Supplementary Material S1

The Footprint of Wildfires on Mediterranean Forest Ecosystem Services in Vesuvius National Park

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1. Introduction

In the following paragraphs, we describe the methods used to estimate the wildfire suppression costs and to obtain the economic valuation of ecosystem service (ES) detriments after the wildfires that occurred in the Vesuvius National Park (Southern Italy) in the summer of 2017. An appropriate methodological approach that merges forestry and ecological principles with economics methods is applied to estimate ES losses. In detail, we illustrate the methodologies applied for the estimation of the following six ES: burnt woody biomass, erosion control, habitat maintenance, pollination, carbon stocks, and ecotourism.

2. Wildfire suppression costs

From the fire suppression operations reports produced by the Carabinieri Corps (Department of Forest Protection of Campania), the number and hours of personnel (crews) and vehicles (engines, helicopters, and Canadair planes) involved in the firefighting operations were extracted. Overall, the firefighting service suppressed 149 wildfires between 2 July and 31 August 2017. The fire suppression costs (V_{FP}) were estimated as the sum of the costs of the firefighting crews (k_{FT}), and both terrestrial (k_{TV}) and aerial (k_{AV}) firefighting vehicles:

$$V_{FP} = k_{FT} + k_{TV} + k_{AV} \tag{1}$$

2.1. Estimation of firefighting ground crew costs

The firefighting crew costs (k_{FC}) were calculated according to the standard daily costs of a specialised firefighter operator. Based on the tools and categories of vehicles used for wildfire suppression (see also 2.2), two types of standard crews were considered: the first (FC-A) consisting of 3–4 deployed firefighter operators and the second (FC-B) of 2–3. The average hourly cost of a fire fighter was extracted from the

SMA Campania Prevention and Forest Fire Fighting Service Centre (http://www.smacampania.info/). Overall, 98 FC-A and 132 FC-B firefighting crews were involved in wildfire suppression operations, totalling 673 operators. The total cost of a firefighting crew (k_{FC}, in €) was estimated as follows:

$$k_{FC} = k_H \cdot n_H \cdot (n_{FC\text{-}A} + n_{FC\text{-}B}) \tag{2}$$

where k_H (€ h^{-1}) represents the average hourly cost of a fire fighter, n_H (h) corresponds to a standard workday, and $n_{FC\text{-}A}$ and $n_{FC\text{-}B}$ are the total number of workers belonging to FC-A and FC-B firefighting crews, respectively.

2.2. Estimation of firefighting terrestrial vehicle costs

The cost of terrestrial vehicles (k_{TV}) includes all the expenditures for the three categories of terrestrial vehicles. During fire suppression operations, two categories of vehicles were equipped with tankers and used directly in fire suppression, while the third category included vehicles used only for transporting personnel. Overall, 182 water tankers and 48 personnel-transport vehicles were involved in the fire suppression activities, amounting to 230 terrestrial firefighting vehicles. The unit costs of the categories of terrestrial vehicles were taken from Ciancio et al. (2007) [1]. All these costs include insurance, maintenance, and fuel. Therefore, K_{TV} (in €) was estimated as follows:

$$K_{TV} = \sum_{i=1}^{n} (k_{TVi} \cdot n_{FO} \cdot n_{HV}) \tag{3}$$

where n_{FO} indicates the number of firefighting operations, n_{HV} represents the number of hours of vehicle autonomy, and k_{TVi} is the hourly unit cost of each terrestrial vehicle *i*.

2.3. Estimation of firefighting aerial vehicle costs

The cost of aerial firefighting vehicles (k_{AV}) comprises the costs of all aircraft resources, including the helicopters and Canadairs used to attack and suppress the wildfires. The fire suppression operations involved the use of tanker aircraft that released water in front of the wildfire. All these costs include insurance and maintenance, supporting personnel, and equipment costs, but not fuel. The latter value corresponds to the aircraft-fuel market price. Therefore, the unit cost of the tanker aircraft vehicles (k_{AVi}) was estimated as follows:

$$k_{AVi} = k_{vi} + (C_{Fi} \cdot P_F) \tag{4}$$

where k_{vi} (€ h^{-1}) corresponds to the average hourly cost of aircraft vehicle *i*, C_{Fi} (L h^{-1}) represents the hourly fuel consumption of aerial vehicle *i*, and P_F is the market price of aircraft fuel. The following three categories of vehicles were used in the fire extinction operations: *a*) Canadairs, *b*) S64F helicopters, and *c*) a set of AB412, EC135, and AS350 B2-B3 helicopters. Finally, the cost of the firefighting aerial vehicles (K_{AV}) was computed as follows:

$$K_{AV} = \sum_{i=1}^{n} (k_{AVi} \cdot n_{FO} \cdot n_{HV}) \tag{5}$$

where n_{FO} indicates the number of firefighting operations, n_{HV} represents the number of autonomous vehicle hours, and k_{AVi} is the hourly unit cost of aerial vehicle *i*.

3. Provisioning Services

3.1. Wood biomass

3.1.1. Stand parameter collection

To assess the aboveground stand volume and its partitioning into wood assortments, one year after wildfire occurrence, 40 circular plots (radius = 15–20 m) were established, according to a stratified sampling method, in the burnt forest areas classified into the high and moderate–high severity categories. In each plot, the diameter at breast height (DBH ≥ 5 cm) and total height (m) of each tree were measured. Species-specific allometric equations were used to calculate the aboveground burnt standing volume of each forest type. Therefore, the estimated volume corresponds to the volume of the stems and branches with a diameter threshold of > 5 cm [2]. The aboveground standing volume was estimated exclusively for the broadleaved and coniferous forest categories.

To estimate the economic value of the wood, the following two types of wood assortments were considered: timber and chips. The timber assortment was estimated exclusively for *P. pinea* and *P. pinaster* with dbh > 20 cm and total height > 15 m, assuming it would be possible to obtain at least two basal logs with diameters > 20 cm and 2.5–3.0 m length. The value of the chip assortment was estimated for both conifers (felled trees with a DBH < 20 cm and branches > 5 cm) and broadleaved forest stands.

3.1.2. Residual value estimation

Roundwood production losses were estimated by applying the stumpage price defined by the residual value (RV) method [3–6]. The RV of the roundwood products (chips and timber) was calculated as the difference between the current market price of chips and timber assortments that could be harvested, considering all the costs associated with each assortment. This valuation defines whether the value of the wood products under consideration represent a surplus or a deficit value.

The market price data for these categories were collected from the Italian National Institute of Statistics (https://www.istat.it/en) for both the conifer (i.e., *Pinus* spp.) and broadleaf (i.e., *Quercus* spp.) wood assortments. The residual value of each wood assortment (RV_{wa}) was computed as follows:

$$RV_{wa} = \left(P_j \cdot V_j\right) - K_j \quad (6)$$

where P_j represents the market price of the wood product, V_j is the estimated aboveground volume in the logged burnt area, and K_j is the total cost of utilisation for each achievable wood assortment (j). The product in parentheses represents the gross RV before processing the standing volumes into the commercial wood assortments.

For each assortment (j), the total cost of utilisation (K_j) was calculated as the sum of the forestry crew cost (k_{FC}), the cost of felling and loading operations (k_{FP}), the cost of gathering and tree extraction operations (k_{GE}) to the log landing (any other transportation costs were excluded), the cost of chipping and loading operations (k_{CL}), and overhead costs, that is, management and administrative costs (k_{MA}), as follows:

$$K_j = k_{FC} + k_{FP} + k_{GE} + k_{CL} + k_{MA} \quad (7)$$

3.1.2.1. Felling burnt trees–crew costs

We calculated the cost of forestry crews by considering the standard daily costs of skilled forestry workers and foremen. A standard forestry crew is composed of one generic worker, two qualified workers, and one foreman. The daily costs of a standard workday (6.5 h) for each team component were taken from the "official tabulate of daily labour costs" of Campania Region (https://www.eipli.it/documenti/uploads/2018/11/CIRL-Campania_a.pdf).

Moreover, in our estimations, the daily efficiency of the felling operations was considered separately for conifers and broadleaved forest stands. This differentiation is related to the divergent stand structure between the two burnt forest categories (high mature forest and coppices, respectively). The efficiency of felling operations, in terms of daily aboveground standing volume processed, was estimated to be 30 m^3 day^{-1} in burnt broadleaved stands where the trees are smaller, and 40 m^3 day^{-1} in burnt conifer stands.

For each burnt forest category, the cost of the forest crew (k_{FC}) was computed as follows:

$$k_{FC} = k_{SFC} + \left(\eta_d \cdot V_j\right) \quad (8)$$

where k_{SFC} (€) is the cost of a standard forestry crew composed of four workers, η_d (m^3 day^{-1}) represents the daily efficiency in aboveground volume processed, and V_j is the estimated aboveground standing volume of conifers and broadleaved stands, respectively. The product in parentheses corresponds to the number of workdays needed to process the estimated standing volume.

3.1.2.2. Felling and preparation operations

This category of costs covers all the operations from tree felling to the first rough separation of branches from the trunk and the preparation of logs *in situ*. These operations were performed using two chainsaws for ¾ of the daily working time (n_h = 4.9 h). The average hourly cost of a chainsaw (k_h) is assumed to be 3,30 € h^{-1} and includes fuel, oil, and lubricants. Therefore, the cost of felling, branch separation, and log preparation (k_{FP}, €) using the two chainsaws was computed as follows:

$$k_{FP} = [(k_h \cdot n_h) \cdot n_c] \cdot \left(\eta_d \cdot V_j\right) \quad (9)$$

where n_c is the number of chainsaws used, η_d (m^3 day^{-1}) represents the daily efficiency in the aboveground volume processed, and V_j is the estimated aboveground standing volume of a specific forest category. The product in the square parentheses represents the daily costs of the two chainsaws.

3.1.2.3. Gathering and extraction operations

The gathering and extraction operations include two steps: the extraction of full-trees or roughly prepared logs, and their subsequent accumulation at the forest gate. We considered a mobile tower yarder to be the most appropriate method of supporting these operations on a range of slopes (25–50%) of the study area. The average cost of the mobile tower yarder (k_{vMTY}) per unit of aboveground volume processed was assumed to be 25 € m^{-3}. Therefore, the overall cost of the gathering and extraction operations (k_{GE}) was computed as follows:

$$k_{GE} = k_{vMTY} \cdot V_j \tag{10}$$

where V_j represents the estimated aboveground standing volume of each forest category.

3.1.2.4. Chipping and loading operations

Chipping and loading operations are performed at the forest gate (log landing) by a drum-chipper machine. The average cost of a drum-chipper per unit of tree volume processed (k_{vDC}) is approximately 0.40 € m^{-3}. The cost of the chipping and loading operations (k_{CL}) was computed as follows:

$$k_{CL} = k_{vDC} \cdot V_j \tag{11}$$

where V_j represents the estimated aboveground standing volume of the broadleaved and conifer forest categories.

3.1.2.5. Overhead costs

In the following paragraphs, we estimate the overhead costs related to the abovementioned felling and harvesting operations. All the coefficients used were based on the common calculations adopted in the region of the study area by standard forest enterprises.

3.1.2.5.1. Management costs and insurance

The management costs were calculated as a percentage of the forestry operations costs and the gross economic value of the estimated aboveground volume (P_j V_j). The cost of insurance (k_{Ins}) includes health insurance for workers and the insurance expenditure for each type of machine used in the forestry operations. This was computed as follows:

$$k_{Ins} = \left[\frac{k_{FC} + k_{FP} + k_{CL} + \left(\frac{k_{GE}}{6} \right)}{4} \right] \tag{12}$$

The costs of insurance account for a quarter of the sum of the costs of the forestry crew (k_{FC}) and the two operation groups: felling and preparation (k_{FP}) and chipping and loading (K_{CL}). The insurance cost is estimated to be one sixth of the gathering and extraction operations (k_{GE}).

All operation phases require supervision and administrative activities. Administration and supervision costs (k_{AS}) accounted for 5% of the sum of the direct costs of all forestry operations, plus the cost of insurance. This cost was computed for each wood assortment using the following equation:

$$k_{AS} = (k_{FC} + k_{FP} + K_{GE} + k_{CL} + k_{Int}) \cdot 0.05 \tag{13}$$

Interest (k_{Int}) is typically calculated as 10% of the gross economic value of the estimated standing volume ($P_j \cdot V_j$). This was computed as follows:

$$k_{Int} = \left(\frac{P_j \cdot V_j}{10} \right) \cdot \left(\frac{1}{(1 + r)^n} \right) \tag{14}$$

where the second term is the present value of an annuity in which r corresponds to an interest rate of 3% and n corresponds to the time in months (6 or 12).

In Italy, the project-maker salary/fee (k_{Pro}) accounts for 10% of the total gross profit of roundwood assortments ($P_j \cdot V_j$).

$$k_{Pro} = \left(\frac{P_j \cdot V_j}{10}\right) \tag{15}$$

Unforeseen costs account for a further 1% of the total gross profit of roundwood assortments.

$$k_{Unf} = \left(P_j \cdot V_j\right) \cdot 0.01 \tag{16}$$

4. Regulation and maintenance services

4.1. Control of soil erosion, runoff, and habitat restoration

The values for the control of soil erosion, runoff, and habitat restoration were estimated by applying the replacement cost method (RCM) [7,8]. The RCM assumes that the functions of the considered service can be provided by an alternative system; this opportunity cost represents the value of such a service. In this case, the value is computed based on the cost of replacing the ecosystem function with an artificial substitute [9]. In turn, the substitute represents the most valid alternative to replace the conservation and protection functions of forests. Recently, the RCM has received increased attention in studies that attempt to estimate the value of the regulation and maintenance of ecosystem functions, such as the regulation of water flow and hydrological regimes, soil erosion prevention, and habitat restoration [10,11].

Considering the characteristics of the forest types affected by high severity wildfires, to ensure an efficient level of restoration, an appropriate bioengineering technique was chosen to replace the forest hydrological functions and to simultaneously re-establish the forest habitat. Because of the multiple functions of the replacement option, the estimation of these two services was pooled.

The value of habitat restoration and the control of soil erosion (K_R, in €) was calculated as the product of the cost of implementation per unit surface (K_{Imp}, € ha^{-1}) and the surface area of the high severity burnt forest stands (S_{High}, ha), as follows:

$$K_R = K_{Imp} \cdot S_{High} \tag{17}$$

4.1.1. The bioengineering system

Considering the topography, geomorphology, soil, and vegetation features of the high severity burnt surfaces, the bioengineering system consisted of a combination of two operations: a) the introduction of anti-erosion log barriers and b) the planting of native tree and shrub species.

The severity of fire-induced changes in chemical and hydrological soil properties [12] and the length of time needed for soil to recover to its pre-fire functionality are dependent on the severity of the fire itself [13]. Consequently, where the fire severity was high, a stabilisation strategy was adopted to reduce soil erosion processes by means of a set of log-dams, consisting of in situ contour-felled log erosion barriers made from burnt logs laid out on the ground along the slope contour [14,15].

In Vesuvius National Park, the pre-fire conifer forest type was mainly represented by *Pinus pinea*. Moreover, *P. pinea* stands represent the largest portion of the forest areas burnt by high severity stand-replacing wildfires. Although the thick bark of adult *P. pinea* trees helps to insulate the cambium from lethal temperatures, this Mediterranean pine cannot naturally regenerate via seeds after wildfires [16]. Indeed, this species is classified as having low resilience to fire disturbances [17]. To increase landscape resilience and reduce future fire risk, the use of native broadleaved trees and shrub species, mixed with the key species *P. pinea*, was suggested for the conservation and restoration of Habitat 9540 "Mediterranean pine forests with endemic Mesogean pines". All tree and shrub species selected for planting belong to the native Mediterranean and sub-Mediterranean flora, which in turn are better adapted to cope with fire disturbance [18,19].

The costs involved in implementing the bioengineering system are represented mainly by the materials (tree and shrub seedlings) and the felling of the burnt trees. These costs were obtained from the values reported in the "official environmental engineering price list of the Campania Region" (http://www.regione.campania.it/assets/documents/drd-281-26-10-10.pdf). Therefore, the cost of implementation (K_{Imp}) per surface unit was estimated by summing the cost of each material *i* (k_{mi}) across a planted area of 1 ha, as follows:

$$K_{Imp} = \sum_{i=1}^{n} k_{m_i} \quad (18)$$

Moreover, K_{Imp} is inclusive of all overhead (operational and administrative) expenditures.

4.2. Pollination

Globally, crop pollination is one of the best-known ES provided by insects. Either directly or indirectly, a large portion of the human diet is the result of insect-mediated pollination [20].

In Vesuvius National Park, the Piennolo cherry tomato of Vesuvius is a protected designated-origin product (EU regulation NO1151/2012) and is the most profitable agricultural product in the area. Insect pollination is an essential condition for tomato reproduction [21] and wild bumble bees (*Bombus* spp.) are the main pollinators of Vesuvius cherry tomatoes, with an assumed contribution to the annual production value of 8% [22].

The value of the tomato production lost owing to the reduced wild bee pollination was estimated to be equal to the share of production that depends directly on insect pollination [23]. Following this approach, we estimated the decrease in tomato production resulting from a decrease in the population of bumble bees. Severe fires destroy nest sites, such as tussocks and underground cavities, resulting in almost complete destruction of the bumble bee population [21].

All the information collected allowed us to define the following formula for the production decrease:

$$V_P = (Y_T \cdot P_T \cdot S_T) \cdot D_I \quad (19)$$

where V_P (€) is the lost value of tomato production mediated by insect pollination, Y_T (kg ha^{-1} year^{-1}) is the mean annual production of tomatoes, P_T is the average market price, S_T (ha) is the total cultivated area (drawn from the official site of Campania Region, www.regione.campania.it/), and D_I is the insect–crop dependence factor.

4.3. Carbon stocks

Damage to carbon stocks was calculated assuming two types of values. The loss of carbon stocks was calculated in terms of the amount of carbon emissions released during the wildfire. During a wildfire, CO_2 is the most important emission in vegetation fire smoke [24,25]. For the purposes of this study, the value of CO_2 emissions was computed from the leaf biomass in the tree canopy and the litter biomass that combusted during the 2017 wildfires. In the European Emission Trading System (EU ETS), CO_2 emissions are traded as a production factor, similar to every other raw material [26].

The price range for carbon credits was determined from the average permit price in 2017 [27,28], taken from the EU ETS using the carbon price-viewer available at the official website of the Quandl Inc. (https://www.quandl.com/data/CHRIS/ICE_C1/); the average 2017 price was € 6.00/Mg CO_2 (Figure S1).

Although the value of carbon is generally measured using market prices [27,28], given the context of this work, in which estimation was carried out after the occurrence of large wildfires, another estimate for this ES was added. CO_2 emissions contribute substantially to climate change [25,26,29]. Therefore, the damage in question is incurred by the society. For this reason, we also considered the social cost of carbon, which corresponds to the costs imposed by greenhouse gas emissions, capturing the externalities of CO_2 atmospheric emissions [29,30]. When lacking site-specific information, it is possible to transfer the value of this service using the benefit transfer method, as computed in other similar studies [31]. Specifically, it was calculated from a variety of models that evaluated the influence of CO_2 emissions on the future evolution of the country's economy [32]. In the present work, the social cost of carbon emissions was stated as 20.00 € /Mg CO_2, the median social cost of carbon [33].

$$V_{CE} = P_{CO_2} \cdot \left[\left(C_{Leaf} + C_{Litter} \right) \cdot F_{C\text{-}CO_2} \right] \quad (20)$$

where P_{CO_2} is the price of CO_2 (market price or median social cost), and C_{leaf} and C_{litter} correspond to the estimated mass of the carbon content in the canopy leaves and litter, respectively. Thus, to estimate the CO_2 mass from carbon, a conversion factor ($F_{C\text{-}CO_2}$) of 3.67 was applied [10], which stoichiometrically considers the contribution of the molecular weight of oxygen [34].

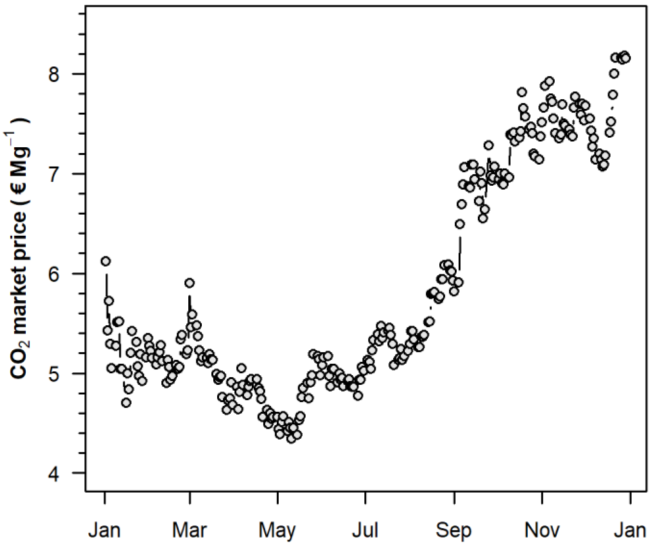

Figure S1. Trends in the CO_2 market price (€ Mg^{-1}) in 2017. Data source: the official website of the Quandl Inc. (https://www.quandl.com/data/CHRIS/ICE_C1/).

4.3.1. Carbon content of canopy leaves

CO_2 emissions were estimated exclusively for forest and shrub stands struck by high and moderate severity burns. While high burn severity completely combusted the leaves and small twigs (diameter < 3 cm) of tree crowns and shrubs, moderate severity fire resulted in a percentage of the total biomass (40–70%) effectively combusting. The coefficient of leaf biomass consumption (α_{Ltj}) was assumed according to the burn severity levels. The mass of the carbon content in the leaves was estimated using the following equation:

$$C_{leaf} = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(Lv_i \cdot \alpha_{Ltj}\right) \cdot F_{leaf} \quad (21)$$

where C_{leaf}, expressed in Mg, represents the carbon content of the leaves, n represents the number of vegetation types, m is the number of burn severity levels, and α_{Lj} is the coefficient of litter biomass consumption, which is assumed according to three burn severity levels. $Lv_{Biomass}$ (Mg) is the dry biomass of leaves estimated using species-specific allometric equations (Table S1) and a leaf carbon fraction of 0.5. The allometric equations allow the estimation of dry leaf biomass by tree size (diameter or circumference at breast height). As an allometric equation for leaf biomass has never been developed for the shrub *Genista aetnensis*, the leaf biomass was estimated using an allometric equation developed for the morphologically equivalent Mediterranean shrub species *Retama sphaerocarpa*. To estimate the quantity of carbon released into the atmosphere by each burnt forest and shrub stand, a constant carbon conversion factor of 0.5, was considered. This value corresponds to the mass fraction of carbon content in leaf tissue.

Table S1. Species-specific allometric equations for the dry biomass of leaves (L_{dB}, in kg). DbH and CbH represent the tree diameter and circumference at breast height, respectively, both expressed in cm; H represents total height expressed in m. ln is the Napierian logarithm. An allometric equation for *Retama sphaerocarpa* was applied to estimate the *G. aetnensis* leaf biomass.

Species	Equation	Source
Castanea sativa	$L_{dB} = 0.0044 \cdot DbH^2 + 0.0981 \cdot DbH - 0.156$	la Marca, 1984 [35]
Quercus ilex	$L_{dB} = 0.0041 \cdot DbH^2 + 0.5625 \cdot DbH - 4.579$	Susmel and Viola, 1975 [36]
Pinus pinea	$ln(L_{dB}) = 2.62178 \cdot ln(CbH) - 0.75075$	Rapp and Cabanettes, 1981 [37]
Genista aetnensis	$L_{dB} = (5 \cdot 10^{-4}) \cdot H^{2.5897}$	Alias et al., 2015 [38]

4.3.2. Forest and shrub floor (litter and duff)

The carbon content of the litter biomass was estimated for all burnt surfaces in which the effect of combustion led to the exposure of mineral soil. Specifically, the coefficient of litter biomass consumption (α_L) was assumed. While litter combustion was considered complete when the degree of severity was high or moderate–high, only partial litter combustion (50%) occurred when the degree of severity was low or moderate–low.

For this purpose, one year after wildfire occurrence, eight litter and duff samples were collected from representative unburnt forest and shrub stands (i.e., *P. pinea*, *C. sativa*, *Q. ilex*, and *G. aetnensis* stands) using a PVC collar with a surface area of 0.313 m^2. The litter samples were oven-dried at 65 °C for 48 h, and their dry mass weighed.

The litter and duff carbon fraction (C_{Litter}, in Mg) was calculated by multiplying the litter samples (Lt) dry mass by the coefficient of litter biomass consumption (α_{Lj}) and by the 0.5 carbon fraction in the litter (F_{litter}), as follows:

$$C_{Litter} = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(Lt_i \cdot \alpha_{Ltj} \right) \cdot F_{Litter} \quad (22)$$

where *i* represents the four vegetation physiognomies (i.e., *P. pinea*, *C. sativa*, *Q. ilex*, and *G. aetnensis*) and *j* is the corresponding burn severity.

5. Cultural services

Vesuvius National Park is a world-renowned tourist attraction. The estimation of the value of the cultural services was based on the quantification of tourist recreational value [39]. One of the principal attractions of the National Park is the "Gran Cono" tour of Vesuvius and the most recent lava flows (eruptions of 1906, 1929, and 1944) colonised by the endemic lichen *Stereocaulon vesuvianum* [40] which initiates the primary succession of vegetation. Given that the park footpaths are free, visitor statistics, available in most other protected areas, represent a knowledge gap. The value of the benefit conferred by interactions with the Mediterranean forests of the park can be represented by a marketable good: the entry ticket to the cone of Vesuvius tour, led by a specialised guide. Consequently, the touristic value is considered a direct-use value, and can be represented by tourism income, as summarised by the park entrance fees [3,41].

In the summer of 2017, during and after the fire period, roads were temporarily closed and access to the volcano cone was interrupted for several days. The estimation procedure started by calculating the annual tourism income for 2016 and 2017. The year 2016 was used as the benchmark, as no disturbances occurred in this year. Comparison between the number of visitors in 2016 and 2017 allows the likely decrease in tourists induced by the wildfire to be quantified [42–44]. A similar valuation method has been previously applied in other protected areas affected by wildfires [45,46]. The value of tourism services (K_T, in €) was estimated as follows:

$$K_T = \sum_{i=1}^{n} \Delta N_i \cdot P_{ticket} \tag{23}$$

where ΔN is the absolute difference between the total monthly number of visitors in 2016 and 2017, referring exclusively to the *ith* month (July, August, or September), while P_{ticket} is the cost of the entry ticket.

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