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HOW VINEYARDS AND WINE PRODUCTION CAN BE PROTECTED FROM FUTURE WILDFIRES IN GREECE

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Abstract: Wildfires in the wider area of southern Rethymno, Crete Island, Greece, have proven to be detrimental to the local economy in many ways, which is mainly based on agricultural and livestock activities. The fire that burned the vineyards around the town of Melampes on July 15, 2022, is such a characteristic and catastrophic fire with negative effects caused by the loss of dozens of hectares of vineyards and olive groves. At the region, we can find the vine varieties of Vidiano, Thrapsathiri, Melisaki, Plytos, Liatiko, Kotsifali, Mavromeikos cultivated in over 60 ha. In this work, we used fire simulation models to understand how and where future fires may start and threaten the vineyards and olive groves of Melampes, with what intensity they are predicted to burn, and from which areas they are most likely to propagate with high fire spread rate. Simulations can also show where measures to reduce fuel or change the composition, structure and arrangement of vegetation will be most effective to mitigate these future fire incidents. This study suggests areas where, based on the fire simulation results, by implementing fuel management or creating new fire breaks (i.e., zones with complete remove of surface and overstory vegetation), can enable the containment or reduction of the intensity and severity of burning. The main goal of this study is to protect the vineyards of Melampes from a new fire and the results to act as an auxiliary and complementary to the future drafting of the Fire Protection Plan of the prefecture of Rethymno. This paper provides a brief history of the study area and analyzes the dominant types of vegetation and surface cover, fuel types (i.e. what are the loads and arrangements of dead and living biomass on the surface available for combustion from a fire) and the expected fire behavior in each of these. A brief description of the evolution and immediate effects of the fire of July 15, 2022, is presented. Regarding materials and methods, the simulation models, inputs and assumptions made to produce the results of the analysis are described. The results are presented with maps that depict important information related to wildfires in the study area. Finally, a discussion follows highlighting the conclusions and proposals regarding the fire protection of the vineyards.

Keywords: Wildfire simulations, Fuel treatments, Crete, Agricultural production, Minimum Travel Time algorithm

INTRODUCTION

The wildfire in the prefecture of Rethymno, near the town of Melampes (Crete Island, Greece) on July 15, 2022, burned a large agricultural area dedicated for olive and grape production, which in turn are used to produced different wine varieties and extra virgin olive oil in cooperative and private facilities of the region. Apart from the direct economic losses that are obvious and measurable, the fire caused a psychological burden and disappointment to the producers and vinters of the region, which, if not reversed, can cause social problems such as the migration and exodus of young people, in addition to the halting of investments and entrepreneurship of investors. It is therefore imperative to take measures to mitigate the negative socio-economic effects the fire has caused. Even more important is to understand the historical patterns of the region's fires and to predict, as far as possible, how future fires may start and develop into large-scale incidents, threatening crops, settlements and people for one more time.

The difference of southern Rethymno in relation to other fire-affected areas of mainland Greece is that the vegetation is comprised of phryganic ecosystems and grassland instead of forests dominated by pines, and when a fire burns into the area it does not have a strong ecological impact since the species composition has inherent ability to fully recover to its previous state after three to five years. This is positive from an ecological perspective, but extremely negative and worrying for the issues of fire protection, since after a short recovery cycle, the biomass becomes abundant again and can cause a new fire, exactly like the previous (or even worse). This does not occur in coniferous or broadleaf forests, in which the vegetation returns to its previous state after 10-20 years, during which new fires have different characteristics (surface instead of crown), rate of spread (higher compared to the previous state) and moderate spread and intensity (lower than in the past).

The wider area of southern Rethymno is mountainous with steep slopes and rough terrain, which makes it difficult for fire trucks to access and operationally utilize them due to the long transition time from one area to another through narrow roads with many turns, but also the rate of spread that fires can develop there (large slopes increase the speed of fire rate of spread). The vineyards of Melampes are at altitudes between 500 - 900 m above sea level. Regarding slopes, 55% of the study area has slopes up to 12 degrees, 28% of 12-21 degrees, while steep slopes dominate at 12% (21-30 degrees) and 5% (30-45 degrees). The wider area of the vineyards has a north and northeast exposure, which gives more moisture to the area compared to the southern and southwestern exposures facing the Libyan Sea.

The types of land cover, as they were mapped from the combination of Corine 2018 and the results of the First National Forest Census of 1991 are presented in Figure 1. The wider study area has a total area of 40.000 ha. The area is dominated by the Olives with over 10.000 ha, followed by the meadows with sparse woody vegetation (mainly brushwood) with 9.500 ha and the sclerophyllous vegetation which covers 5.000 ha. In total, the vineyards extend to an area of 400 ha, of which 62 ha are in Melampes. The most characteristic fuel types of the study area are presented in Figure 2.

In Crete, grape phylloxera (Ph. *vastatrix* or *vitifolia*) appeared during the 1920's since there was no extensive viticulture and all vineyards were planted in sandy soils. However, when Phylloxera arrived, the Greek state reacted quickly by calling on producers to replant with new tolerant varieties, subsidized at the time, to eradicate the insect. In Heraklion, where there were more intensive cultivations, and historically, it was mentioned that during the Venetian era, there was intense commercial activity both in the transport of grapes, grape "must" and wine from the ports, and large-scale replanting was observed during the period. There, the soils are clay and limestone, so the native varieties such as Sultanina, Tachtas, Kotsifali and Liatiko disappeared. In Rethymno, as the cultivation of vines was mainly intended for domestic consumption and not commercial, the growers did not pay much attention to replanting, as the soils are intensely sandy and the insect cannot survive there. Today, therefore, Rethymno, along with some areas of Sitia, are the only areas in Crete, and of the few in Greece, where pre-phylloxera vineyards are found.

Specifically, in southern Rethymno, in Melampes, in 1979, 70 ha of self-rooted vineyards were recorded. Unfortunately, today, after the successive fires (14 in total during 1964-2022), only half of them remain. In Fourfouras (Amari), a village at the foot of the mount range Psiloritis, about 10 ha exists, but there is also a strong abandonment of the land, mainly due to overgrazing. Scattered autonomous vineyards can be found in other villages. In an old, preserved vineyard we can find the varieties Vidiano, Thrapsathiri, Melisaki, Plytos, Liatiko, Kotsifali, Mavromeikos and some table varieties and the quota depends on the region. In Melampes and neighboring villages, there are 40 winery partners (growers).

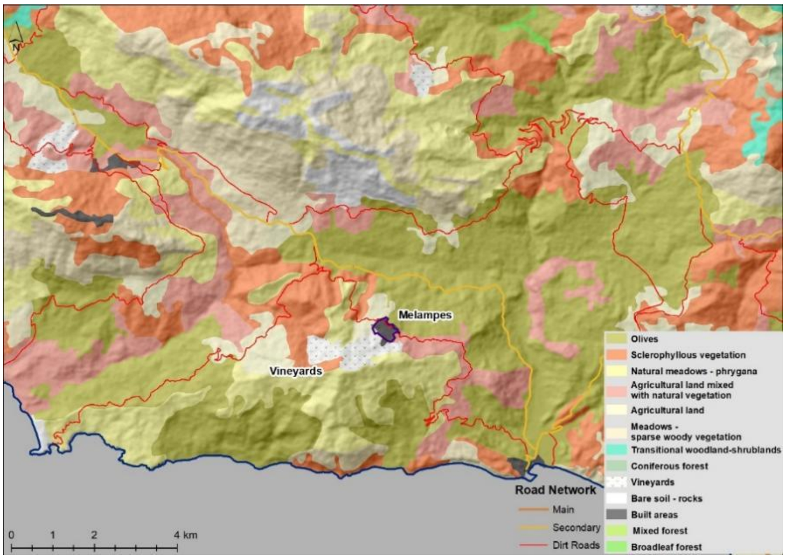

Figure 1. Types of land cover according to Corine 2018 and the First National Forest Census of 1991

In southern Rethymno, the "Iliana Malihin winery" is the only one, and in the entire Prefecture, only six established and certified wineries exist, while in Crete there are 36 in total (more than 40 if we count the uncertified). According to the Greek Statistics Agency, in 2022 the total production of grapes was about 708 thousand tons and in 2023 608 thousand tons, and we know that after 2023 the production has decreased sharply due to climatic conditions, hence the strong price increases in grapes. The vineyards at the neighboring to Melampes village of Saktouria were intensively affected by the 2022 fire, all consumed. In Melampes we know that during the 80s, at the peak of production, about 500 t of grapes were produced. Today, after the fire and the difficult climatic conditions, they harvest an average of around 2000 kg/ha from the old vineyards.

In Southern Rethymno intense drought prevails, and strong winds at sensitive stages of plant development can heavily affect production. The disease of powdery mildew, currently found in the area, is treated with wetting sulfur or dust. In 2023 there was mild powdery mildew effect, but due to the dry winds it only affected the leaves without substantial reduction of production. The State agricultural policy is not very supportive of the vineyard growers without providing substantial help, deterring young people from working in vineyards. Phylloxera is speculated to still exist, which is why it is mandatory to plant resistant plants. Now the variety "Vidiano" is basically planted due to its popularity but there the varieties Thrapsathiri, Melisaki, Plytos, Liatiko, Kotsifali, Mavromeikos are cultivated. The "Iliana Malihin winery" produce the single-varietal wine Vidiano, another wine with Thrapsathiri, and a third blend wine, i.e. co-vinification of all the varieties.

The fire that burned the vineyards and threatened Melampes started at 10:48 on July 15, 2022. On that day, the official fire danger risk index issued by the General Secretariat for Civil Protection ranked the whole island of Crete in a danger class of 4, i.e. Very High. The duration of the active burning of the fire (i.e., until the final demarcation of the perimeter at its maximum spread) was about a day and a half, i.e. until late afternoon of July 16, 2022. Despite the final demarcation of the perimeter, the fire remained under partial control resulting in flare-ups in the wider area until July 17, 2022, while the final burning in the vineyards of Melampes happened on July 18, 2022.

From information received from nearby weather stations, the dominant direction of wind was the north, while there were periods when the winds turned to northeast and northwest, mostly during the night. The winds were blowing with gusts of up to 85 km/h (9 Beaufort), while at the time of its ignition they ranged between 6 and 8 Beaufort (45-60 km/h). The average wind speed ranged between 12-28 km/h (3-4 Beaufort). The effect of these strong winds, which blew from the aforementioned directions, drove the fire with momentum to the south, reaching as far as the Libyan Sea, overcoming the mountain range above Melampes, burning a total of 2.000 ha according to the official record of the Fire Service (Figure 3).

Figure 2. Characteristic quantity and arrangement of live and dead fuel in fuel model (Scott and Burgan, 2005) GS1 (top-left), GS2 (top-right), SH5 (bottom-left) and GR1 (bottom-right)

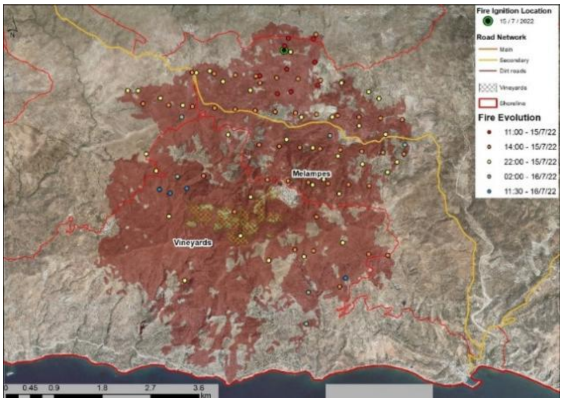

Figure 3. Burned area and evolution of the fire that broke out on the morning of July 15, 2022. The fire burned 2.000 ha and started near a provincial road west of the settlement of Orne

To extinguish the fire, the Hellenic Fire Service used direct methods of suppression, i.e. with extensive use of water both by ground firefighting equipment and with the use of helicopters since due to the strong winds, the firefighting planes were unable to operate in the area. On July 15, 2015, an all-night battle was given, but the fire could not be controlled and continued its southward course the next day. The situation became very difficult because the stormy winds were constantly changing directions, such as at midnight on July 15th where the wind turned from the northwest direction to the northeast. During the first day, 110 firefighters, 33 vehicles and four helicopters participated in the firefighting operation. In total, according to the official data of the Fire Service, 186 firefighters, 44 ground personnel, 10 Army personnel and 36 others (volunteers and residents) participated in the operations. According to the official data of the Fire Service, the burned forested areas amount to 336 ha, the grassland - phrygana areas to 532 ha and the agricultural and livestock areas to 1.118 ha. Satellite image analysis calculated that of the about 2.000 ha affected, olive groves account for 38.5%, natural pastures for 26.7%, sclerophyllous vegetation for 15.6%, agricultural land (crops) for 12.7%, vineyards for 4.9%, and areas with sparse vegetation 1.2%. Using the cadastre data, forest areas make up 16.5%, grassland 7.5% and non-forest areas 76% of the burned area. Finally, of all vineyards in the west Melampes (62 ha), 18% remained unburned and unaffected, i.e. 11 ha (Figure 4).

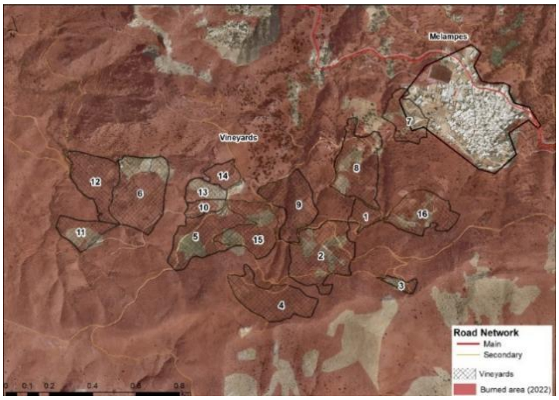

Figure 4. The main vineyards in Melampes and the footprint of the fire of July 15, 2022 (brick color). The areas within the vineyards that were not affected by the fire and amount to 11 ha are distinguished with light brown color

MATERIAL AND METHODS

For fire behaviour simulations, it is necessary to use data and information describing topography, weather conditions, fuel moisture content and vegetation status. The parameters that are most difficult to model and map concern vegetation and especially the properties of the fuel. Modeling is a complex and time-consuming process that requires a detailed classification through measurements of the various physicochemical properties that characterize it in the field, followed by its quantification through the application of methods and working hypotheses (Keane et al., 2001). As mentioned above, fuel models (FM) mainly provide information about the fuel load in each diameter class, i.e. how "thick" the dead branches are in each area, the dead fuel, but they are also directly related to the percentage of moisture content of each fuel size class.

For forest canopy height, ETH Global Canopy Height, 2020 edition data were used (Lang et al., 2022). Crown cover was derived from Copernicus' Tree Cover Density at a spatial resolution of 10 m and reference year 2018. For canopy base height, we used data from field inventories and local/specific knowledge to assign species-specific fixed values for canopy base height depending on the vegetation species. For the canopy bulk density, we used mapping tables (Table 2 in Keane et al. 2001) that described the available canopy fuel in kilograms per cubic meter for three canopy cover classes (Low: 21-50%; Medium: 51-80%; High 81-100%).

Since the available biomass that can be consumed from a fire in the study area is mainly surface and the trees there came from plantation of orchard trees or are individuals in a sparse arrangement, the fires simulated are in their vast majority surface and the crown data contributed only minimally to the spread and intensity of the fires since there are not dense forest stands there.

The FlamMap software (Finney, 2002, 2006) was designed to extend the application of established fire behavior simulation models at the field level (landscape). All equations and models of calculating fire behavior assume that fuel moisture, wind speed, and direction are constant over time. FlamMap is designed to investigate the spatial variation of fire behavior with calculations performed autonomously for each cell of a gridded. FlamMap requires spatial inputs from GIS for both topography and for the distribution and quantity of fuel in the landscape, which are either required or optional and are coalesced into the software to create a new Landscape file (LCP).

Conducting fire behavior simulations with the MTT algorithm of the FlamMap software offers several advantages. The spread of fire is calculated based on the equation of Rothermel (1972), while the start and spread of the headfires relies on the work of the Van Wagner (1977), combined with Huygens' rule. The MTT algorithm is suitable in cases of parallel data processing and multi-processing analysis, having the advantage that it generates combustion probabilities of the entire analysis area by simulating thousands of possible new outbreaks. This probability is an estimate that a cell will burn from some random ignition among the thousands of ignitions simulated. MTT is looking for the fastest path of fire spread along straight cross-sections, connected by knots (Finney, 2002). The result is the production of a Burn Probability (BP) map that shows which areas are most vulnerable and prone to burn from one or more fire incidents, as well as which are more "fire-proof". The BP for each cell is an estimate of the probability that this cell will burn from an accidental ignition within the analysis area and with combustion conditions similar to those of historical wildfires in the region. The map values have a BP range from 0 (unburned) to 1 (maximum probability of burning). The Conditional Flame Length (CFL) is the weighted probability of the flame length, considering that the start and behavior of the fire acts as a measure of assessing the risk it causes (Ager et al., 2010).

High probability values are linked to the size of fires that will occur within an area, which means that under the same circumstances, larger fires produce higher burn probability than small fires (each burning a larger part of the area). The MTT does not include the assessment of the absolute risk of future fire occurrence, but it does provide a quantitative framework for the analysis of potential losses from specific fire incidents, while at the same time it is a method for quantifying the effectiveness of fuel management scenarios in the field, calculating the possible spread, intensity and impact of the fire.

The calculations of the Treatment Optimization Model (TOM) are based on the calculations of the Minimum Travel Time (MTT) algorithm to identify the dominant transmission flows of a fire and aims to effectively block them by applying fuel management methods organized in projects with the appropriate dimensions (Finney, 2007). Aiming to assess the impact of prevailing weather conditions, specific areas are sought for the implementation of fuel management projects that will reduce the growth rates of a fire as much as possible for the given intensity of application and extent of the projects (i.e., which methods will be applied and to what extent). The TOM requires an ideal landscape that should describe the proposed implementation of fuel management projects, both surface and crown, in each pixel of the landscape to which management may be applied, and not only in the pixels where they are planned or feasible (e.g. legal constraints) to be implemented. TOM compares the rate of spread (ROS) between the existing and the ideal landscape. The results are rendered in a spatial raster file where each pixel receives values of +1, 0, and -1. The positive sign reflects the areas where the TOM calculated that the rate of spread of the fire decreased after the implementation of the management, the zero those pixels without difference, and the negative sign the areas where the rate of spread of the fire increased after the management.

Initially, it was necessary to determine which wind directions are most often in the area during the months of June, July and August where we have the greatest risk of new fire incidents (all the large fires that affected the vineyards of the area occurred during these three months). Daily data on the prevailing wind direction were collected from nearby weather stations to obtain the frequency of each direction. Almost 40% of all winds blow from the northwest (NW and NNW), followed by the north (N, NNE, NNW) with 27%, the northeast directions with 24% (NE and ENE) and the south directions with 6% (S, SSE, SE, SSW and SW). The humidity conditions defined are very dry for all fuel models (1hr: 3%, 10hr: 4%, 100hr: 5%, LH: 30%, LW: 60%), the wind speed was set at 60 km/h at 10 m above ground with activation of the Wind Ninja model which models the spatial variations in wind speed and direction caused by topography and vegetation, but also the effect of the local winds in the area. The foliage moisture of the crown was set to 100% (120% is an appropriate value for average mid-summer conditions and 100% value for drought conditions), activating Finney's (2004) method with a probability of spotting at 10%. The effect of ground and aerial forest firefighting on any part of the fire perimeter was not simulated. A total of four simulations were carried out with the same parameters, with the only difference being the front fireline (one north, one northwest, one northeast and one south), setting 335°, 300°, 35° and 180° respectively as the dominant wind direction.

The aim was to assess how fires that can start from different areas in the landscape driven by the wind can affect the vineyards in Melampes, but also where there are opportunities to stop the dominant flows of their spread before they reach the vineyards. We point out that the types of vegetation affected by the 2022 fire have the potential to regenerate rapidly and return to their pre-fire state (structure, composition and biomass loads) between 1-3 years after the fire (with some exceptions such as dense shrubs that require about five years). In southern Rethymno new fires within the burned area after three years will have a behavior (intensity and speed of spread) at least 75% of what happened three years ago - so burning an area does not make it fire-protected and inflammable.

A simulation was carried out with TOM with the fuel conditions prevailing before the 2022 fire. The targeted changes we foresee to be applied should be implemented in all brushlands with fuel models that contain annual vegetation with brushwood (GS1 and GS2) or dense and continuous grassland (GR2 and GR4) converted to low and sparse grassland (GR1).

RESULTS AND DISCUSSION

Stochastic fire simulations with the MTT algorithm showed that about 620 possible fires from a set of 100.000 simulations for the domain of Western Crete can reach Melampes and burn the vineyards, again. Most (580 cases) started within a radius of 5 km from the vineyards, while a few cases burned a very large area, most started even 11 km east of them. This finding, combined with the knowledge we have about the historical fires of the area, demonstrates the spatial mismatch at the level of risk perception and prevention. It is not right to think locally, and it must be understood that the risk can come to the vineyards from fire incidents that are far from the management and prevention capabilities that a community, like Melampes, can implement on its own. Simply put, the future fire that can burn the vineyards again will come from other villages and parts of Rethymno and this requires wider adoption of prevention measures. However, we should not overlook the fact that many of the fires, and those that cause the greatest exposure of vineyards, started near them.

Figure 5 (Left) illustrates the probability of burning, i.e. which locations are most likely to burn a future fire. If, for example, 100 fires are simulated and 10 of them pass and burn from a specific point in the landscape, then this means that the specific cell has a 10% chance of burning. We see that 13 of the 15 vineyards have a high probability of burning (except for 11 and 7), i.e. they are in a high-risk area through which many fires pass and start from many different locations. We note here that the simulations are extended to multiple fire seasons so that we can estimate the effect of different meteorological scenarios and starting points.

Figure 5 (Right) shows the estimated fire intensity expressed in meters (flame length), i.e. how far (not high) the flames reach from the surface. We find that the entire area to the north and northeast of the vineyards has very high flame lengths, exceeding 3 m, which makes it prohibitive to use personnel and earthmoving machinery for a direct attack on the fire front. It is positive that within the vineyards the flame length is low, and this allows vehicles and ground personnel with fast moving firefighting vehicles to easily suppress the flames if there is sufficient water. If an automatic fire extinguishing system with sprinklers is installed in the area, the results show that it will be sufficient and able to suppress possible future fires (something that would not be possible if the flame lengths were higher). In conclusion, the vineyards of Melampes are at risk of frequent fires which, however, will not burn with great intensity, something that was also recorded by the fire of 2022 when after a few months the vines managed to regrow from the vines without requiring new plantings in most of the vineyards. This would not have happened if the intensity of the fire had been greater and it burned longer inside them.

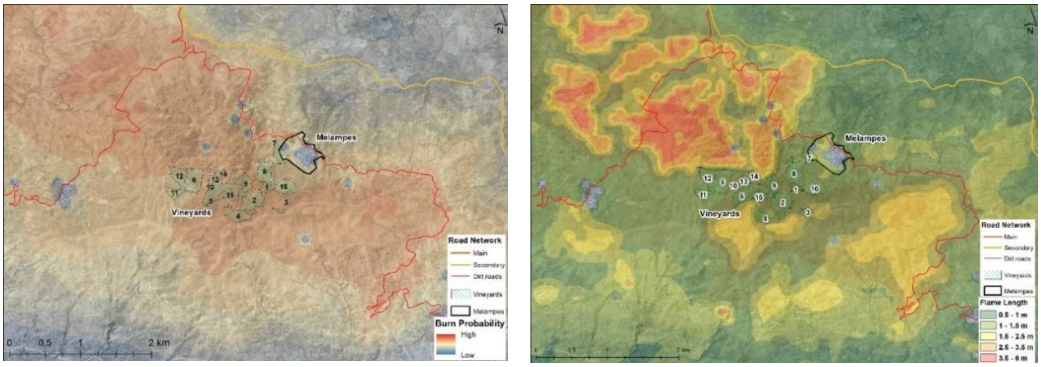

Figure 5. Chances of burning from a large number of simulated fires, with warmer colors indicating a greater probability of exposure by possible future fires (left). Estimated burning intensity (flame length), with warmer colors indicating greater burning intensity from possible future fires (right)

Simulation results of fire spread under extreme conditions show where the major spread flow paths will move faster in the landscape. If it is possible to contain them, then there is a high chance that the fire will not reach the vineyards. Initially, we looked to find at which locations, mainly across the road network, new fire breaks or reduced fuel zones can be opened or widened. These locations intersect the dominant fire flow paths. It is emphasized that a fire break cannot stop a fire on its own and active suppression using water or hand tools from firefighting crews are required to achieve suppression. Figure 6 shows the simulations from four different wind-driven fronts. The proposed fire breaks around the area of Melampes and its vineyards can be seen in bright blue color, in places with a high probability of stopping the dominant flows, placed as a priority across the existing road network. Figure 6 (upper left) shows a potential fire that spreads from a front that started north of the vineyards under the influence of a north wind. It is proposed to construct five new fire breaks with a total length of 2.2 km, two to the north of the vineyards and three to their west-northwest.

Figure 6 (upper right) shows a potential fire that spreads from a northeast front under the influence of a northeast wind. It is proposed to construct four new fire breaks with a total length of 2 km, one to the northeast of the settlement of Melampes, two which will be connected to the settlement of Melampes by extending the zone of fuel removal (the settlement is naturally inflammable or low flammable), and another one in a NNE to SSW direction intersecting the vineyards. Figure 6 (lower left) shows a potential fire that spreads from a northwest front under the influence of a northwest wind. It is proposed to build four new fire breaks with a total length of 1.3 kilometers, the largest of which will be on the provincial road, two smaller that will extend outside the road network and another one to the west of the vineyards. Finally, Figure 6 (lower right) shows a potential fire that spreads from a southern front under the influence of a south wind. It is proposed to build six new fire breaks with a total length of 1.6 kilometers. One fire zone will be on the saddle between the peaks of Vouvala and Santali, one between southern vineyards, and additional four south of vineyards.

Figure 7 illustrates the extent to which FlamMap's Treatment Optimization Model indicated that it can significantly contribute to reducing the rate of spread of a potential fire if fuel reduction and removal techniques are applied at the center of the study area (pink color). Vineyards have different color gradations, with the warmest colors attributed to vineyards that were estimated to have the greatest exposure to possible future fire incidents (a result of stochastic fire simulations). In total, it is proposed to open or widen new or existing fire breaks with a total length of 7.2 km, and to manage an area of 88.5 ha (pink color). In addition, it is proposed to open a 15-meter deforestation zone with absolute removal of fuel around all the vineyard polygons, the area of which reaches 16.8 ha.

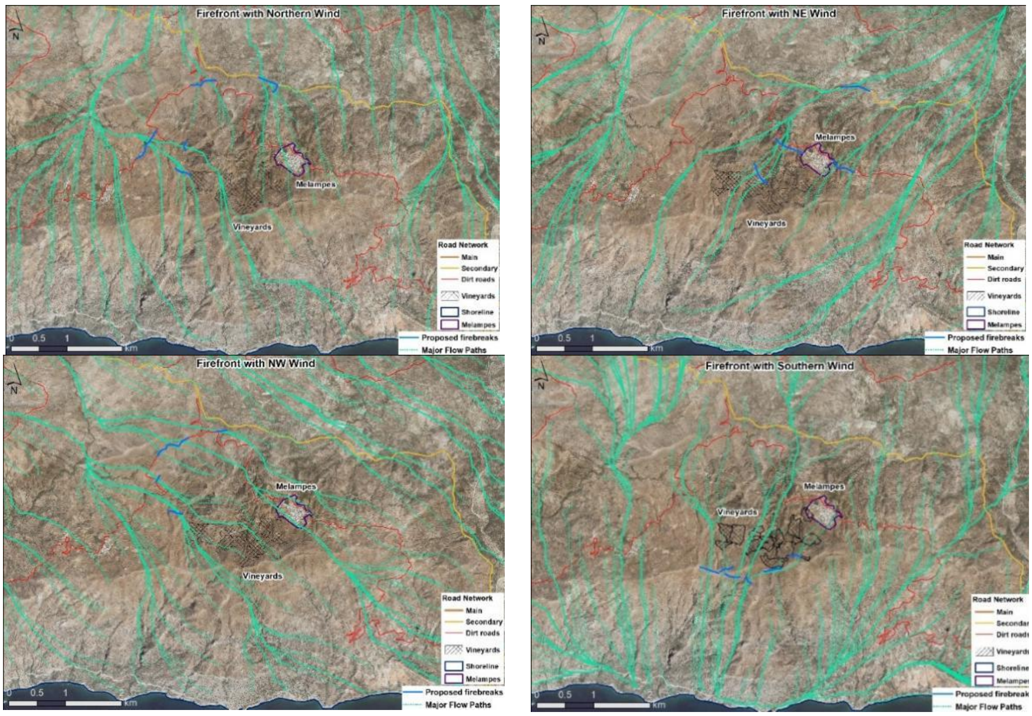

Figure 6. Dominant transmission flow paths (cyan) of a fire that will start from a northern front (top-left), northeast front (top-right), northwest front (bottom-left) and southern front (bottom-right)

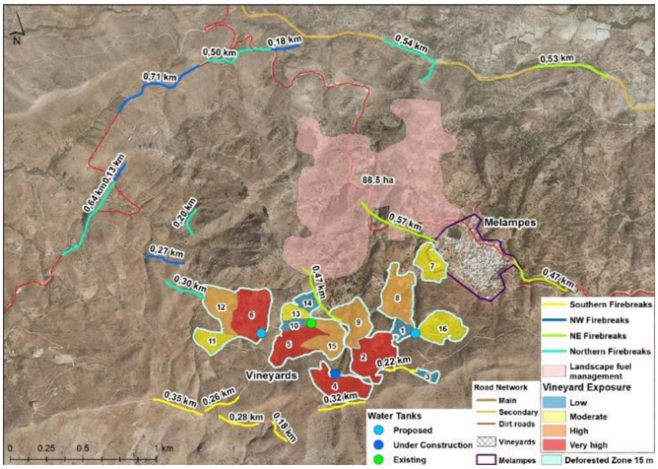

Figure 7. Representation of the proposed fire breaks and fuel removal areas around the vineyards of Melampes. The locations of the two under-construction water tanks are shown in blue, green is an existing one, and cyan are the two proposed

Proposed Measures and Costing

Supply and installation of two plastic water tanks with 25.000 l capacity

Vertical type tank, cylindrical with lid, capacity 25.000 liters, black color, base diameter 3.70 m. The tanks will be made of linear polyethylene resin and will contain antioxidants and UV stabilizers for solar radiation. The material will meet the relevant conditions of the European Union regulations EC 1935/2004 and EU 10/2011. Each tank will have valves for the inlet and exit of water, for drainage, and for overflow. The unit price includes the supply and transport of the water tanks on site and their installation (landscaping, concrete base if required), the valves, spherical isolation switch as well as the connecting micromaterials. Price per unit: 5.000 euros; Total 10.000 euros.

Supply of 4X4 pickup fire trucks with integrated 600 l autonomous pumping system

Supply of a 4X4 vehicle with a removable fire superstructure for the needs of forest protection, prevention and extinguishing of forest fires. The price includes the supply of the fully equipped vehicle, transportation, registration process and other expenses. Price per unit: 55.000 euros.

Fuel removal and pruning in oak forests or olive groves

For the pruning of trees up to 2.5 m from the ground, the removal of the understory, the cleaning of the surface vegetation and the transport of residues by a rented vehicle, the costs are the following:

a) Cleaning of understory and surface biomass; Skilled worker per 0.1 ha: €16.85 X 4 hours = €67.36
b) Pruning; Logger per 0.1 ha: €21.11 X 2 hours = €42.21

c) Transport of residues - Stacking; Skilled worker per 0.1 ha: €16.85 X 1 hours = €16.84
d) Transport of cleaning residues; Dump truck of 6-ton load per 0.1 ha: €414.8 X 0.2 hours = €82.96
Price per 0.1 ha: €209.37 X 88.5 ha = €185.292

Fire breaks and construction of reduced fuel zones around the vineyards

In total, it was proposed to open new fire breaks of 7.2 km which, in order to be effective, must be at least 50 m wide (although the 2020 fire management plan specifications provided for this type of vegetation, i.e. brushwood and shrubland, require to be 15 m wide at 70% slopes). Therefore, the total area of fire zones can reach up to 36 ha. To this area, 16.8 ha of reduced fuel zones around the vineyards will be added, i.e. a total of 52.8 ha of fuel removal. For cleaning in broadleaf or brushwood evergreen shrubs and the transport of cleaning residues with a rented vehicle, the costs are the following:

a) Vegetation clearing; Skilled worker per 0.1 ha: €16.85 X 6 hours = €101.06
b) Transport of residues - Stacking; Skilled worker per 0.1 ha: €16.85 X 2 hours = €33.68
c) Transport of cleaning materials; Dump truck of 6-ton load: €414.82 X 0.3 hours = €124.45
Price per 0.1 ha: €259.18 X 52.8 ha = €136.847

CONCLUSION

In summary, this study highlights the need to take the following measures for the protection of the vineyards of Melampes. First, we suggested the creation of new fire breaks 7.2 km long, 50 m wide and with a total area of 36 ha. Second, the creation of fuel reduction zones with complete removal of biomass at a width of 15 m around the vineyard polygons, with a total area of 16.8 ha. Third, the cleaning of the understory and pruning in oak forests and olive groves with a total area of 88.5 ha. Fourth, the supply of two new water tanks of 25 t each and installation near vineyards. Finally, the supply of a 4X4 pickup fire truck with built-in autonomous pumping system and 600 l water capacity.

Figure 8 shows an example of new vineyard plantations in a former forested area dominated by conifers and eucalyptus trees, in northern Portugal in the wider Douro Valley (near Porto). This area burned a decade ago and land was granted to vine farmers so that instead of an extensive deforestation zone without vegetation, new vineyards can be planted there with a goal of having a maintained zone with no dead fuel that will be under the constant care of the farmers, thus, making this zone act as a natural defense zone against possible new future fire incidents. The vineyards of Melampes can perform this role (i.e. the containment of future fires) if enough area can be allocated around them, enabling their expansion, but also to create a zone of complete biomass removal with 15 m width.

Figure 8. Use of vineyards as a reduced fuel zone within a burned area, instead of a deforested fire break in Valo do Douro in Porto (Portugal)

It is easy to understand that the biggest problem with the implementation of the proposed measures is the ownership of the proposed lands to receive fire management measures. This does not mean, of course, expropriations or any change in ownership. The opening of these zones will protect the vineyards, the olive groves and the settlement of Melampes. In addition, it will protect the properties that will accept the implementation of these fire protection measures. The protection and economic development of the region is in everyone's interest. Many of the proposed areas may be either abandoned (e.g. the owners have emigrated), or Municipal / Community / State, or classified as Forested by the Greek Land Registry. These forested areas must be found and prioritized for fuel management and fire protection actions, since there will be fewer social tensions there. We emphasize that the proposed fire protection measures that include the removal of biomass are not permanent since any measure implemented will have a specific life span, between 3-5 years, after which the vegetation will return to its previous state. This requires maintenance of the new fire breaks whenever necessary to maintain their ability to contain future fires. The two new water tanks will fill a gap in firefighting ability for the eastern and western vineyards and can be used both for irrigation (it was proposed to place them at a higher altitude to facilitate the easy natural flow of water), but also for the case of vehicle refueling or even, for the supply of water to automated spraying systems for extinguishing fires if they are installed in the area. Finally, the supply of a new ready-to-act fire truck (i.e. small, flexible and with the ability to carry up to 0.6 t of water) can help with the timely response and suppression of small fire incidents. The vehicle's suppression capabilities will be maximized by utilizing the three new plus one existing water tanks.

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