TEV_{sk} \qquad [3]$$

Where:
AD_k = avoided damage of k-th burned surface
$TEVr_k$ = TEV of real event occurred in k-th burned surface (fire extinction activities planned)
$TEVs_k$ = TEV of simulated fire in k-th burned surface (fire extinction activities not planned)

3 RESULTS

3.1 Simulated fires

Figure 2 shows the results of the simulation model with different durations of fire. The 3D images highlight how the orography and the land use are heavily related to the evolution of the fire. Simulations carried out with a fire duration higher than the real one (seven days more in Hypothesis 1, 14 days more in Hypothesis 2) has showed with different shades of red, while the boundaries of the real event are drawn in white.

Figure 2a: Hypothesis of fire simulated without fire extinctions activities. Simulation 0.

Figure 3b: Hypothesis of fire simulated without fire extinctions activities. Simulation 1.

Figure 4c: Hypothesis of fire simulated without fire extinctions activities. Simulation 2.

The surfaces destroyed by fire in simulation 0 (Figure 2a) have an extension of 500 ha, and they almost match the boundaries of the real event that occurred in Verniano. An exception is represented by the

area situated in the top part of the image, which, in reality, was not covered by flames. It is evident that the real evolution of the fire was conditioned by the extinction activities. In this area, there are residential and tourist buildings that the extinction activities had protected and safeguarded. The surfaces destroyed by fire in simulation 1 (Figure 2b) have an extension of 600 ha (Figure 5a). The fire in simulation 2 (Figure 2c) covers a surface of 620 ha; this fire has destroyed a lot of agricultural land and therefore slowed down the flame front. From the examination of the images, the fire has slightly extended its perimeter in the south-west direction, while it remains unchanged in the other directions. By comparing simulations 1 and 2 is possible to note that the difference in surfaces burned is only 20 hectares: this probably due to the agricultural area that in the summer period would not have represented a sufficient source of fuel to guarantee the expansion of the fire.

3.2 Economic evaluation of the avoided damage

Considering the fire extinction activities, the TEV of areas destroyed by the fire that occurred in Verniano is equal to 51,660 euro per year. The TEV of areas affected by the three simulated fires is 66,197 euro per year (simulation 0), 70,671 euro per year (simulation 1) and 70,700 euro per year (simulation 2). In simulated events, fire extinctions activities were not planned.

By applying equation 2 to these data, the avoided annual damages were:

- Simulation 0 = 14,537 euros per year
- Simulation 1 = 19,011 euros per year
- Simulation 2 = 19,040 euros per year

It is important to consider that forests destroyed by fire need time to restore initial environmental conditions, in order to provide their functions again. This recovery time depends on many variables; in particular, it is strongly influenced by forest species and turnover of forest management (coppice or high forest).

In order to calculate total TEV of areas covered by fires, a fourth equation was applied by considering restoring time and discount rate. A discount rate is used because, as affirmed by Malagoli and Bertoldo (2007), Michieli and Michieli (2011) and Gallerani et al. (2011), it is one of the most efficient parameters used in economic estimation in order to use monetary values considering the time variable (Equation 4).

$$AAD_k = AD_k \frac{q^n - 1}{rq^n} \qquad [4]$$

Where:
AAD_k = Accumulation of avoided damage of k-th burned surface
AD_k = avoided damage of k-th burned surface
q = 1 + r
r = discount rate
n = restoring time

In a second phase, a sensitivity analysis has been conducted to assess the accumulation of TEV. The sensitivity analysis was performed considering the discount rate as variable over time and keeping all other

factors fixed at their nominal value. Another parameter used in the analysis was the turnover of forest management (restoring time).

Five restoring times were considered (20, 40, 60, 80 and 100 years). For the discount rate, as argued by Ciancio et al. (2007), Nordhaus (2007), Bottalico et al. (2016), a range between 1% and 8% was considered.

Table 1 shows the sensitivity analysis considering the avoided damage (AD) of scenario 0 (14,537 euro per year).

Table 1. Sensitivity analysis of TEV.

Restoring time	Discount rate							
	1%	2%	3%	4%	5%	6%	7%	8%
20	262,328.20	237,700.79	216,273.85	197,562.57	181,163.15	166,738.24	154,005.19	142,726.41
40	477,317.83	397,666.60	336,019.44	287,727.55	249,441.64	218,728.02	193,803.05	173,348.10
60	653,511.39	505,319.01	402,319.67	328,877.67	275,175.08	234,938.67	204,087.58	179,917.93
80	797,909.85	577,765.99	439,028.50	347,658.05	284,873.75	239,993.23	206,745.29	181,327.48
100	916,250.81	626,520.74	459,353.29	356,229.17	288,529.07	241,569.27	207,432.10	181,629.89

In the Tuscan Region, the main method of forest management is represented by coppicing, so we considered a restoration time equal to 20 years: after this period it is possible to suppose that the ecosystem services provided by the forest are completely recovered.

The dynamics of the simulation model showed that in the absence of extinction, the fire would also have involved residential buildings. Considering this, we added to avoided damages the values of buildings potentially destroyed by the fire, using data from the archive Osservatorio Immobiliare dell'Agenzia delle Entrate[2], which defines the real estate prices by province, municipality, and residential area. Unlike the values of TEV, real estate estimates have not been discounted to 20 years from the event, as it is assumed that the original condition of the buildings will be restored after one year from the event.

The avoided damages considering building values (AADb) are calculated in Equation 5 and shown in table 2.

$$AADb_k = AD_k + RE_k \qquad [5]$$

Where:
$AADb_k$ = accumulation of avoided damage considering building values of k-th burned surface
AD_k = avoided damage of k-th burned surface
RE_k = real estate value of buildings potentially destroyed of k-th burned surface

Table 2. Avoided damages.

Event	TEV	Avoided damage (AD)	Accum. of avoided damage (AAD)	Real estate values (RE)	Damage avoided build. (AADb)
	euros/year	euros/year	euros (20 years)	euros	euros

[2] http://www.agenziaentrate.gov.it/wps/content/nsilib/nsi/aree+tematiche/osservatorio+del+mercato+immobiliare+omi

Real	51,660	-	-	12,199,750	12,199,750
Scenario 0	66,197	14,537	237,701	12,199,750	12,437,451
Scenario 1	70,671	19,011	310,857	16,636,700	16,947,557
Scenario 2	70,700	19,040	311,331	16,862,200	17,173,531

4 CONCLUSIONS AND FINAL REMARKS

The Tuscan Region spends about 12 million euro every year in the prevention and suppression of forest fires. In this context, this study aims to verify the economic and environmental benefits derived from the activities of prevention and suppression of fires.

Considering the prevention and extinction activities, a monetary approach to the quantification of direct damage "avoided" on the environmental components and anthropic activities has been applied.

The fire growth simulation modelling system FARSITE created for the Tuscan context has demonstrated its effectiveness and representativeness. Using different variables (e.g., land use, meteorological conditions, type of fuel), we have defined the spatial and temporal dynamics of fire in a case study located in the province of Siena.

All data used in the work have been implemented in a Geographical Information System and have been georeferred with high level of detail, using a pixel resolution of 10 metres. This represents a strength because, as argued by Nelson and Kennedy (2009), Zandersen and Tol (2009), Bernetti et al. (2011), Baerenklau et al. (2010) and Bottalico et al. (2016), the application of georeferenced data with high resolution represents a new frontier in spatial territorial planning.

Despite the need for the Fuel Model created for the FARSITE system to be refined, the results of the study show that even the current product is able to provide useful results.

The monetary quantifications of ecosystem services represent another strength in order to analyse damages from an economic and environmental point of view.

A future improvement of this quantification is related to the accumulation of the annual TEV of forest considering a restoring time. The values related to restoring time could be differentiated by type of function and the restoring processes could following a gradual function (with our model we consider that functions are completely restored all at once at year 20).

The results show that the values of the buildings preserved by the fire are particularly relevant in the evaluation of the damages avoided.

The extinction activities were in fact characterized by a massive use of men and airplanes in the first four days to avoid their propagation towards an inhabited area. The high extinction costs of the observed fire are therefore justified by the high value of the saved private goods. Indeed, despite the high annual costs of maintenance, the activities of prevention and extinction provide economic benefits related to the defence of environmental functions: these benefits which resulted were higher than the costs incurred.

Even considering the costs of fire extinction activities (over 1.2 millions of euros), the avoided damage was still approximately 12 times greater. The results achieved have confirmed the effectiveness of the forest fire service and forest management.

Another future recommendation could be represented by an extension of the wildfires sampled and an improvement of the Fuel Model.

Unfortunately, a deficiency of the model is related to the availability of meteorological data related to specific areas. A large amount of meteorological data is necessary to develop the FARSITE model. This study is limited to a sampling analysis of the phenomena.

Furthermore, the model does not take into account the "management" choices operated by the coordinator of the extinction fire operations. This is an important parameter because the extinction time is heavily dependent on it. Future recommendations could be focus on the improvement of simulations and potential applications to support extinction activities.

Nevertheless, considering the remarks outlined above, this work offers a useful basis both for forecasting the benefits derived from forests and the progress of fire to further improve, as argued by Boncinelli (2015) and Riccioli et al. (2016), the choice of correct planning strategies based on sustainable management of natural areas.

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