Chapter 6

Abiotic Stressors – Fire Hazard

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/56273

1. Introduction

Forest fires are worldwide recognized as one of the main factors affecting the forest ecosystem equilibrium, leading to direct and indirect impacts on the functions provided by forests (production, protection, wildlife, tourism, etc..). Forest fire ignition and propagation are closely linked to site-specific conditions: fuel characteristics, forest structure and composition, weather and topography. Within the MANFRED project, ERSAF was aimed to identifying potential evolution scenarios of forest fires danger due to climate change in the Alpine Space.

2. Forest fires in the Alpine space

Some statistics and considerations about the state of the art of forest fires in the Alpine Space, can be derived from the forest fire database, collected through a joint action between the project MANFRED and ALPFFIRS (Alpine Space Programme). The database contains information on forest fires for all the Alpine regions of Austria, France, Germany, Italy, Slovenia and Switzerland. All the events occurred in the period 2000-2009, with the exception of Germany (2005 -2009), were collected and analyzed.

Looking at the geographical pattern (Figure 1), two different situations can be distinguished. The 90% of the fire events in Alpine Space occur in France and Italy. In the countries located in the in the north of the Alps (Austria and Germany) the occurrences showed an overall lower incidence (5% of the events). At yearly level, in the analyzed decade, 2003 emerged as the year with the highest fires frequency (Figure 2). It was characterized by very high summer temperatures and a prolonged drought period. At seasonal level, it can be observed that, unlike the European countries of the Mediterranean area (F: Méditerranée – I: Liguria) showing a prevalence of forest fire events during the summer, the rest of the Alpine Space is characterized by a winter-spring regime of fires. At monthly level, the highest frequency of forest fires was recorded between March and April, with a secondary peak, in July and August (Figure 3). The only exception is France where the maximum frequency is commonly reached during the summer. This result is influenced by the events occurred in the Southern region of France where Mediterranean climate is responsible for this kind of fire regime (Wastl et al., 2013).

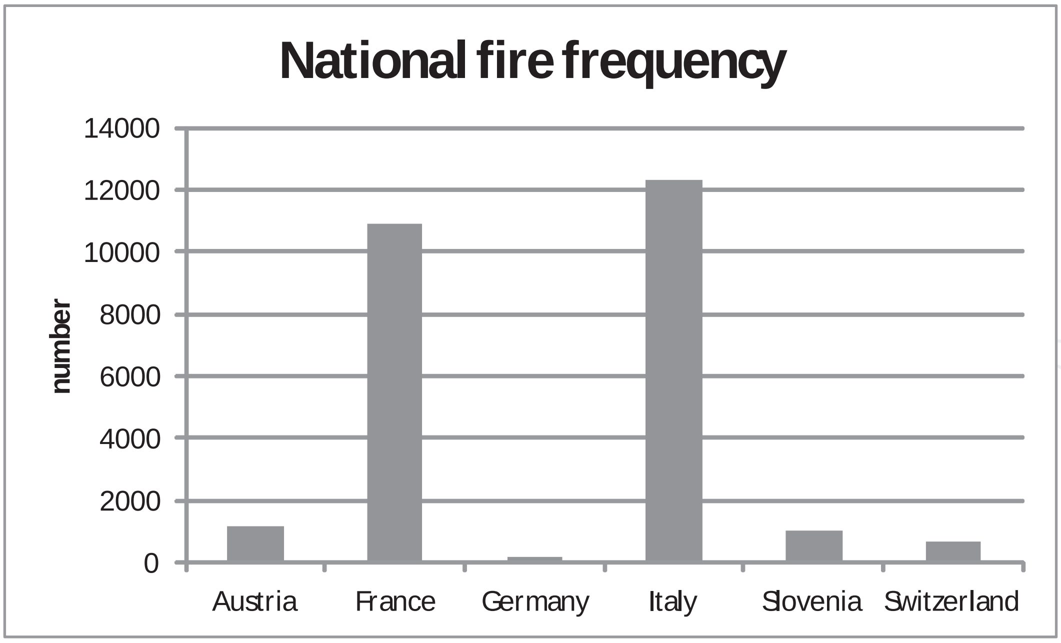

Figure 1. National fire frequency in Alpine Space (2000-2009)

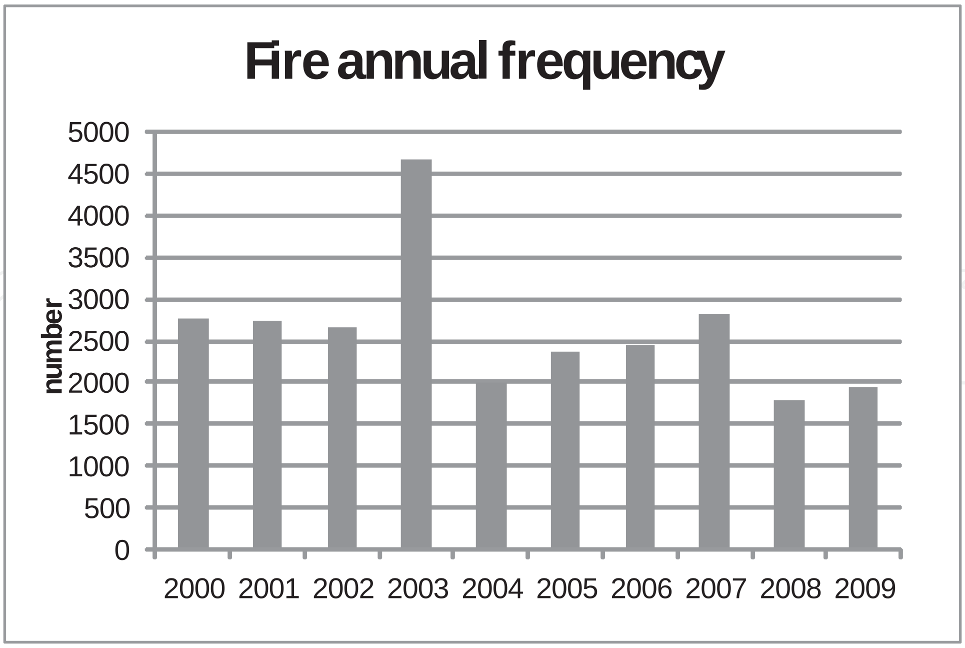

Figure 2. Fire annual frequency in Alpine Space (2000-2009)

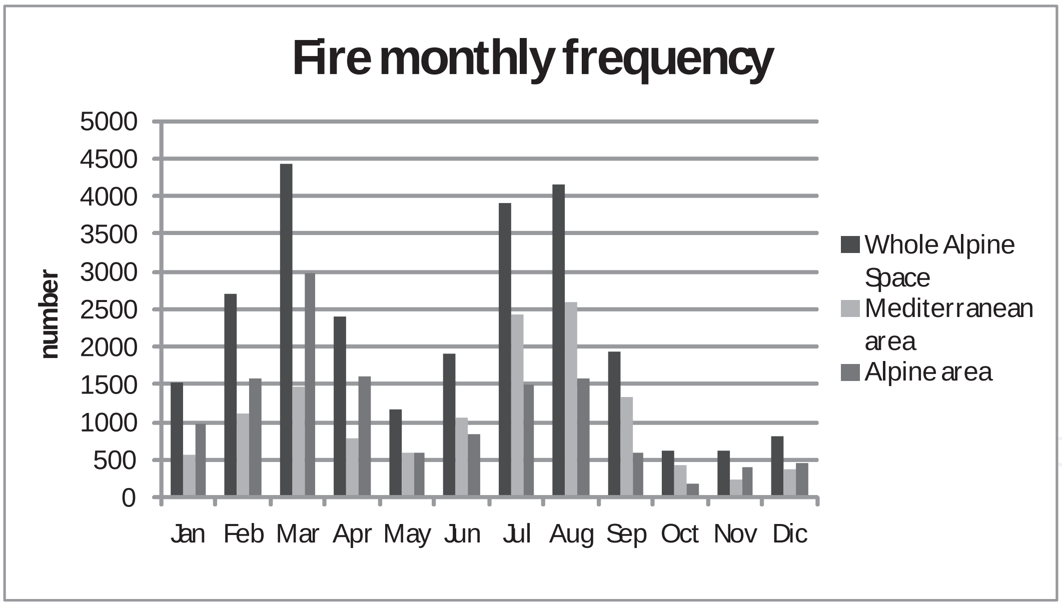

Figure 3. Fire monthly frequency in Alpine Space (2000-2009)

3. 4FI.R.E. (Forest Fire Risk Evaluator) — Tool for forest fire risk calculation

In the framework of MANFRED, ERSAF developed a tool for forest fire hazard and vulnerability evaluation. **4 FI.R.E.** is a stand-alone application composed by two separate modules:

4FI.R.E – Hazard, capable of generating, from a set of input spatial layers, a series of forest fire hazard maps, and **4FI.R.E – Vulnerability**, capable of generating, from a set of input spatial layers, a series of forest fire vulnerability maps.

The tool was tested at the Alpine Space and regional/country level (Lombardy Region / Slovenia), while the vulnerability model has been applied only at pilot area level (Valle Camonica, ERSAF pilot area).

3.1. 4FI.R.E — Hazard

The 4FI.R.E – Hazard module is dedicated to forest hazard mapping. This module is almost mature and functional, and a screenshot of the main user interface in visible in Figure 4.

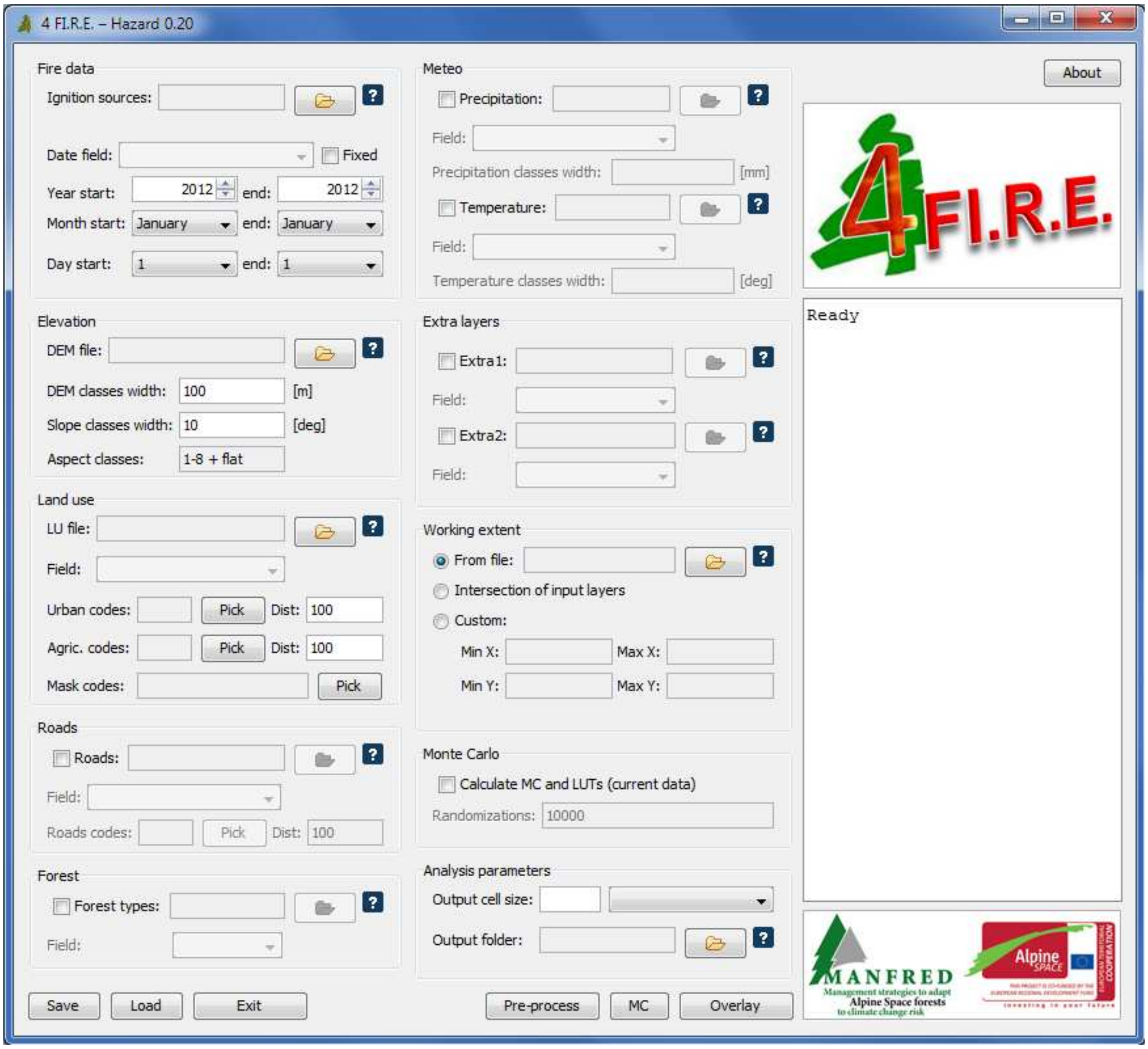

Figure 4. R.E Hazard main user interface

The 4FI.R.E software automates a series of procedures for data import and consolidation, for statistical analysis of spatial layers and for output creation. The creation of the hazard maps involves the statistical analysis of the distribution of historical fire events to reclassify input layers in terms of their correlation to fire events. See Conedera et al. (2009) for details on methodology.

The Hazard module requires a set of input spatial layers, some compulsory, others optional. The compulsory layers are the historical fire data, the Digital Elevation Model (DEM), and the land use map. The optional layers include the roads map, the forest map, the rainfall and temperature maps. The module also allows for the selection of two additional layers to fit specific user requirements. The input layers can be of raster of vector type. In the former case, the ESRI ASCII GRID raster format is supported; in the latter the ESRI Shapefile format is supported.

Conceptually, the hazard mapping is made of three steps:

1. Import of input layers; 2. Calculation of Monte Carlo maps from input layers based on historical fire data; 3.Overlay of Monte Carlo scores layers to generate the hazard maps.

The data import step includes a set of processing operations that depends on the input layer characteristics. Nevertheless, since the two following steps require the data to be in raster format, all the input layers, if necessary, are rasterized. Then, they are clipped on the user specified extent, and resampled into the output cell size. More specific operations are also performed on input data: from the DEM, slope and aspect maps are calculated; from the land use map, distance from agricultural areas and distance from urban areas are calculated; from the roads map the roads distance map is created. All the layers are finally reclassified into discrete classes, pre-defined (e.g. eight aspect classes) or user defined.

The calculation of the Monte Carlo scores is carried on for every input layer after its import. The distribution of the historical fire data is compared against every input variable (i.e. every input layer). Fire event frequencies are used to calculated random-based distributions (typically 10000 simulations for each variable). As a result, input variables are reclassified into seven significance classes, ranging from -3 (little significance) to +3 (high significance). The output of this process is a series of new layers (one for every input variables), carrying the Monte Carlo ranks.

The overlay of the Monte Carlo layers for the different variables can be performed using three different methods: a simple linear combination, a Principal Component Analysis data reduction, and an overlay based on the Analytic Hierarchy Process. The user interface for the layer combination is visible in Figure 2. The linear combination simply adds up all the Monte Carlo maps and then rescales the output layer in the 1-10 range. The PCA data reduction implies the calculation, from all the input Monte Carlo maps, of their Principal Components (PC). Then, a backward transform is used to reconstruct the Monte Carlo information using only a small number of PCs (typically just one). The PCA-based combination has the advantage of eliminating, if present, data redundancies of input layers. The AHP combination requires a series of ancillary input data, where one or more experts evaluate the relative importance (in terms of fire hazard) of every input variable when compared to every other variable. The tool is capable of importing AHP data from txt files, to calculate metrics, such as the Consistency Ratio (CR), to evaluate the validity of AHP data. A sub-module is also present to input AHP data.

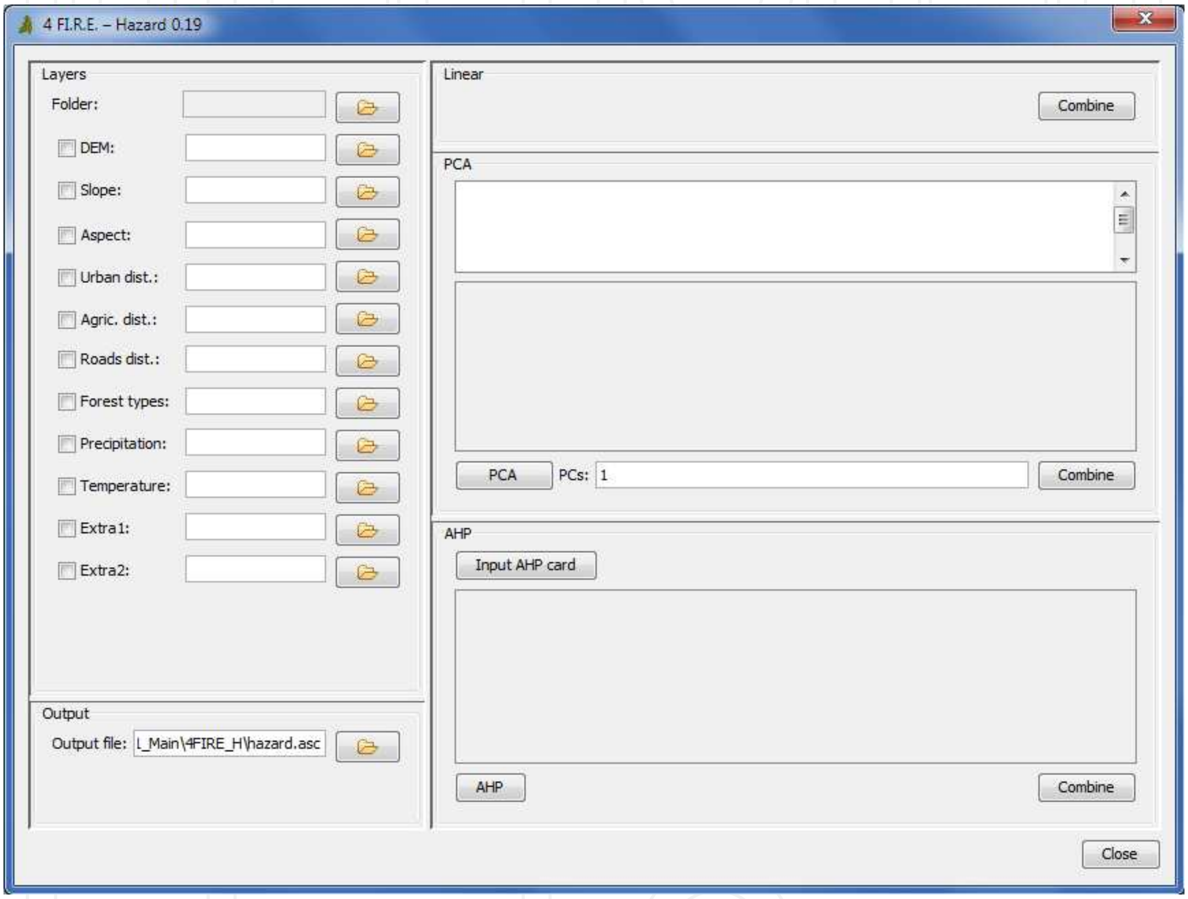

Figure 5. Layer combination user interface

The procedure described so far applies to fire hazard analysis performed on actual data. The Hazard module provides also a means to create hazard maps for future scenarios. The procedure to analyse future data is the following:

1. Import of input layers for actual scenario; 2. Calculation of actual Monte Carlo maps for input layers based on historical fire data; 3. Generation of Lookup Tables (LUTs) to link every actual variable class to its Monte Carlo score; 4. Application of the LUTs to future data to derive future Monte Carlo maps; 5. Overlay of future Monte Carlo maps to generate the hazard maps for future scenario.

This procedure is based on the assumption that the relationship between every variable and its contribution to fire hazard is constant in time. The two different data flows for the current and future data processing are depicted in Figure 3.

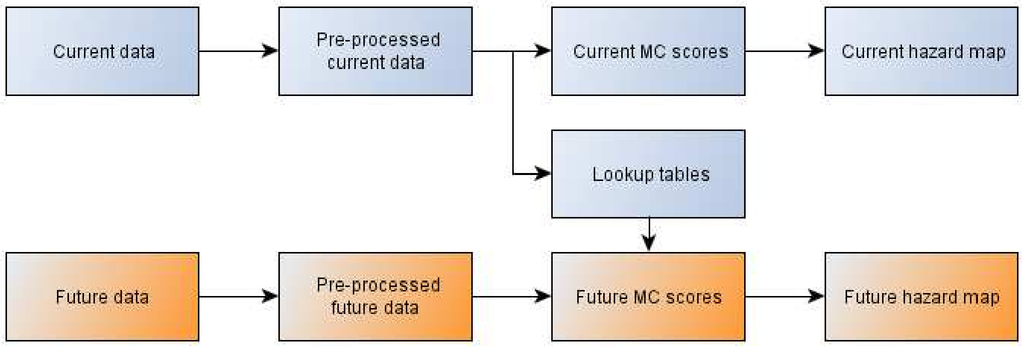

Figure 6. Data flows for actual scenario (blue) and future scenario (orange).

The tool has been utilized to obtain hazard maps for the current situation and, based on future scenarios of temperature, precipitation and land use, the fire danger evolution up to 2080. Therefore, in the short-term, the tool results in an efficient support in the planning of hazard mitigation strategies. In the long-term, it allows to address strategies for forest management according to the hazard scenarios that will be faced in the future.

3.2. 4FI.R.E — Vulnerability

The 4FI.R.E – Vulnerability module is dedicated to forest vulnerability mapping. The vulnerability is conceptually made of three components: woodland vulnerability, urban and infrastructure vulnerability, and population vulnerability. These three components are included in the Vulnerability module as three sets of input layers. The input layers are imported, rasterized (if needed), resampled and linearly combined to yield the final vulnerability map.

The woodland vulnerability component is made of several sub-components: vegetation resistance, vegetation resilience, vegetation protective function, vegetation productive function, vegetation naturalistic function, vegetation touristic function, and vegetation carbon stock function. Typically the input layers are classified in three classes: low, medium, high. The naturalistic function is given by the combination of the protected areas present. If the protective function map or the productive function map is not available, they can be replaced by proxy data. The protective function map can be replaced by the slope map. The productive function map can be replaced by two maps: the biomass map, and an accessibility map. The latter map is generated by the Vulnerability module from an input DEM combined with the roads map. A screenshot of the main user interface in visible in Figure 4.

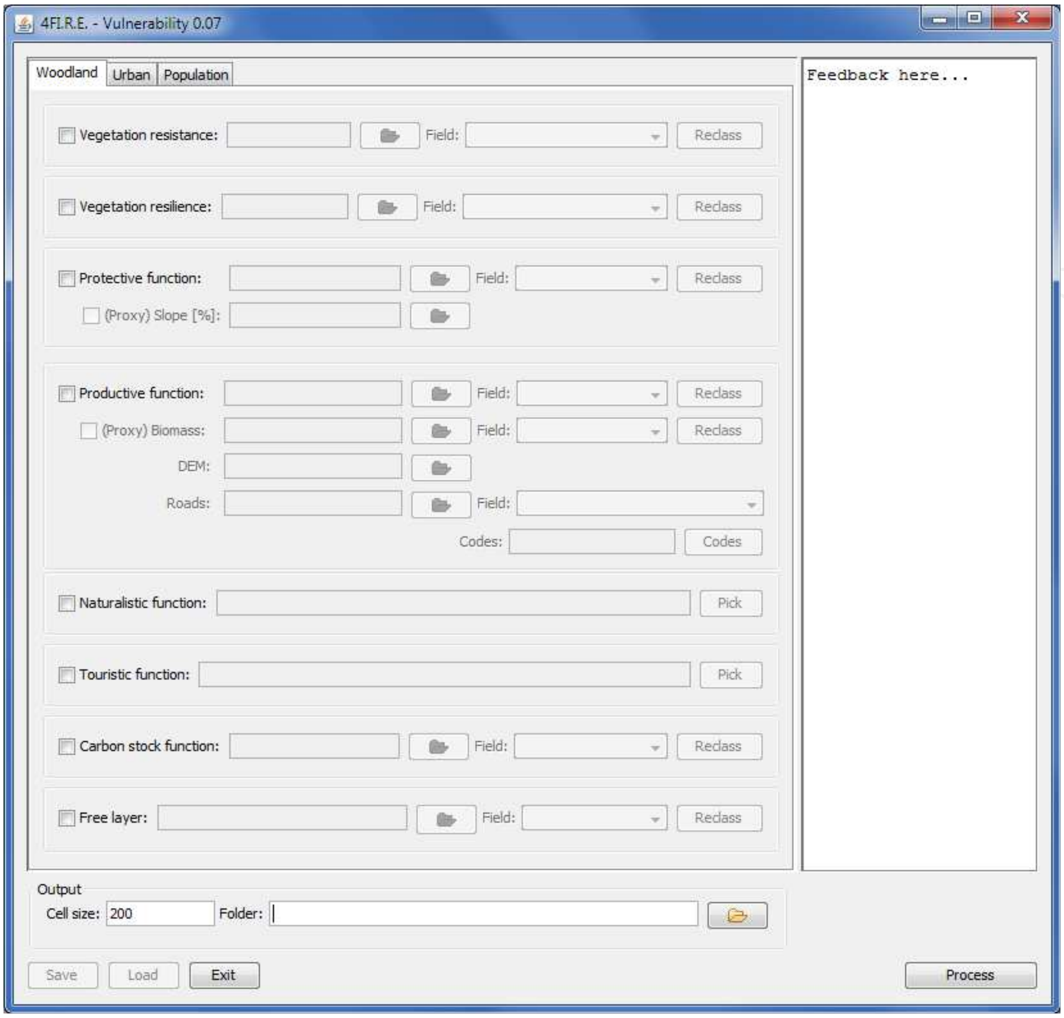

Figure 7. R.E Woodland vulnerability main user interface.

The urban and infrastructure vulnerability map is generated from a combination of a series of urban areas and features map given in input. The distance map from urban areas and features is calculated, and then reclassified into three classes.

The population vulnerability map is derived from the resident population map, reclassified in three classes.

The vulnerability map is given by the linear combination and normalization of all the pre-processed and reclassified input layers. The relative weights of the single input layers can be specified by the user.

3.3. 4FI.R.E — Risk

The definition of risk embedded in the tool refers to the likelihood of having a disaster or outcome, combining the probability of the hazard event with the expected consequences of the hazard (Allen, 2003; Brooks et al., 2005). Risk is defined by the following formula:
Risk = Hazard × Vulnerability

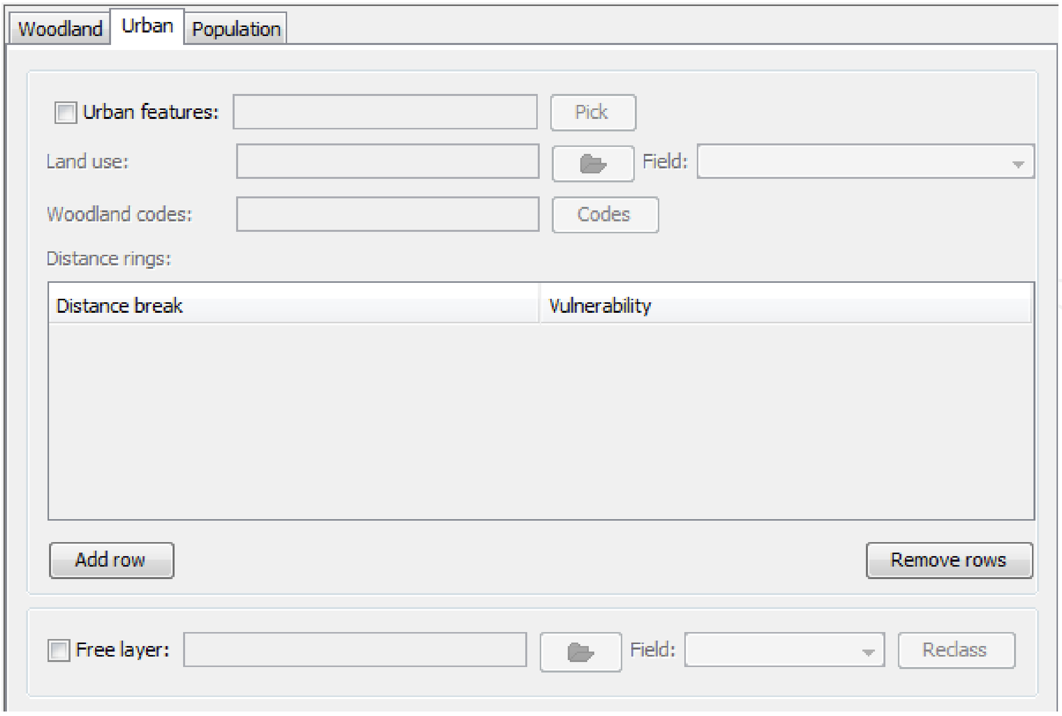

Figure 8. R.E Urban vulnerability main user interface.

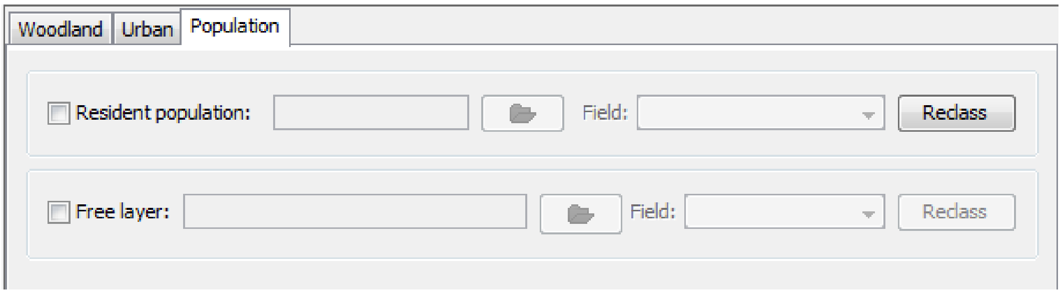

Figure 9. R.E Population vulnerability main user interface.

The final risk map builds on the integration of the hazard and vulnerability maps, where for a defined region, the level of risk is related to hazard potential, vulnerability or both.

4. Fire risk in the Alps: Today and future scenarios

4.1. Alpine space scale

The aim of this analysis was to evaluate forest fire hazard within the Alpine Space focusing the attention on current situation (year 2011) and a future scenario (year 2080). The probability maps of forest fires were produced by means of the tool 4FI.R.E (see previous section). The following data sources were used to derive maps of fire hazard: forest fire ignition points, Digital Elevation Model (elevation, slope, aspect), Land use (Urban and Agricultural areas -

buffers), Vegetation Map, Seasonal Precipitation and Seasonal maximum length of dry episodes (30-year mean; Winter: Dec./Jan./Feb.; Spring: Mar./Apr./May; Summer: Jun/Jul/Aug; Autumn: Sept./Oct./Nov.). Data on precipitation and maximum length of dry episodes for current and future scenarios were provided by AIT - Austrian Institute of Technology, whereas data on land use for both scenarios were made available by WSL - Swiss Federal Institute for Forest, Snow and Landscape Research. In detail, the hazard calculation was performed using the A1b scenario data (Intergovernmental Panel on Climate Change - IPCC, 2000). The ignition point coordinates were available only for a subset of the data (i.e. Italy, Austria, Slovenia, Switzerland), as shown in Figure 10. The seasonal hazard maps for the current and future hazard scenarios in the Alpine Space were produced by using the available ignition point coordinates, required as input for the hazard processing.

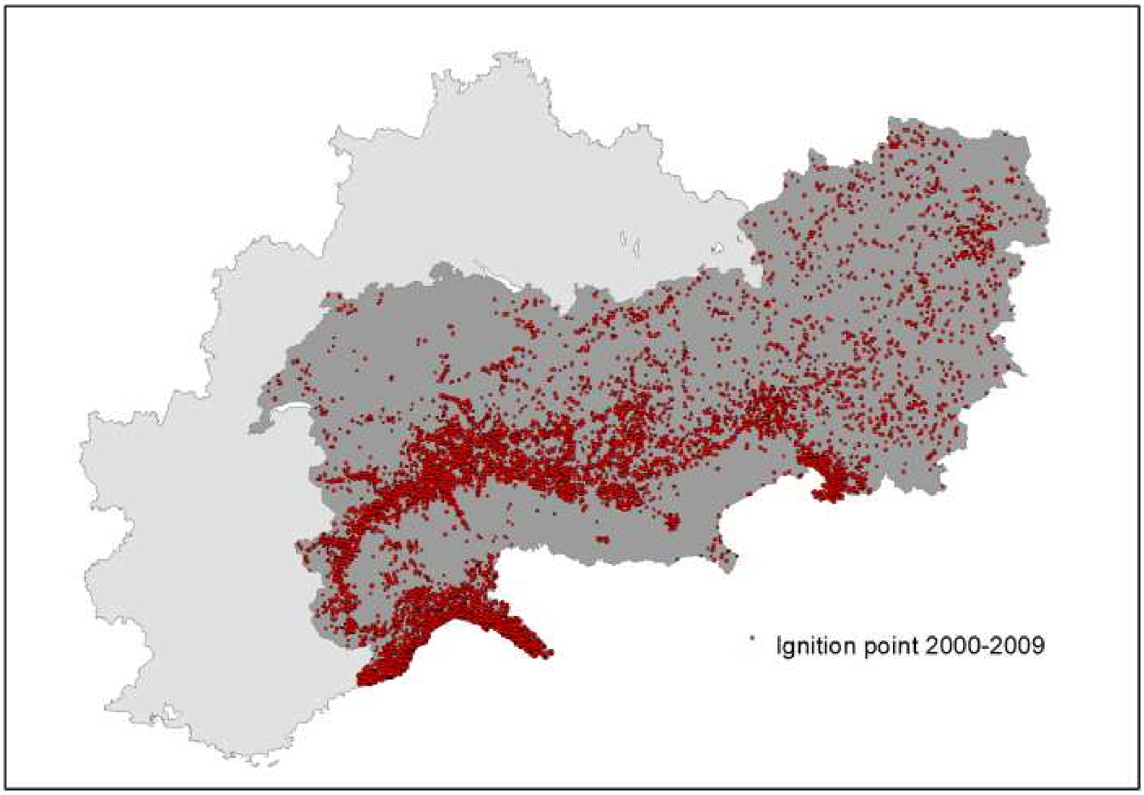

Figure 10. Alpine Space, ignition points 2000-2009

The comparison of the seasonal hazard maps (2011 vs 2080,) showed some significant changes between summer and winter seasons (Figure 11 and 12). According to the future scenario at 2080, it's possible to state that larger part of the analyzed area will be affected by an increase of the likelihood of forest fires events.

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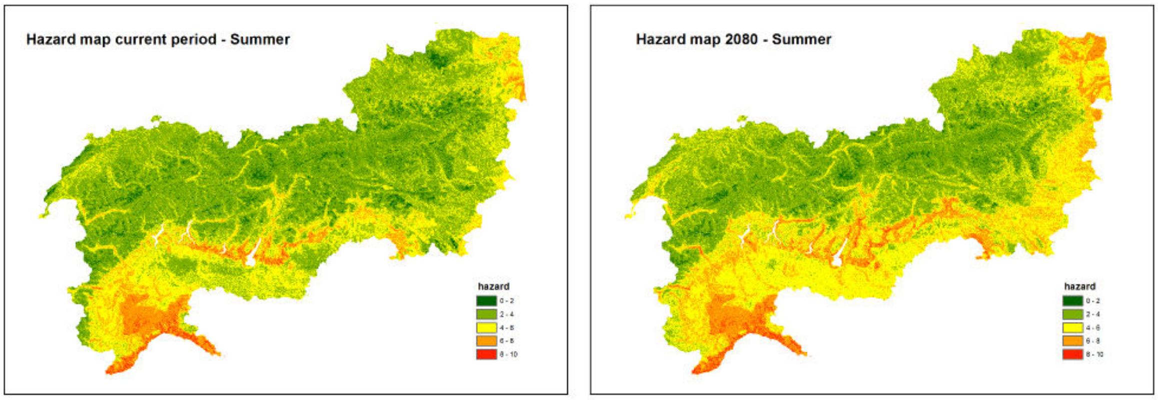

Figure 11. Alpine Space, maps of summer hazard (2011 - 2080)

It is likely that the adopted future climate scenarios showed an overall reduction in precipitation and increase in maximum length of dry episodes both in winter and summer seasons. This fact is probably related to the concentration of precipitation events in short time periods. The trend outlined for the hazard fire depicts a lower hazard in spring and autumn driven by the increase of rainfall and a slight increase in the maximum length of dry episodes.

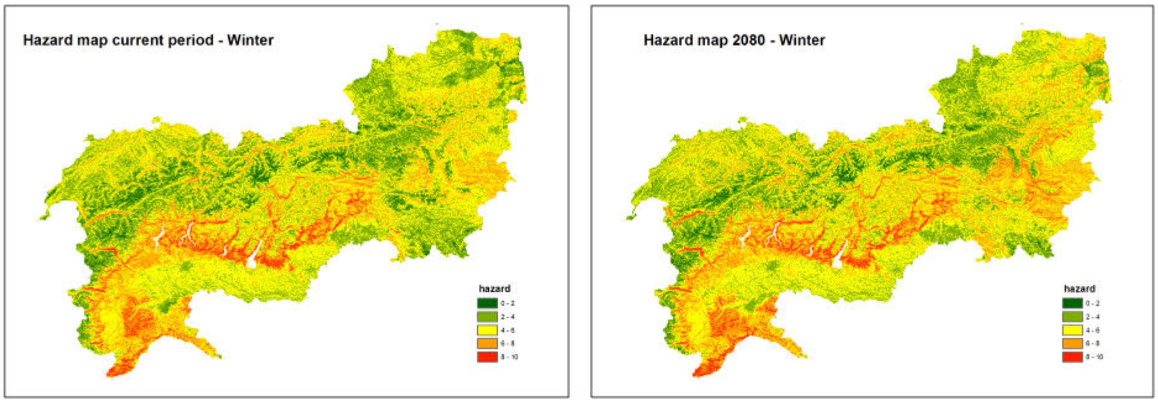

Figure 12. Alpine Space, maps of winter hazard (2011 - 2080)

4.2. Regional scale: Lombardia region and Slovenia

4.2.1. Lombardia region

As in the previous analysis carried out at Alpine scale, the objective was to have a picture about forest fire hazard of the current (2011) and future (2080) scenarios at regional level. Again, the hazard maps of scenario were produced by means of 4FI.R.E tool. using the following data: forest fire ignition points, Digital Elevation Model (elevation, slope, aspect), Land use (Urban and Agricultural areas - buffers), Vegetation Map, Seasonal Precipitation and Seasonal temperatures (30-year mean; Winter: Dec./Jan./Feb.; Spring: Mar./Apr./May; Summer: Jun/Jul/

Aug; Autumn: Sept./Oct./Nov.). Precipitation, Temperature and land use data under current period and future scenarios were made available by WSL - Swiss Federal Institute for Forest, Snow and Landscape Research. In detail, the hazard calculation was performed using A1b scenario data (IPCC, 2000).

The hazard maps comparison (2011 *Vs* 2080) showed for the future scenario a general increase in the hazard, lead mainly by temperatures increase. During summer and winter seasons Lombardia region is likely to face a the most important change in fire hazard with a shift from low to medium hazard classes. In autumn the future trend depicts an increase in the higher hazard classes. The spring scenario shows a reduction of risk closely related to the future increase in rainfall events. Following a clear spatial pattern, the eastern part of the region will be most likely to face higher hazard levels than the western part. Graph 1 shows the number of past fires events (2000-2009) divided per season and danger class. The number of past fire occurrences increases linearly with the hazard values. Only the class 9-10 shows a decrease in the number of fires events in respect to the previous classes.

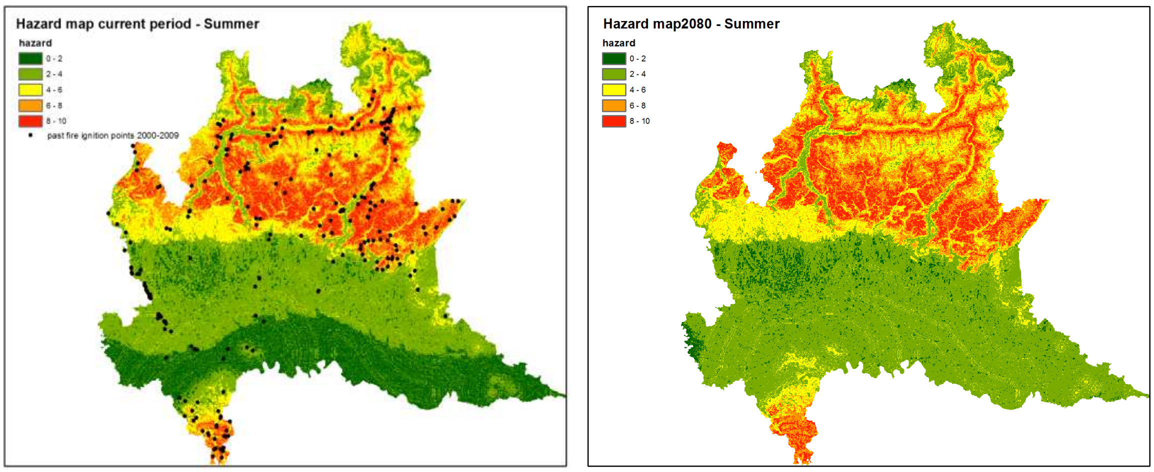

Figure 13. Lombardia Region, maps of summer hazard (2011 - 2080)

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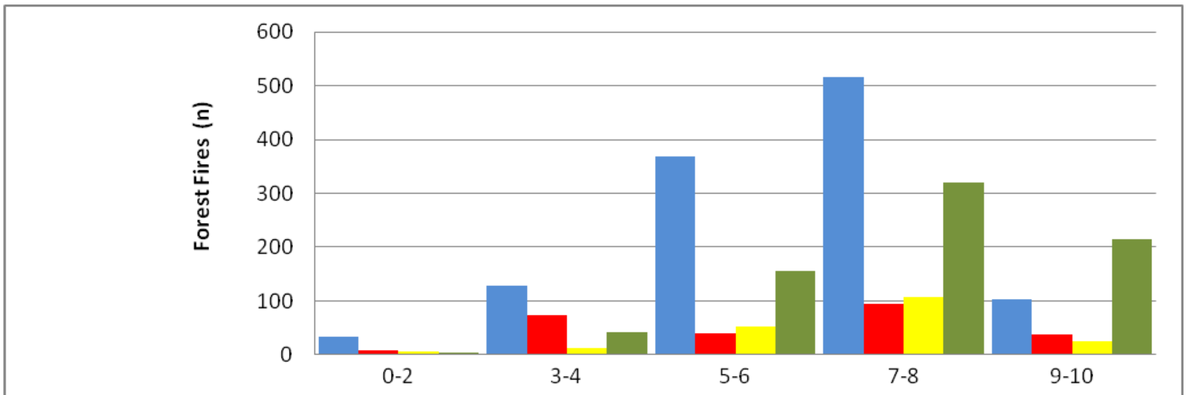

	0-2	3-4	5-6	7-8	9-10
Spring fires 2000-2009	34	128	369	515	104
Summer fires 2000-2009	8	73	41	95	37
Autumn fires 2000-2009	6	13	53	107	25
Winter fires 2000-2009	4	43	156	321	215

Figure 14. Intersection of past fire occurrences (2000-2009) and 2011 hazard map

Here we have to take into account that the hazard maps were produced considering, as relevant factors, morphological features (elevation, aspect) and meteorological conditions (precipitation, temperature).

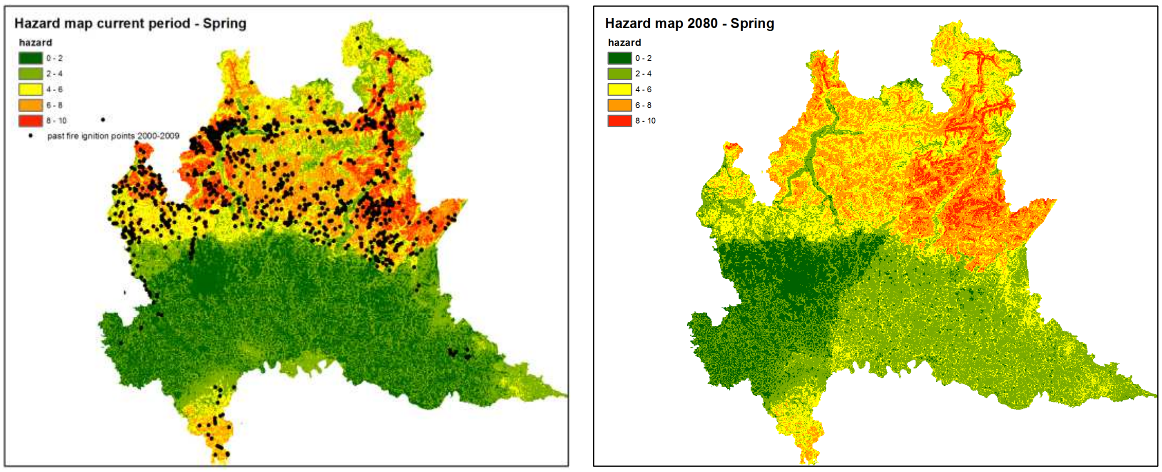

Figure 15. Lombardia Region, maps of spring hazard (2011 - 2080)

Some other factors, mainly linked to human interference were only partially considered due to lack of information.

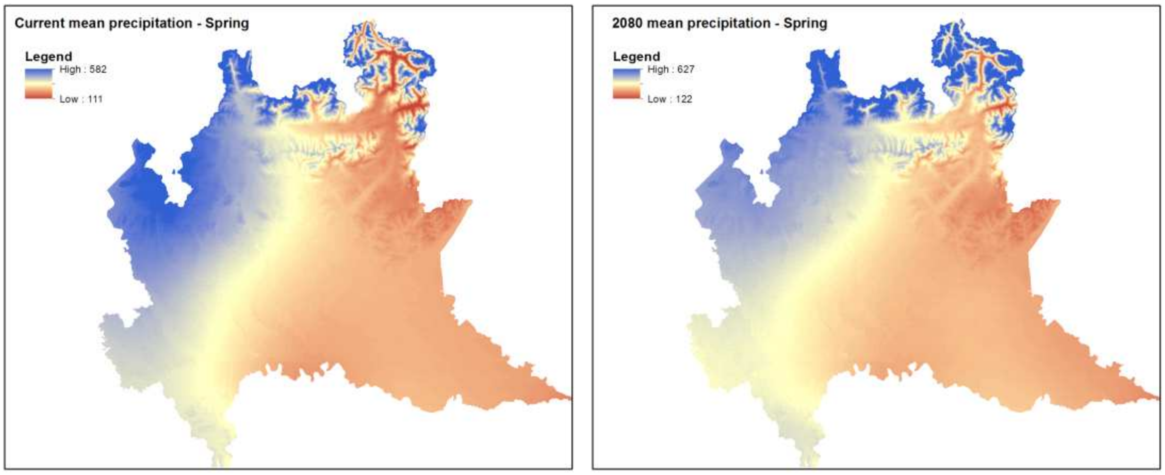

Figure 16. Lombardia Region, maps of spring precipitation (2011-2080)

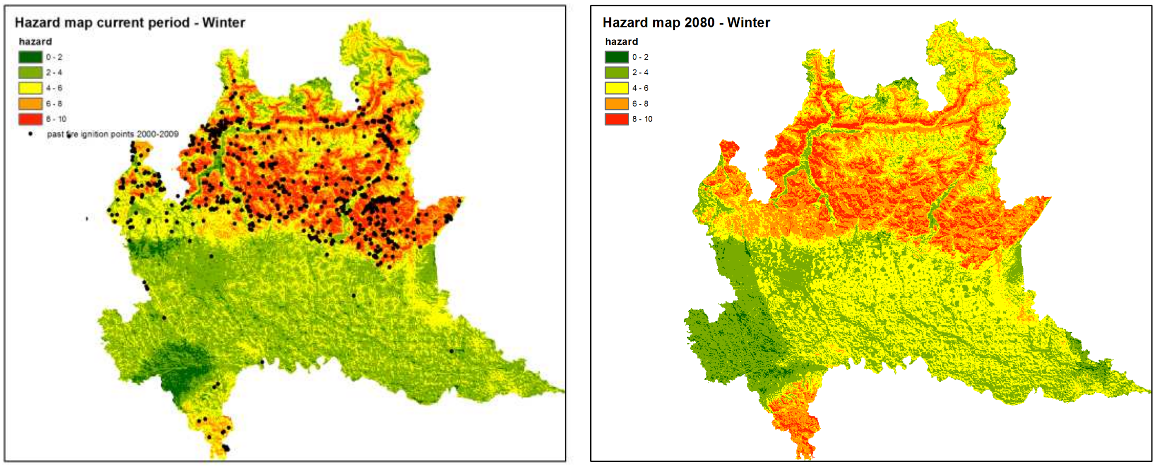

Figure 17. Lombardia Region, maps of winter hazard (2011-2080)

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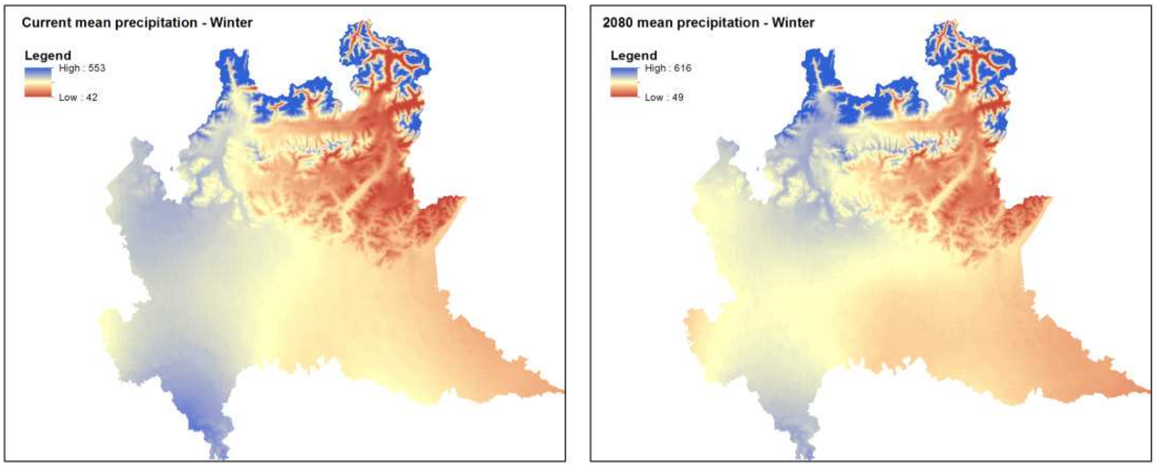

Figure 18. Lombardia Region, maps of winter precipitation (2011-2080)

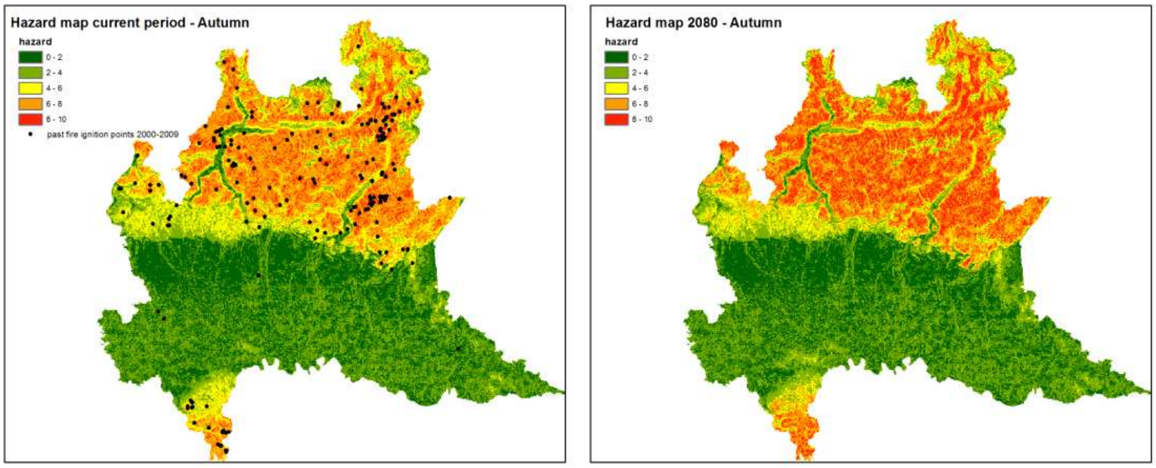

Figure 19. Lombardia Region, maps of autumn hazard (2011 - 2080)

4.2.2. Slovenia

Objective of the following analyses is to obtain some additional information about present and future fire hazard risk scenarios in Slovenia. For this purpose hazard tool 4FI.R.E was used.

GIS layers that were used in the model were:

location of past fire ignition sources (points)[1] (from years 1995 until the end of 2009);

digital elevation map[2]–cell size 100x100 m;

1 Dataowner: SlovenianForestryService, 2012

2 Dataowner: The Surveying and Mapping Authority of the Republic of Slovenia, 2005

map of land use[3] (Urban and Agricultural areas)– cell size 100x100 m;

1. mean precipitation for months April - September (summer) and October- March (winter) for the present time (year 2011) and the future (year 2080),
2. mean monthly temperature averaged for months April - September (summer) and October - March (winter) for the present time (year 2011) and the future (year 2080).

Precipitation and temperature data for present and future scenarios were obtained from WSL - Swiss Federal Institute for Forest, Snow and Landscape Research. The hazard calculation was performed based on the data from A1b scenario (IPCC, 2000), model name "mpi_clm_echam5_ar4_wccru". Land use scenarios maps provided by WSL were not used in this model due to their coarser precision (cell size 250x250 m), so national land use maps were used which are in vector format. We assumed that the change of land use will not be so obvious in the near future comparing the resolution differences of both maps.

Comparison of modeled hazard maps created for present time (summer and winter) with the locations of past fire events in Slovenia shows good matching results for the Karst area (figure 17 - left). This part of the country was in the past also the most endangered part concerning the number and size of fire events. In addition, we have to stress that created hazard maps have some deviances, especially in central (south of the Ljubljana) and in south-eastern par tof Slovenia. In these two areas the hazard maps show high fire risk, but as could be inferred from past fire ignition data (1995 - 2009) there were few fire occurrences in the past. The north-western (only for summer time) and north-eastern part were endangered in the past with fire events while the hazard maps predicted low fire risk.

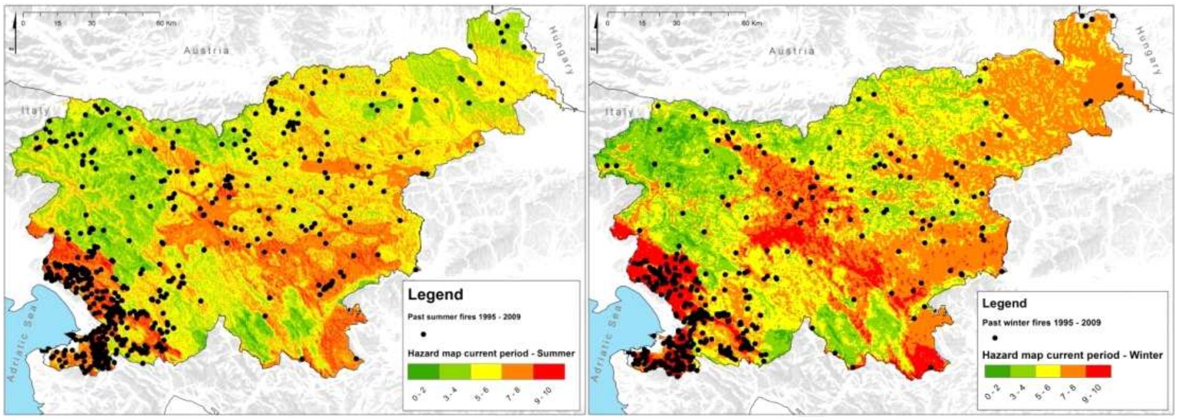

Figure 20. Slovenia summer hazard maps (left) and winter hazard map (right) with locations of past fire ignition points

Intersection of past fire occurrences with modelled hazard maps created for present time (Table and Graph 2) show proper agreement with hazard values 0 to 8, e.g. the number of past fire occurrences increases linearly with the higher hazard values, but there are some deviances in class 9-10.

3 Dataowner: Ministry of Agriculture and the Environment, 2012

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Value of hazard	Summer fires	Winter fires
0-2	8	2
3-4	105	33
5-6	260	139
7-8	343	259
9-10	32	94
Total number of past fires	764	541

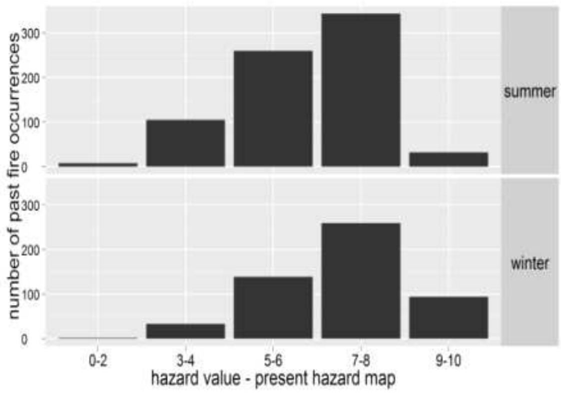

Figure 21. Intersection of past fire occurrences (1995 – 2009) with the present hazard maps

Those areas should be the most endangered but the number of past fires events is very low. Nevertheless we have to take here into the consideration that the hazard maps show the potential hazard area which is based on elevation, aspect, precipitation etc. but not on some other factors, e.g. anthropogenic interference.

The comparison of hazard maps (summer period) for 2011 and 2080 shows that Karst area will remain the most endangered part of Slovenia. Fire ignitions are predicted to increase in the eastern and especially in the north-eastern part of Slovenia. The area with hazard classes 9-10 will decrease from 7 700 ha to 4 100 ha, but the sum of area of classes 7-10 will increase from 268 600 ha to 272 000 ha in next 70 years. One of the key factors affecting the increase of the fire risk in eastern parts of Slovenia could be the predicted reduction of precipitation (figure 18) during the summer. On the contrary, the decreased hazard in central Slovenia could be a result of predicted higher summer precipitations.

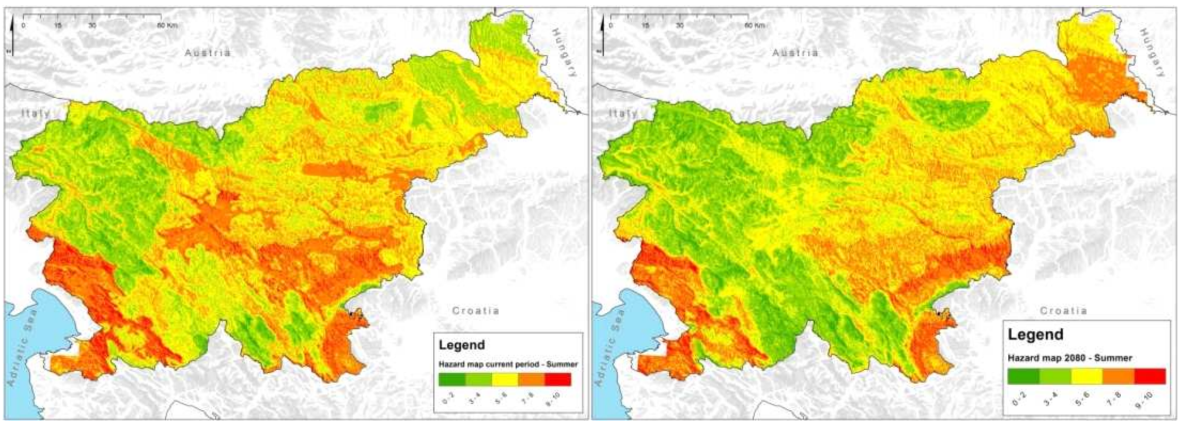

Figure 22. Slovenia summer hazard maps (left: current hazard situation; right: future hazard situation 2080)

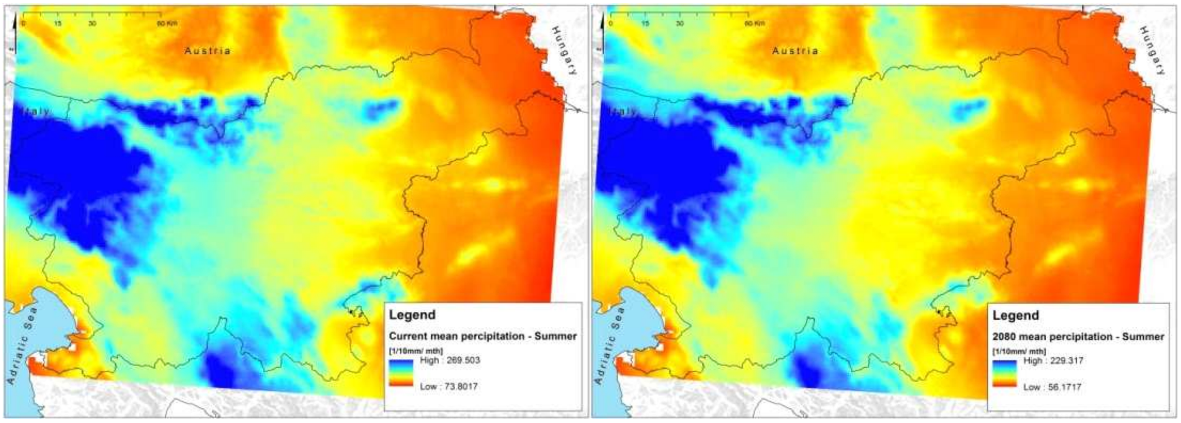

Figure 23. Summer precipitation maps for Slovenia for current period and prediction for the year 2080 (source: WSL)

The comparison of hazard maps (winter period) for 2011 and 2080 show that in the future we can expect the decrease of hazard at the Inner Carniola-Karst region, small part of the Southeast Slovenia and in the northern part of Central Slovenia. The highest increase of hazard is supposed in the northern part of Slovenia. The cross tabulation of both maps show that at this time 38 120 hectares of Slovenia is under high hazard risk (class 9-10) and this area will increase to 40 294 hectares in the year 2080.

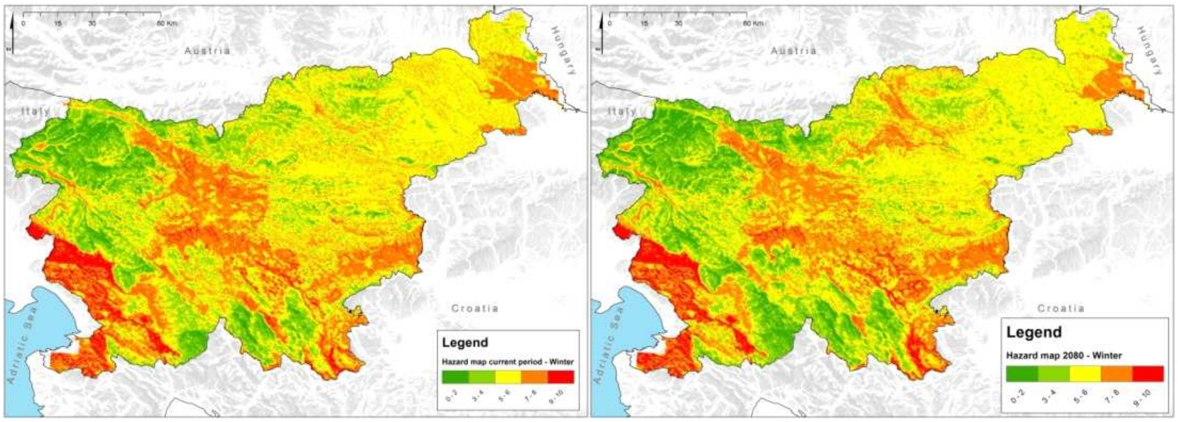

Figure 24. Slovenia winter hazard maps (left: current hazard situation; right: future hazard situation 2080)

From created fire hazard maps for year 2011 and 2080 we can speculate that the number of summer and winter fires will increase in the eastern part and decrease in the central part of Slovenia. One of the main reasons for these changes could be found in predicted changes of precipitation regimes. The Slovenian Karst region will remain a high risk area also in the future.

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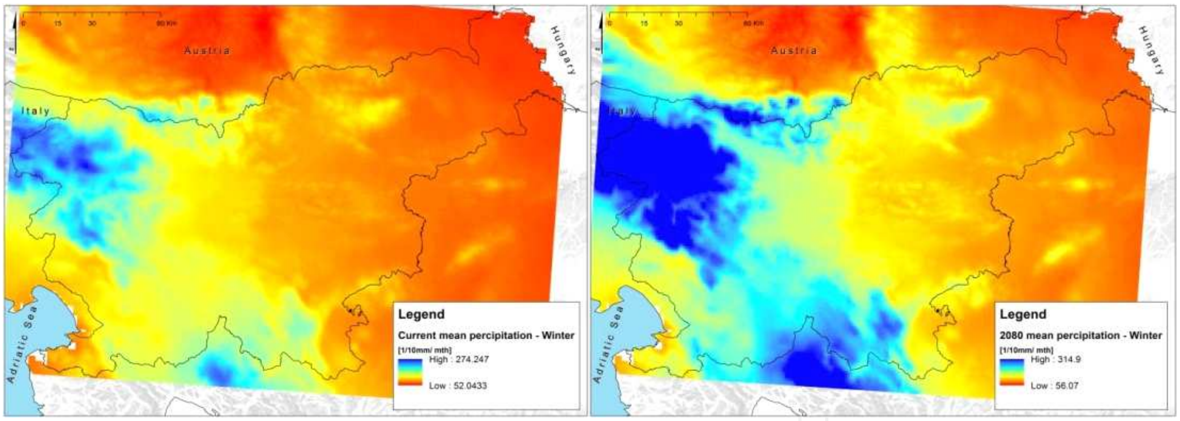

Figure 25. Winter precipitation maps for Slovenia for current period and prediction for the year 2080 (source: WSL)

5. Introduction and objectives

It is well known that wildfires create profound changes in the ecosystem, and in terms of remote sensing signal these changes provoke variations in surface reflectance, moisture and temperature. The use of spectral vegetation indices is a common tool in many studies regarding forest regeneration after fire disturbances. For example, the NDVI (Normalized Difference Vegetation Index), is associated to vegetation greenness and provides a means for monitoring density and vigor of green vegetation, being the most extensively used to assess and monitor post wildfire processes. Another index, sensitive to canopy greenness and canopy structure is the EVI (Enhanced Vegetation Index) that is becoming common in studies related to burned area mapping and assessment. Satellite remote sensing has been successfully employed to evaluate post-fire dynamics and, depending on the eco-regions, a post-wildfire recovery period has been found vary from 5 to 9 years (boreal forest of Canada) and more than 13 years in Siberian forests. However, no study has been carried out to evaluate the performance of satellite vegetation indices to analyze forests after a wildfire disturbance in Alpine areas.

This study investigates the dynamics of postwildfire in Alpine forests exploiting time series of NDVI and EVI indices derived from Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite. Time series from 2000 to 2010 were used to analyze characteristic temporal patterns and post-wildfire dynamics in the Lombardia Region (Italy) in order to evaluate different behavior of post-wildfire recovery period.

5.1. Methodology

Study area and forest burned area database

The study area is located in Lombardia region, Northern Italy and it is composed by a mosaic of deciduous, evergreen forest and pasture, where wildfires mainly occurs in winter period.

The forest burned area map used in this study was produced by ERSAF Lombardia and it was used to select the samples for this investigation. Overall, dataset consists of 3385 polygon occurred from 2000 to 2009. For this study, based on MODIS data, only large fires were considered (area> 40 ha) and a subset of 84 events was considered. Post-wildfire dynamics were investigated by analyzing the selected burned areas in comparison with paired adjacent unburned areas (control plots). Particular attention was paid to extract burned and unburned surfaces. Pixel of interest were identified by intersecting the MODIS grid (250x250 m) with the map of fires (polygons), retaining only the pixels which showed at least 80% of burned surface area.

Development of satellite time series - MODIS 16 days composite NDVI and EVI data with 250 m spatial resolution acquired from Terra platform in the 2000-20010 period were used to evaluate the post-fire dynamics. Maximum NDVI and EVI values were automatically extracted and the start and end of season dates were then computed as the day of the year (DOYs) corresponding to the first and to the last zeroes of the third derivative of the fitted curve. The pairs of burned and unburned areas were grouped according to the year of the fire. The difference of the vegetation indices was then calculated for each pair to analyze the response of NDVI and EVI to disturbance over time, accounting for the influence of interannual variability and other environmental factors captured in the unburned areas. In this case the zero on the time scale of the time series represents the year of burn.

5.2. Results and discussion

The EVI time series of burned and unburned area along 10 years of the Monte Argua Covallo winter fire event that involved 75 ha of a mixed deciduous forest type is shown in Figure 26. The EVI shows reduced values at the time of wildfire followed by a gradual period of recovery. A one-way ANOVA indicated that after 4-5 years after the wildfire, the differences between the burned and unburned areas were not significant at the 95% confidence level for the EVI.

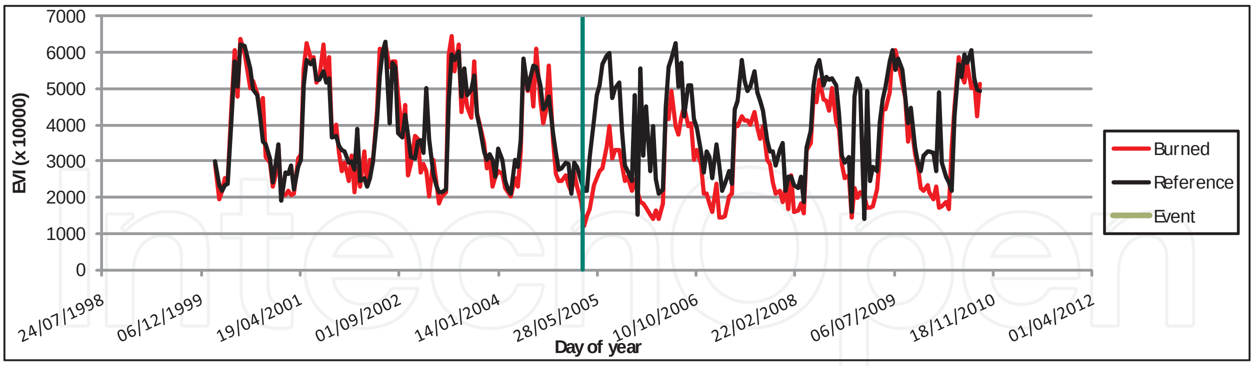

Figure 26. Example of the MODIS EVI time series of the of Monte Argua Covallo winter fire and for the reference surface.

Wildfire effects on EVI max and NDVI is clearly evident in Figure 27.

The drop in values at the time of the wildfire event corresponds to a massive or total loss of healthy, life vegetation combined with the reflectance signal of the ash covering the soil and burned materials. The subsequent increase in the first years following the fire is often caused by a rapid growth of the herbaceous layer and possibly surviving shrubs (Colombo et al., 2011). In the subsequent years, seed regeneration occurs. This gradually increases the amount

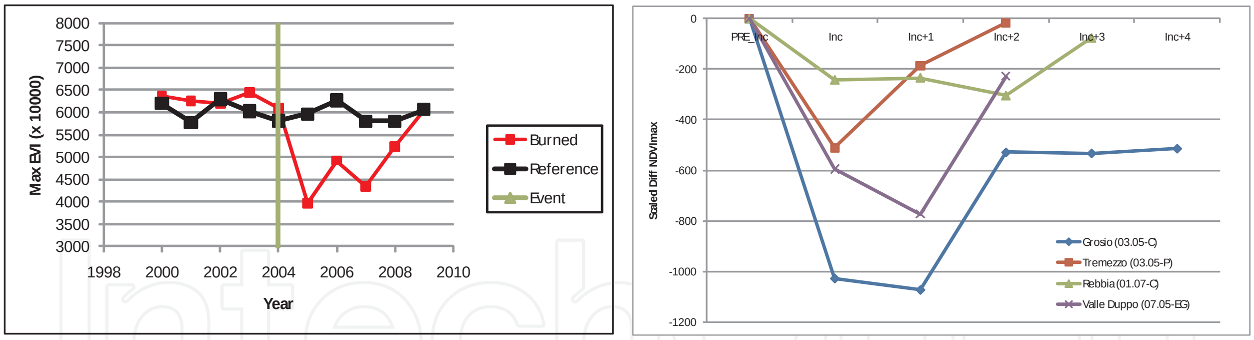

Figure 27. Example of the MODIS EVI maximum values time series for the of Monte Argua Covallo winter fire and for the reference surface (left) and the temporal variability of fires occurred on different land cover

of healthy green vegetation and re-introduces a vertical structure, causing a further increase in both NDVI and EVI.

The difference between the burnt area and the control sites can be considered a measure of the impact of wildfire on the NDVI/EVI. Although for the Monte Argua Covallo this impact is not very large, it continues until 4 years after the fire. After this, the forests follow a similar trend towards full recovery of the EVI signal. These observations are consistent with those found in previous study with similar recovery periods for different ecoregions.

The analysis of the length of the growing season shows that fire affects its temporal variability differently. It was found that some events are characterized by strong variations in the overall length of the growing season, while other recover quickly after fire events.

5.3. Conclusions

The post-wildfire regeneration of Alpine forests in Lombardia region was investigated using a 10-year observation period of remotely sensed MODIS NDVI and EVI time series. Satellite images allowed us to preliminarily explore the damage and vegetation recovery following wildfires. In this study, the terms regeneration or recovery of NDVI and EVI were related to the process of post-wildfire regeneration or recovery as measured by these indices and not the process occurring on the ground (e.g. the satellite signal may be the same even if different vegetation species are present after the fire). This means that, for example, the NDVI signal after a stand-replacing wildfire may return to the pre-wildfire levels but the vegetation on the ground is not in the same state (e.g. there are different species before and after the wildfire) as it was before the wildfire. By coupling data from adjacent burned and unburned control sites, we were able to separate interannual variations caused by the local climate from changes in the behavior due to a wildfire. Results indicate that spectral indices and phenological parameters can be useful to evaluate the response of the vegetation to fire events. Sometimes it takes more than 5 years for the NDVI and the EVI signal to fully recover after severe wildfire and the length of the growing season may decrease of about two weeks. In other cases, the effects are smaller, or not visible at all.

6. Forest management strategies

6.1. Risk mitigation: Key concepts

Prevention strategies are recognized as a key aspects in forest fire risk management and mitigation. On the basis of the adopted strategies, preventive measures against forest fire risk can be distinguished into indirect and direct (Figure 24).

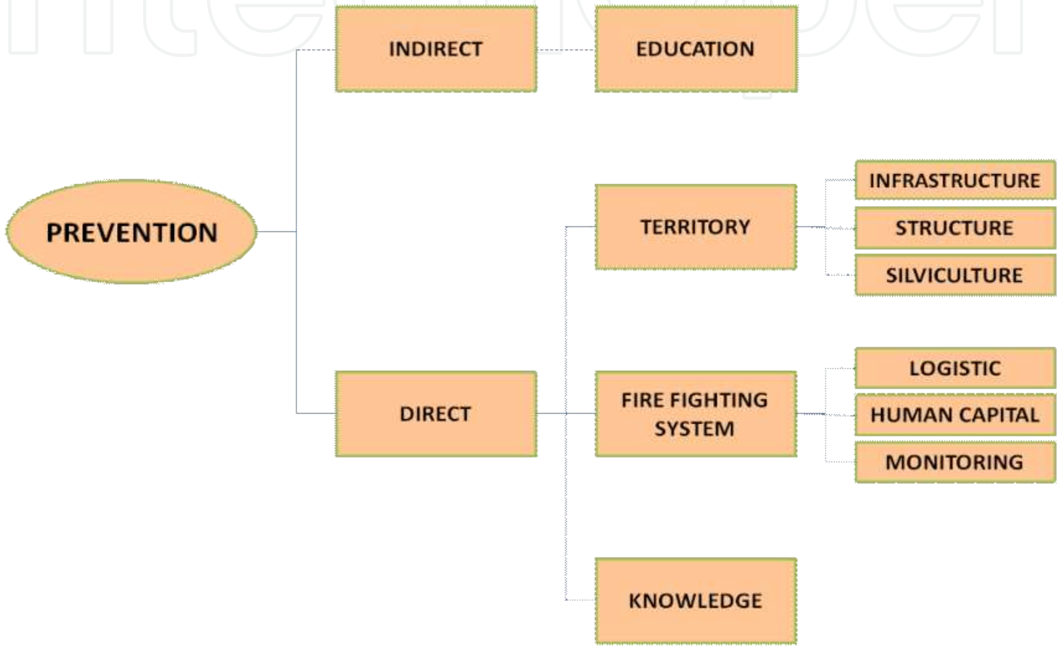

Figure 28. Summary scheme of preventive measures.

Indirect prevention includes strategies and activities aimed at controlling determinant causes of forest fires. It encompasses the set of measures designed for dissemination, training and education towards population. In detail, the activities are mainly focused on:

- reduction of forest fires due to human causes;
- protection of life and properties;
- increasing awareness and self protection abilities.

Direct prevention includes prevention activities acting on predisposing factors that may favor spread or control of fires. This is expressed through direct actions on the ground, on the fire alarm system (system organization, training and monitoring) and on knowledge system (research, planning).

6.1.1. Indirect prevention

Indirect prevention refers to activities against forest fires mainly oriented on determinant causes such as education and information on forest fires problem to population. In fact, at

Alpine level, the greatest part of forest fires are caused by human activities, often due to careless and unintentional actions linked to agricultural and forestry operations. Hence, targeted public education become a key issue in those areas showing an higher forest fire risk. Target groups need to be identified and adequately informed about fire risk by means of education and media (radio, television, press releases and news). In the process of target group definition it is always advisable to analyze the causes of forest fire. For instance, if fires are mainly caused by a carelessly tossed cigarette, then indirect prevention actions must be addressed to smokers, identifying the most appropriate channels to spread information. In general, it is important to increase awareness about forest fire risk with general public, properties owners, stakeholders and people involved in forest fire prevention.

6.1.2. Direct prevention

Direct prevention measures are taken to avoid outbreak and spread of fires, working on ecological and forestry parameters (i.e. density, structure, composition) in order to decrease danger and damages.

Three main categories can be considered in the analysis of direct prevention and forest fire risk mitigation:

- **Fire Infrastructure/Structure/Equipments -** Includes all the infrastructures, structures, equipments that can be used in forest fire fighting (roads, fixed tanks, water points, lakes and reservoirs for aircraft, helicopter landing sites, etc.).
- **Organization of Forest Fire Fighting System (FFFS) -** FFFS's has a central role in forest fires fighting. FFFS is expressed in terms of: number of teams, volunteers, vehicles, equipment (mobile tanks, modules, and blowers), support equipment (radio fixed, mobile and vehicular).
- **Planning and Monitoring (prevention) -** It includes action plans for forest fire fighting at ground level and monitoring measures carried out by means of aerial flights (air patrol) and/or fixed cameras positioned in strategic areas. This kind of prevention enables to seize peculiarities and problems of each territory, providing appropriate measures to achieve mitigation objectives.

6.1.2.1. Direct prevention — Territory

Infrastructure

The accessibility of the territory ensures the possibility of territorial monitoring and an early intervention in case of fire.

Road network. An efficient road network is important to allow access of forest fire fighting personnel, equipment and means, in areas prone to forest fires. Forest roads in particular are important to control fire spread, acting as physical barriers to fire movement and increasing accessibility for fire suppression activities. New forest roads should be planned according to forest fire risk plans in those regions more sensitive and prone to forest fire ignition and spread. Technical characteristics of agro-forestry road network, related to planning and management purposes, should facilitate forest fire fighting operations (e.g. setting of temporary water supply points). Forest road maintenance should be regularly carried out over time, planning interventions (e.g. cleaning of the channels), in order to keep the road surface in good condition, removing any obstacles that restrict the access to forest fire means and vehicles (i.e. logs or boulders). Accessibility is another key point to ensure early and appropriate interventions, avoiding that a fire develop into an uncontrolled event.

Structure

The presence of structures, functional for prevention and forest fire control, is an essential element in any efficient fire management system.

Water supply. Water supply (natural watercourses, dams, wells, ponds, underground water tanks, etc.) placed in strategic locations can be used in firefighting operations. Water reservoirs once implemented should be regularly checked for functionality and accessibility to enable their efficient use during fire suppression phases. Water supply can be distinguished in permanent water supply and mobile water supply. Permanent water supply are located and usually dimensioned in view of the mean burned area (derived from statistic data on forest fire) of a specific area. In order to allow a correct fire management, in the Alpine area the capacity level of permanent water supply have to reach at least 20000 liter per hour (l/h). The water has to get at least 1 m depth corresponding to the minimum level allowing a correct water supply of helicopters.

Permanent and temporary and helipads. Permanent and temporary helipads are settled up in those areas showing a higher probability of forest fire occurrence. Helipads need to be dimensioned to helicopter size (with at least a 30 meters side) and road network characteristics. It is also advisable that the location selection considers the minimum number of helicopter discharge during a forest fire event (15-20 per hour).

Silviculture

Preventive silviculture aims at preventing occurrence and spread of fires by decreasing the amount of flammable material and promoting ad hoc forest management practices to reduce forest susceptibility to fire. The main objective of silvicultural measures is to avoid that a ground fire transforms to a crown fire (difficult or almost impossible to extinguish). In this sense, one of the most effective ways to reduce the likelihood of having a crown fire is to reduce the amount of fuel. Silvicultural practices must be addressed to avoid situation of monospecificity, supporting at the same time conversion of coppice to high stand forests (highly recommended in chestnut forests) and presence and maintenance of less represented forest types. The most common silvicultural practices addressed to forest fire management and risk reduction are:

a. thinning, cutting and removal of small trees in presence of forests characterized by high tree densities or physiological stress (may include the removal of dead trees and shrubs);

b. selection cutting performed in adult and monospecific forests to improve structural complexity and to increase the presence of deciduous trees. Increasing the proportion of deciduous trees decrease the likelihood that a ground fire evolves into a crown one;

c. cultural practices adopted in intensively managed coppice, to decrease dead fuel availability;

d. conversions applied in degraded coppice located in areas with high danger of forest fires;

e. reafforestation programs to enhance the restoration of degraded forest habitats in presence of monospecific structure or over-managed areas;

f. environmental cleanup: post-fire treatments to remove dead vegetation;

Post-fire restoration generally refers to long-term efforts required to restore habitat quality, resilience, and productivity. According to the main forest function (timber production, disaster protection, recreation, environmental...) measures consist of:

1. cutting of burned trees: cutting of burned trees and release of subjects with the highest survival probability;

2. direct seeding: seeding of herbaceous and woody species to prevent surface run-off;

3. reafforestation in order to mitigate potential increases in runoff and erosion which can occur immediately after a wildfire and promote wide range of forest associations less prone to forest fires, more resilient, productive and with higher biodiversity values

4. construction of fire breaks (vegetated fire breaks, protective strips and fuel breaks):

5. vegetated breaks consist of strip of land (100-300 meters wide buffer strip) with presence of trees offering an higher degree of resistance to fire passage. The strip is suitable to contain the spread of forest fires increasing the probability that a crown fire downgrades into an easier to control fire

6. protective strip is a strip of land (20 to 30 meters wide buffer strip) covered by tree from which readily flammable material (twigs, shrubs, dry or deadwood) has been removed. The strip is created with the aim to decrease the flame front speed thus aiding fire suppression operations

7. fuel break is a strip of land (5 to 20 meters wide buffer strip) constructed and maintained along railways, motorways and highways and forest roads in those areas showing an high forest fire danger rate. In particular, fuel breaks along forest road network should be made on both sides of the roads

8. prescribed fire. Prescribed fire is the application of fire to a specific land area to achieve both prevention purposes (i.e. fire hazard reduction) and resource management objectives (e.g. plant community restoration, landscape and habitat conservation, etc). In forest fire prevention this technique is widely used to reduce the amount of ground fuel readily flammable. Fuel reduction is essential to prevent crown fires which burn at high intensity and are capable of causing irreversible damages. At Alpine level this fire management

tool has been recently introduced and fruitfully applied mainly for hazard reduction purposes.

6.1.2.2. Direct prevention — Fire fighting system

Logistic

The changing technology and increasingly demanding for safety led to the need of a regular equipment adaptation, means and resources for forest fire operators. Logistics includes PPE (Personal Protective Equipment), up to date means (aerial and terrestrial), office and field support for mobilizating firefighting resources during suppression operations (e.g personnel with GIS & GPS expertise).

Human capital

Human capital refers to the knowledge, skills, and abilities which people involved in forest fire fighting gathered over time trough education, training and culture. One of the key factors influencing incidence and spread of forest fires is the inadequate organizational system of fire prevention, prediction and active fight. This issue is mainly related to:

- poor capacity of cooperation;
- lack of knowledge about behaviour of the phenomenon;
- preparedness response and recovery

For that, long term training programs need to brought into play to provide (to qualified personnel) definite techniques and procedures to be adopted during suppression activities.

Monitoring

Remote sensing systems. Traditional and remote sensing systems for automatic monitoring and early detection of forest fires are of great importance in the context of prediction and prevention of fire danger and risk. The most used systems refer to ground or aero-satellite monitoring.

Ground monitoring stations. Ground monitoring stations are based on cameras located in strategic places. Terrestrial systems based on ground monitoring stations (video cameras, thermal imaging cameras, infrared spectrometers) allow an early detection of sources of heat with a low rate of false alarms.

Aero and satellite systems. Ground monitoring system is integrated by aerial monitoring. Planes are equipped with high spatial resolution cameras and a GPS system. GPS data allow for georeferencing and for orthorectification of the captured images in post-processing. Acquired images and data can also be send in real time to the operative centers of civil protection.This system allow to:

- provide information and images on forest fire behaviour;
- survey and mapping burned surface in real time;

http://dx.doi.org/10.5772/56273

- provide, during a forest fire, real time data useful for better coordination of suppression activities to local entities (municipalities, mountain communities, etc.).

Recently new remote sensing technologies like light detection and ranging (LiDar) and near infrared images (NIR) have produced significative advances in forest fire prevention.

Forest fire hazard indices. Forest fire hazard indices are a early warning tool designed for monitoring and predicting forest fire danger. Fire hazard indices are normally calculated on a daily basis starting from meteorological data as input (obtained by weather stations or radars). Fire hazard indices are recognized as a valuable tool allowing alert, preparedness and readiness of fire fighting services and civil protection. The most widespread index used to assess fire danger is the Canadian Forest Weather Indices (FWI).

6.1.2.3. Direct prevention — Knowledge

Knowledge management refers to the achievement and combination of technical and scientific advances, to accomplish resource and fire management goals and objectives. These information are directly transferred into prevention programs (i.e. fire management plans) and implemented on a broad legal and institutional framework. Fire management plans are the key element to identify and analyze risks caused by forest fire hazards providing long-term and sustainable solutions to address prevention, preparedness, readiness and recovery of communities, infrastructures, biodiversity and ecosystem.

Acknowledgements

This work was conducted under the European Project MANFRED, funded by the European Regional Development fund of the Alpine Space Program, reference number 15-2-3-D (MANFRED). We acknowledge the Italian National Forestry Corps and Valle Camonica Mountain Community for their support in this work.

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References

[1] Allen, K. (2003). Vulnerability reduction and the community-based approach, in Pelling (ed.), Natural Disasters and Development in a Globalising World. , 170-184.

[2] Brooks, N, Adger, W. N, & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change. , 15, 151-163.

[3] Colombo, R, Busetto, L, & Fava, F. Di Mauro, B., Migliavacca, M., Cremonese, E.,Galvagno, M., Rossini, M., Meroni, M., Cogliati, S., Panigada, C., Siniscalco, C., Morra di Cella, U., (2011). Phenological monitoring of grassland and larch in the Alps from Terra and Aqua MODIS images. Italian Journal of Remote Sensing. , 43(3), 83-96.

[4] Conedera, M, Torriani, D, Neff, C, Ricotta, C, Bajocco, S, & Pezzatti, G. B. (2011). Using Monte Carlo simulations to estimate relative fire ignition danger in a low-to-medium fire-prone region. Forest Ecology and Management. , 261, 2179-2187.

[5] IPCC(2000). Nebojsa Nakicenovic and Rob Swart (Eds.) Cambridge University Press, UK. , 570.

[6] Wastl, C, Schunk, C, Lüpke, M, Cocca, G, Conedera, M, Valese, E, & Menzel, A. (2013). Large-scale weather types, forest fire danger, and wildfire occurrence in the Alps. Agricultural and Forest Meteorolology , 168, 15-25.