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ECONOMIC EVALUATION OF FUEL TREATMENT EFFECTIVNESS. AGENT-BASED MODEL SIMULATION OF FIRE SPREADS DYNAMICS.

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ECONOMIC EVALUATION OF FUEL TREATMENT EFFECTIVNESS. AGENT-BASED MODEL SIMULATION OF FIRE SPREADS DYNAMICS.

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ABSTRACT

The paper assess the effectiveness of a fuel management treatment by modeling the main fire regime drivers through a spatially explicit fire disturbance agent-based model. It covers the interplay between spatial heterogeneity and neighboring interaction among the factors that drive fuel spread dynamics. Finally, it argues that fire prevention policy address growing fire risk exposure at a regional level.

1. INTRODUCTION

Every year thousands of hectares of forest and shrub lands are burned by wildfires, causing major ecological and socio-economic impacts, and often-human casualties (A. Shvidenko, 2005). The paper assesses the effectiveness of a fire mitigation strategy through a spatially explicit an agent-based modeling approach.

Forest ecosystems have been strongly modified by fire disturbance. Fire environment components and many of their factors are closely interrelated. Consequently, understanding the role and the relative weight of climate, weather, and ecological factors is of critical importance in anticipating the impact and in implementing management strategies that aim to mitigate or to modulate the damages of wildfires.

Several authors suggest that to reduce the damages of fire hinges considering different fuel reduction related strategies ((P. Corona, 2014), (E. Keeley, 2011), and (A. E. Johnson, 2001)). A correct calculation of compensation value arising from fire damage is a crucial task for a forest manager. There is a need to have a clear articulation of resource costs associated with fires as well as with fire management practice (E. Keeley, 2011). However, the complete economic, social, and ecological impacts of forest fires have not been quantified, although some studies have yielded at least partial estimates of lost wood and the impacts on wildlife (A. Shvidenko, 2005).

Complex system science has contributed to the understanding of ecology in important areas such as patch dynamics. Heterogeneity of environmental resources, succession, and disturbance results in landscape patches of diverse size, shape and type. The probability of vegetation to burn is strongly related to its fuel flammability. Indeed, in the Mediterranean regions, once the ignition occurs, fuel load and connectivity are more relevant in driving fire activity than the frequency of climatic conditions. (A. Regos et al, 2016).

Our analysis gasps the complexity of fire spreads dynamics through simulation of individual, landscape specific spatial variables. In line with the existing literature, we simulate the spread probability by using a cellular automata model in function of neighboring interactions (D.D'Ambrosio 2006). Moreover, in order to preserve different region landscape-specific fires frequency, we extent the model by including wildfires time series.

Analyses are conducted on data released by the regional cartography system and the national environmental information system (ISPRA). Data comprise ecological species characteristics and inventory of land cover types on a representative regional sample. Since information is collected for general purpose, the analysis is carried out by specific data aggregations. Indeed, our final dataset results in a geospatial map with complete landscape covers information at a regional extent. Moreover, land cover type flammability and historical ignition records have the same area extension and overlapping analysis could be performed. Finally, the interaction between observed ignition and flammability of land cover type is modeled through spatial association derived from data published by the Italian National Forest Inventory (INFC).

The main findings concern the importance of spread probability. On the individual side, it mimics the unpredictability of fire dynamics. On the process side, it represents the inner uncertainty that characterized complex systems. Secondly, the results suggest that fire size distribution is first driven by landscape structure. The discussion on the distribution of the Liguria fire events will reveal that, under certain interaction rules, land cover heterogeneity and neighboring interaction are the best representation of fire spread dynamics. On the management side, the results suggest that mitigation treatment concerning wildfire dynamics has a positive effect on the resulting burnt area. Moreover, when environmental damages are disclosed total avoided damages due to fuel treatment strategies accounts for a higher value. As been demonstrated that environmental benefits accounting reduces the monetary losses due to wildfire damages of a consistent amount.

The paper is structured as follow: Section 2 reviews the literature on the topics. Section 3, describes the data and the Liguria wildfire related problem. The agent-based model is presented in Section 4 and implemented in section 5. Section 6 discusses and concludes.

2. LITTERATURE REVIEW

Wildfire behavior has been studied as a part of landscape ecology through the use of models involving local interactions (M. G. Turner, 2015). Some simulations of ecological flows, such as propagation of disturbance, were developed following the cellular automata paradigm. Discrete modeling approach like the one mentioned is widely used for simulating complex dynamical systems whose evolution depends exclusively on the local interactions of their constituent parts (D.D'Ambrosio 2006). Although there is a common underlying mechanism that explains fire activity, there is evidence of non-linear behavior in fire spreads dynamics (R. P. Benson, 2009). Wildfires are highly complex events involving climate variability, vegetation characteristics, and human factors as well as physical and topographic conditions (E. Keeley, 2011). Being a spatially structured phenomenon, spatially explicit models are important tools for a better understanding of fire dynamics. Landscape fire succession models are able to examine the spatial interaction of ecological processes through time, which is of particular importance in a spatially heterogeneous environment (A. E. Johnson, 2001). Simulation studies show that, considering the landscape as a grid of finite cells, each of which is assumed to have a uniform internal state, overcomes the problem of assuming a fire spreading across uniform fuel (J. D. A. Millington, 2009). In addition, fire spread patterns do tend to be repeatable and often predictable in time and space. It has been observed that fire under the same topography and weather conditions follows similar spread patterns, with only fire intensity changing due to varying fuel availability (A. Duanea, 2016). Besides forest ecology, dynamic landscape fire-succession models have also been used to evaluate the potential effect of prevention strategies to mitigate forest fires. Thulke (Thulke, 2008) find that the emergence of spatial structures facilitates eradication, and suggests considering methods that reflect the spatial nature of a dynamic system. In response to consistently rising wildfire management budget requests, assessing the socio-economic impact of wildfire has played an important role in establishing public wildfire management budgets (Rideout, 2013). Designing a feasible strategy is a complicated problem. In particular, managers face uncertainty over the best allocation of limited resources to risk reduction strategies (Price, 2012). In addition, becomes increasingly difficult to assess fire impacts as the usual economic estimates of environmental damage reflect only private costs, which can be much lower than the actual social losses (Services, 2008). Forests and wooded areas have a high biological, ecological, cultural and economic value. Therefore, the main challenge is to evaluate ecosystems services losses. Evaluating the economic and ecological impact of these damages is the basis to assess a valuable cost-benefit analysis to commensurate an effective public investment (Mitsopoulos, 2006). Our analysis considers fire dynamics patterns as dependent on spatial heterogeneity interactions. Specifically, we use one of the wildfire main drivers, namely the flammability of a site, to characterize fuel mosaic structure. The focus is on the relationship between the flammability function and the resulting fire size distribution. The design of a management strategy is introduced via a measure to quantify the effectiveness of a silviculture prevention strategy (i.e. leverage). First, annual prevention expenditure is assessed. Second, standard accounting procedures is used to estimate environmental damages. The proposed analysis encompasses several assessment frameworks recognized by the literature and extends them by introducing novelty in modeling approach, as the use of a GIS-based model in conjunction with and agent-based fire spread model. Due to the scope of the analysis we do not account for complex relationship with other spatial factors affecting fire behavior; however, as we will discuss, our results are consistent with the observed fire dynamics.

3. FIRE SPREAD DYNAMICS

3.1. Base line model

The concept of fire regime includes the fuel type consumed, frequency and timing of burning, intensity of the fire and the spatial distribution of individual fire events. The key idea is that these factors act in concert to produce the fire regime and it is the entire fire regime that constrains functional types, community assembly patterns and biome distributions.

Landscape composition and pattern influence the nature and magnitude of ecological processes at a variety of spatial-temporal scales. Complex adaptive theory specifically models how individual variation and changes in that variation lead to system-level responses. By modeling complex adaptive systems decision makers as individual agents, the full effects of the diversity that exists among them with respect to their attributes and behaviors can be observed as they give rise to the dynamic behavior of the system as a whole. Inductive research involves the search of patterns from observation and development of explanations – theories – for those patterns through series of hypotheses. Different scientific studies ((R. P. Benson, 2009) (A. E. Johnson, 2001) (E. Keeley, 2011)) of forest fire events have been conducted describing the interactions between climate, weather, and wildland fire. From an ecological point of view, leaving aside the relative effects of climatic and weather conditions, forest fuel becomes the factor that has changed most significantly, and has also affected the development of wildfires (P. Costa Alcubierre, 2011). Ecosystem differ greatly in both horizontal and vertical patterns of biomass distribution, and thus in fuel structure, and this has a profound impact on fire spread characteristics. Even if the fire environment components and many of their factors are closely interrelated, and the current state of one factor depends on the state of the other factors, fuel flammability is the most important variable that predicts changes in fire behavior. Consequently, the current analysis adopted, as independent variable to explain fire spread dynamics, a proxy of fuel flammability. The model developed by Wilensky (Li, 2001) has been used as reference, and a stochastic forest fire model is considered. Being a spatially explicit raster-based model it allows analyzes the relationship between landscape structure and regional distributed fire risk. It is driven by individual interactions that contribute to the large-scale pattern of fire percolation. The chosen modeling approach includes not only explicit locations of entities, but also processes that incorporate interactions among entities in space that in part drive changes in the focal entity over time. The spatially discrete approach aggregates the dynamics into a small number of discrete states. Developing as cellular automata, the model involves a regular division of space in cells, each of one characterized by a state that represents its actual condition. The state changes according to a transition function that depends on the state of neighboring cells and of the cell itself. This simplification of the local dynamics allows a detailed analysis of the large-scale patterns triggers by different interaction strategies.

1.1. Case studied

The study area constitutes the entire Liguria mainland, which covers approximately 5.410 km^2 of the north west of Italy, extensively covered by forests and shrub lands, about 71% of the entire area (V. Vassallo, 2010). Current available data drawn from the regional plan on wildfire prevention, prediction, and fighting (V. Vassallo, 2010) show that past trends in forest cover have constantly increased, with an annual expansion of about 2.270 ha from 2005 to 2015. According to the regional land-cover map (i.e. “Tipi_Forestali_pg_2013”), broadleaf forests cover 71.5% of total forested area, while conifers and shrublands species cover the remaining 28.5% (V. Vassallo, 2010).

Fire is a major landscape change driver in the region, with about 139.019 hectares being burnt between 1987 and 2014, and a fire seasonality recurring both in summer and winter (see Figure 1).

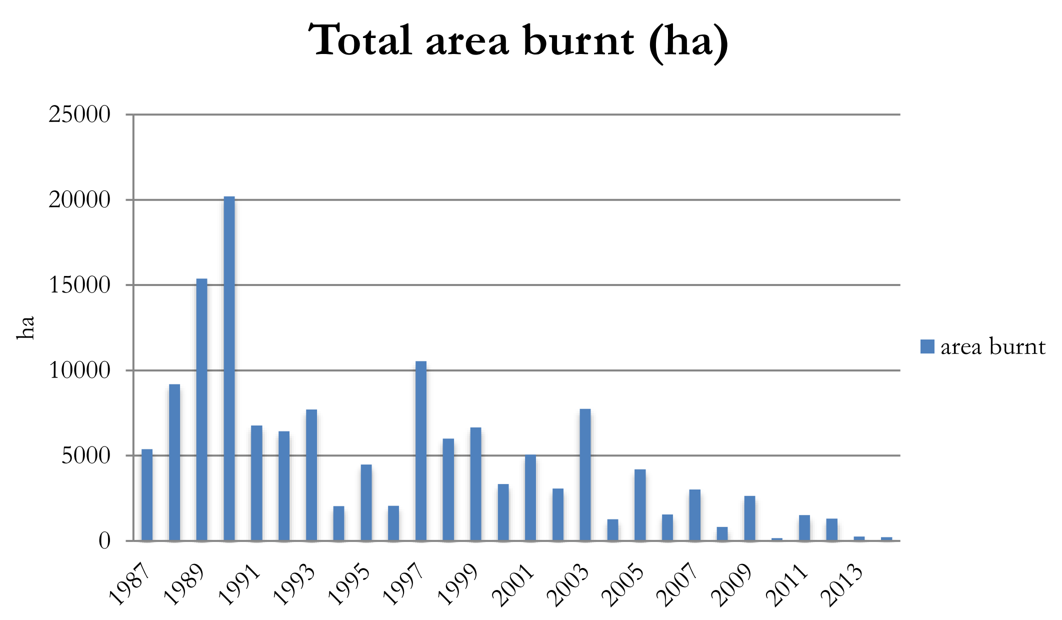

Figure 1. Total area burnt (ha). Number of hectares burnt between 1987 and 2014. Data obtained from regional statistics (V. Vassallo, 2010).

Coppice forests in Liguria are poorly managed, due to the observed recent changing socio-economic conditions that have strongly modified the composition and structure of large forested areas previously managed as coppice. According to the Italian National Forest Inventory, 89% of copies forests in Liguria are over mature; the even-aged wood lowers the forest commercial value due to size, age decay and other factors (Pignatti, 2003). The interruption of the traditional active management has led to substantial biomass accumulation in these forest formations, threatening the conservation of the coppice system from a fire risk prospective. An active management can achieve a more mature stand structure, reducing the risk of fire damage, and allowing economic revenues (V. Vassallo, 2010). In Italy, the budget allocation process of wildfire management plan is managed at the regional level. On the basis of the national law 2000/353[1], each region organizes and coordinates prevention and suppression actions. The yearly planned budget that pays for the pre-suppression organization is divided among the municipalities. Each municipality allocates and coordinates prevention, detection, fuel management and initial attack, as well as restoration expenditure. For instance, in Liguria, the planned budget is allocated for a 5 years programming period. The last budget allocation (i.e. 2010-2014) was about 14 million of €, almost halved if compared with the amount spent between 2005 and 2009, approximately 23.5 million of €.

1.2. Data

The analysis of the Liguria fire spread dynamic is performed on the basis of data obtained from the Regional dataset (Cartografia Regione Liguria), and from national dataset (Rete del Sistema Informativo Nazionale Ambientale, 2012). Regional and national inventories are part of two different systems. The regional cartography used (i.e. "Tipi_Forestali_pg_2013") illustrates forest type specification data, classified on the basis of ecological species characteristics, to establish a detail framework of ecological and vegetation characters of each vegetation species which object is to act as a forest planning instrument (P. Camerano, 2008). The national land cover map (i.e. "Corine_Land_Cover 2012") shows the inventory of all land cover types, divided in 44 classes corresponding to an area whose cover may be consider homogeneous and where each unit represents a significant area of land (CORINE land cover, 1995).

Following the regional classification, land use was reclassified as shown in Table 1, where a new macro category for reforested areas was added.

Both maps used vector features with polygon geometries. The regional forested map .dbf file was modified through a reclassification of its features into the cited macro classes. In

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[1] Number 21, November 2000 n. 353 "Legge Quadro in Materia di Incendi Boschivi"

the same way the attribute table of the national map (i.e. "Corine_Land_Cover 2012") was rearranged. A one-to-one match between forested features of the two maps was performed when possible. Otherwise, the forest regional land cover was kept as reference. Further, non-forested areas defined in Corine were reclassified and associated to the described macro classes. Forested areas in the map were updated using the more detailed features available from the regional one. For instance, the original Corine vector layer was update joining forested land cover attribute from the regional dataset. Our final dataset results in a polygon layer shown in Figure 2 (i.e. LCT – Land_Cover_Type -), with complete information covering the regional extent.

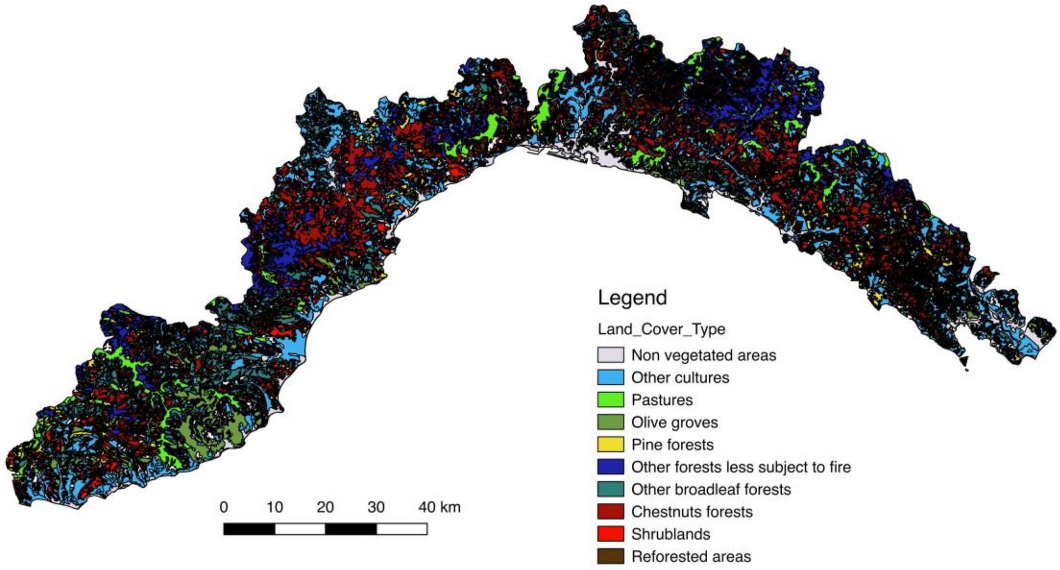

Figure 2. LCT. Land_Cover_Type map.

The analysis investigates the relationship between each land cover type and its flammability. Fuel load values were used as a proxy of a site's flammability. Values for forested areas were drawn from the regional programming document (V. Vassallo, 2010). For non-forested areas, associations between regional and national vegetated species were assessed through the Italian National Forest Inventory (INFC) (Pignatti, 2003) reference classification. Final values, divided in seasonal variables, are reported in Table 1.

Table 1. Summer and winter fuel load values for each LCT in Liguria.

COD	Macro-categories	Summer fuel load (t/ha)	Winter fuel load (t/ha)
10	Non vegetated areas	0	0
21	Other cultures	28	28
22	Pastures	5	5
23	Olive groves	35	35
32	Pine forest	87	82
33	Other forests less subject to fire	45	48
34	Other broad leaves	46	49
35	Chestnut forests	40	45
37	Shrub lands	60	60
40	Reforested areas	38	40

A basic annual fire history map on a regional scale, describing area burnt and ignition points of each fire (i.e. Aree percorse dal fuoco 1996-2013) were used to evaluate the probability of each spatial unit to start a fire. Data were drawn from the regional dataset (Cartografia Regione Liguria) using the wildfire time series at the regional level that covers 18 year period, from 1996 to 2013 (see Figure 3). Overall, the study area experienced about 8.446 fire ignitions, with a mean annual fire occurrence of 469 fires.

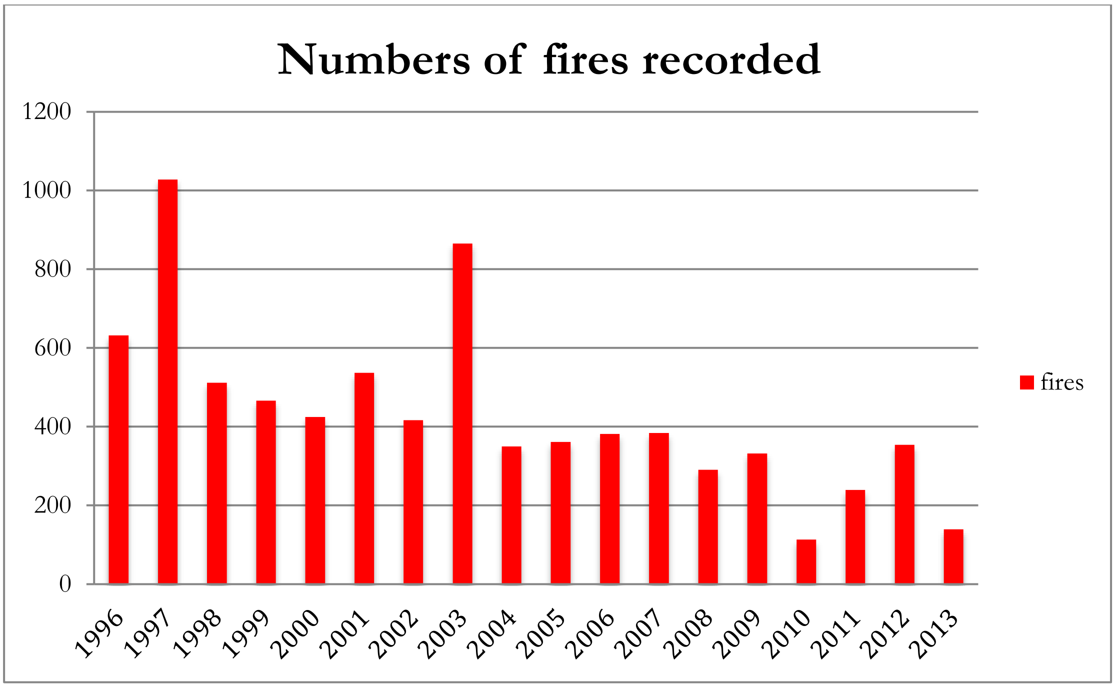

Figure 3. **Number of fires recorded**. Data from regional cartography (Cartografia Regione Liguria)

The explanatory variables used to categorize the basic fire risk were historical ignition records. Those frequencies have been used as inputs to model the ignition probability spatial variable. Observed ignitions were associated to the LCT map (see Figure 4). Consequently, both maps have the same area extension and overlapping analysis could be performed. Moreover, the spatial association between observed ignitions and the built macro categories has enabled the restriction of ignition points to occur in cells with burnable land cover types.

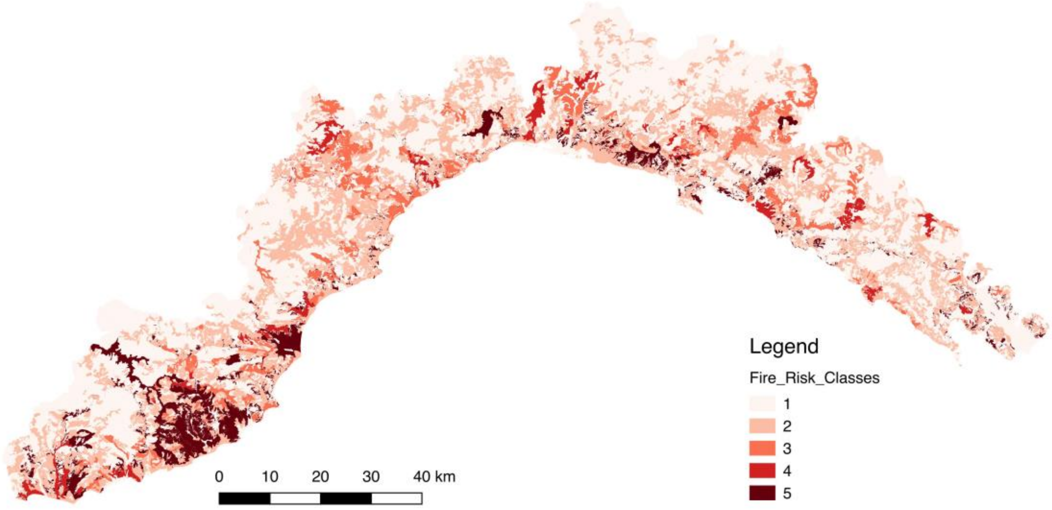

Figure 5. Fire-risk map. Representation of fire ignition points that occurred between 1996 and 2013 for each land cover type areas. Jenks natural breaks classification method was applied to build fire risk classes based on the number of fires per area recorded. Classes were divided as follow: 0-0 (class 1), 1-6 (class 2), 7-13 (class 3), 14-19 (class 4), 20-206 (class5).

Fuel load data and ignition locations were assembled in a gridded landscape file at 200 m^2 resolutions. First, due to season variability, two final raster layers were used to model fuel load values, one with summer and the other with winter fuel load values. Secondly, another raster layer was elaborate to assign the frequency of fire occurrence elaborated from time series.

4. METHODS

4.1. Agent based model

The chosen modeling approach must allow the simulation and investigation of a landscape specific fuel structure on the resulting fire dynamics. For this purpose, we adopted a spatially explicit raster-based model. Our model takes as a starting point Wilensky, et al. (1997), which models spreading dynamics of various classes of agents composing a heterogeneous environment. We do so uploading a raster based geographical space divided in different land cover types. The model is defined as a cellular automaton on a grid with L^d cells. A cell variable is update through two types of input data: a set of ignition characterized by spatial locations, and a set of raster layer representing the potential fire spread landscape driver. Similar to Wilensky's model, agents change their status in the course of time due to the influence of neighboring interactions.

Each geographical global variable is read from a raster layer uploaded through a GIS (Geographic Information System). In more details, three raster layers, at 200 m^2 resolutions, represent respectively summer and winter fuel load values, and ignition points of spatially specific recorded fires (see Table 2). Overall, the space composes a rectangular grid of 1034 x 496 cells, making up 512.864 locations. The value from the given raster dataset were applied to the given agent variable. The first state of the agents is their location. At every time each agent has a fixed position given by a ordered pair (x,y) of horizontal and vertical co-ordinates respectively. Each cell is characterized by a set of spatial variables: *fuel-load* and *ignition-probability* (see Table 2). Fuel load values are used as species flammability factors, which describe the relative flammability and combustibility of tree species and burnable land covers. Ignition probability values (P(I)) are derived from the input layer that describes the number of fires recorded for each grid cell (I), normalized with weights given by P(I) = $I/45$*0,2. Accordingly, each cell could have three states, defined by three binary variables. First, a cell is characterized depending on its flammable or non-flammable condition. Second, a cell is defined by its ignition status; and third, it is signaled through its burns situation, which change due to neighboring interactions. For instance, if the cell selected is flammable it can perform two tasks, ignite and spread fire, while non-flammable cells do not have individual and interaction rules. If a cell ignites and spreads fire it changes its states accordingly (see Table 2).

Table 2. Variables

Environment variables		
summerload-dataset	Global variable	Raster data consisting in grid values of summer fuel load

winterload-dataset	Global variable	Raster data consisting in grid values of winter fuel load
ignitionpoints-dataset	Global variable	Raster data consisting in grid values of spatially recorded fires
Global variables		
probability-of-spread	Global variable	Determines how likely a fire can spreads between cells
Agents variables		
fuel-load	Spatial variable	Defines the 9 macro-classes of land cover type
ignition-probability	Spatial variable	Determines the spatial location of new fires
ignite?	Boolean variable	Set to false if the cell is not an ignition point
flammability?	Boolean variable	Set to false if the land cover type is not burnable
burnt?	Boolean variable	Set to false if a flammable cell does not catch on fire

Consequently, fire disturbance is designed in two separate sub-models. The first process models fire ignition, and the second fire spreads. Ignition points are stochastically determined by randomly picking up a grid cell whit a positive value of the *ignition-probability*. Each new fire ignites in a random location selected from flammable cells with a past history of fires. A local variable called "fires" defines a subset of cells that have *ignition-probability* greater than a random number. Each "fire" compared its fire risk probability to a uniform random real number that ranges between [0,1]. This process has been modeled to stochastically determine the location of new fires among the subset of cells with a positive risk probability. When ignition is activated fire spread is simulated as a percolation process. A stochastic approach has been used by the introduction of a global variable (i.e. *probability-of-spread*) that defines the probability of each flammables cell to be burnt (see Table 2). A stochastic approach is suited to model forest landscape dynamics that are designed to simulate patterns over large spatial and time domains and are not used deterministically to predict individual events. A random continuous distribution in the interval [0,1] is compared with the global variable *probability-of-spread* to determine if spread occurs[2]. Additionally, fire dynamics follows a local interaction rule. Fire may spread into any of the eight cells adjacent to the ignited one based on a hierarchy between flammability values. The neighbors with the higher content of fuel load burn first. Further, if there are other flammables neighbors, the order in which these cells get on fire is randomly shuffle each time step. When a cell burns, its flammable condition changes. Moreover, if a cell is unburned in this process, it may burn later as part of the subset of neighbors of others fire fronts. Besides that, it could not be burned twice as its binary variable change its status when the agent is effectively chosen. The model stops after a fixed amount of time, in order to model an annual fire extent. Alternatively the simulation ends if the fire riches its potential total area to be burnt, in other words when no more flammable neighbors are available or unburned. The number of time steps and the chosen value of spread probability determine the mean size of fires in each simulation. The result represents the average fire size of a scenario where no mitigation strategies are performed, defined as business as usual.

4.2. Management scenario

From a fire-management prospective, fuel complex, spatial distributions and fuel load are the only variables affecting fire behavior that can be adequately managed (A. Regos, 2016). We hypnotized the application of a certain fuel management strategy to assess subsequent reductions of the unplanned fire extension. In particular, a low thinning intensity treatment is assumed, as it is more suitable for fire prevention than crown and selective thinning (P. Corona, 2014). The effectiveness of silvicultural prevention strategies is not the same among biomes characterized with substantially different fire regimes (O. F. Price, 2015). The term leverage has been defined as the percentage reduction in area burned (compared with the untreated landscape) divided by the percentage area treated. In formula

$$L = \frac{A_0 - A_1}{T}$$

Where L is leverage, $A_0$and A_1 the annual extent of unplanned and planned fire, and T the treatment level. Data used for the analysis were drawn from Price (Price, 2012). He suggests that there are fundamental landscape principles that determine leverage from planned fire. Leverage is negatively related to treatment level, and to the probability of

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[2] The process is inspired by the Fire Simple model first extension (Wilensky, NetLogo Fire Simple Extension 1 model, 2006).

spread of the unplanned fire; it is higher for linear-gridded treatment designs than for patchy designs; positively related to the extent of wildfire and to the size of individual fires. The context specific variables values have been used to predict the leverage applied in the present study. Further, the annual cost of the silvicultural system hypnotized is evaluated for the regional planning period 2014-2020 (V. Vassallo, 2010). Considering the initial operational costs, the pre-suppression expenditure are evaluate as follow:

$$P_{treat} = C_u * T$$

Where P_{treat} is the total expenditure, C_u is the unit cost per area treated, and T is the treatment level applied. Data were obtained from the Liguria regional pricing list for agricultural and forestry work (Prezzario regionale).

Benefits originate from a fire management program include the reduced losses that result from limiting the number and size of wildfires and the increased forest resource productivity (A. E. Johnson, 2001). The Italian State Forest Corp (O. Ciancio, 2007) has elaborated three different methodologies to assess natural resources damages. These methodologies evaluate the environmental damage considering the loss of goods with and without a market, through different techniques of environmental accounting. The present work follows the *synthetic approach* that appraises the environmental damages due to wildfire forest loss based on the VAMs (Average Agricultural Values). VAMs defined by each province are used to assess the monetary value of forested landscape. Values are reported in hectares, and are periodically updated by each Liguria Provinces. Environmental damages due to forest fire are computed as follow:

$$DA_{VAM} = \left(VAM_f - VAM_{bg}\right) * Sup$$

where DA_{VAM} is the environmental damages, VAM_f is the average agricultural value of forest covers, VAM_{bg} is the average agricultural value of bare ground, and Sup is the mean annual forested area burnt.

5. RESULTS

The simulated model is conceived as to include geographical factors assumed to impact fire spreads dynamics. In addition, estimates take into account land cover heterogeneity and neighboring interaction. In order to capture the stochastic effect of spread dynamics we assumed the spread probability as the main parameter of the model. Moreover, we account for the importance of uncertainty in fire risk parameter using a random probability based on fire statistics. At the individual level, we consider fuel load as a proxy for the flammability of different land cover types, and a fire risk parameter as a proxy for possible ignition points. Due to the uneven geographical distribution of the variables and the importance of their location, we include a geographical classification to capture interaction effects. The results confirm that fire size distribution is strongly driven by the landscape structure. Further, the average annual area burnt is strongly related with the spread probability. This parameter describes two different phenomena. First, on the process side, it represents the inner uncertainty that characterized complex systems. Secondly, on the individual side, it mimics the unpredictability of fire dynamics. Once a cell has sensed if can spread to neighboring locations, it chose randomly the primarily and the following potential destination.

As not expected, the fuel load content of the burnt cells does not strongly affects the overall results: difference in the mean seasonal fire size area were not significant as the average hectares burned slightly increases in summer although higher winter fuel load values. To be noted that summer and winter values differ on a small scale. On the other side, it confirms that the mean annual area burnt is primarily affected by the spatial interaction resulted from the simulation.

We conducted a second analysis to differ the effect of global variables to the behavior of the system. Testing the sensitivity of model outputs to changes in parameter values can show how strongly the model represents real-world dynamics, and it helps to understand the relative importance of model processes (V. Grimm, 2012). A simple local sensitivity analysis does not account for non-linearity to parameter changes. Moreover, it does not capture parameter interactions and is valid only if the reference parameter is set at its initial condition. However, the outcome shows that the model sensitivity is relatively higher for the main parameter of the system, that controls how likely a fire will spread from a burning cell to its neighboring celling ones. Similarly, the number of ignition points does not seem to represent a process influencing the sensitivity of the model if compared with the main parameter analyzed. It should be noted that it relied on fixed data drawn from time series evaluation, and the simulation results are mainly drive by local interaction rules.

It can be seen that the model estimates are consistent with the available data of fire size distribution in Liguria. For instance, simulation result exceeds around 28% of total forested area burnt defines in the regional statistic as a percentage of annual mean. Discordance in the outcome is due to model oversimplification of real word dynamics. Wildfire propagation and behavior are not only governed by fuels structure, but also by complex relationship with other spatial factors, for instance topography, wind directions and ignition patterns. Consequently, limitation of the spatially explicit model used must be taken into account to avoid wrong decision based on misunderstanding conclusions. Beside this, the average area burnt estimates with random effects results in tighter credibility ranges.

On the management side, policy makers need to adopt the best compromise between fire control and fuel management approach for the future, while considering that the complete exclusion of wildfires is not a feasible and reasonable strategy in the long term (M. Salis, 2016). The management of coppice system in ecosystems commonly observed in Mediterranean area, allows plants to withstand a degree of burning and continue growing despite fire damage, making stand recovery in this system more likely than in other forest type. The fuel treatment level hypothesized has a grid spatial configuration equal to the 1% of the regional forested area. The planned fire extent extrapolated from the analysis shows a percentage reduction of 17% in the mean annual area burnt. Consequently, mitigation treatment concerning wildfire dynamics has a positive effect on the resulting overall fire size. Indeed, both costs and benefits of management strategies must be taken into account in a rigorous assessment. The annual prevention expenditure, compared to the regional allocation founds for the programming period analyzed, corresponds to 57% of the total budget, a slightly increased of the avarage amount spent by the region. Environmental benefits are disclosed when the reduced ecosystem losses are accounted (A. E. Johnson, 2001). Estimation procedures of avoided environmental damages have a major role on the evaluation of total wildfires casualty, as demonstrate in the estimation. Net benefit due to the implementation of the treatment strategy is around 14% of the total damage calculated for the business as usual scenario. In other words environmental benefits accounting reduces the monetary losses due to of wildfire damages of a consistent amount. It must be highlighted that, as reported in the by Ciancio and colleagues (O. Ciancio, 2007) ecological damages are frequently underestimated. However, the aim of the study was not to analyze the environmental costs of a wildfire, but to assess a general procedure that can be used to compute the costs avoided from a prevention strategy.

6. CONCLUDING REMARKS

The paper contributes to the assessment of the estimation of the total impact of forest fires by providing a detailed analysis that the costs and benefit derived by a fire mitigation treatment. EU regulation guidelines are of great importance for the Mediterranean member states. The aim of the EU Forestry Action Programme (The EU Forest Action Plan 2007-2011) includes actions for protection against forest fires. In particular, this programme is primarily oriented at what the EU defines as fire prevention. The impacts of forest fire are neither homogeneous, nor identified to the same level of information. Due to the deficits in the forest fire data collection methodology, only the direct impacts (i.e. burned area) are reported, which are clearly insufficient to determine the total impact to nature and ecosystems (A. Dimitriou, 2001). Because of the lack of such information, it is clear that the estimation of the cost of the impacts of forest fire is much lower than the real one. In the absence of indirect impact indicators, this paper has provided a quantitative framework to analyze losses and benefits from wildfires. As a starting point, the methodology proposed has focused on forest fire simulation methods adequate to analyze the performance of fuel treatment using objective measures. Forest fire modeling approach is currently under the spotlight of the European institutions. An object-oriented procedure facilitates the modeling process, while a spatially explicit model addresses specific regional disturbance and provides insights into fire behavior and control strategies.

Estimate of direct impact of wildfire are obtained through simulation of main landscape composition that drives wildfire disturbance. Land cover types and fire ignition time series variables describe geographical factors. The fuel load variable captures different levels of land cover flammability. The analysis is conceived as to preserve data heterogeneity while highlights interaction patterns. Fuel mosaic structure simulates wildfire propagation and behavior giving relevant information beyond that strictly related to complex system dynamics. As a result, landscape explicit model can inform land managers about the most effective options to address wildfire threats.

The overall assessment of the fuel management strategy demonstrates the effective benefits deriving from forest fire mitigation approach. Avoided environmental damages resulting from the management treatment are on average higher than those based only on direct impacts of forest fires. Including indirect impact of forest fires, although difficult to be estimated, should be considered into any decision-making process since they are closely related to the basic ecosystem functions.

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