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Case Study: Valle Camonica and the Adamello Park

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Additional information is available at the end of the chapter

1. Introduction

1.1. Present conditions in Valle Camonica and the Adamello Park

1.1.1. Site description and geography

Valle Camonica is a N-S oriented valley located in the Rhaetian Alps, and it is characterized by greatly heterogeneous ecosystems in a territory with elevations ranging from the 390 m a.s.l. of the valley bottom to the 3539 m of the Monte Adamello peak (Figure 1). The Adamello massif covers a large area in the north-eastern side of the valley, and it is covered by one of the largest glacier of the southern Alps (Pian di Neve).

The Adamello Park, founded in 1983, encompasses a surface of 51.000 ha and 19 municipalities in the district of Brescia within the Camonica Valley. It is located in the north-eastern part of Valle Camonica and it covers more than 60% of the valley area

The Park shares its borders with the Adamello-Brenta Natural Park and the Stelvio Natural Park, thus determining one of the widest protected area in Europe (even larger if we consider also the near Engadina National Park).

The land cover includes forests for the 37% of the area and pastures for the 14%. Thirteen percent of surfaces are not cultivated while an large amount of the territory, almost 36%, is unusable because covered by rocks or glaciers.
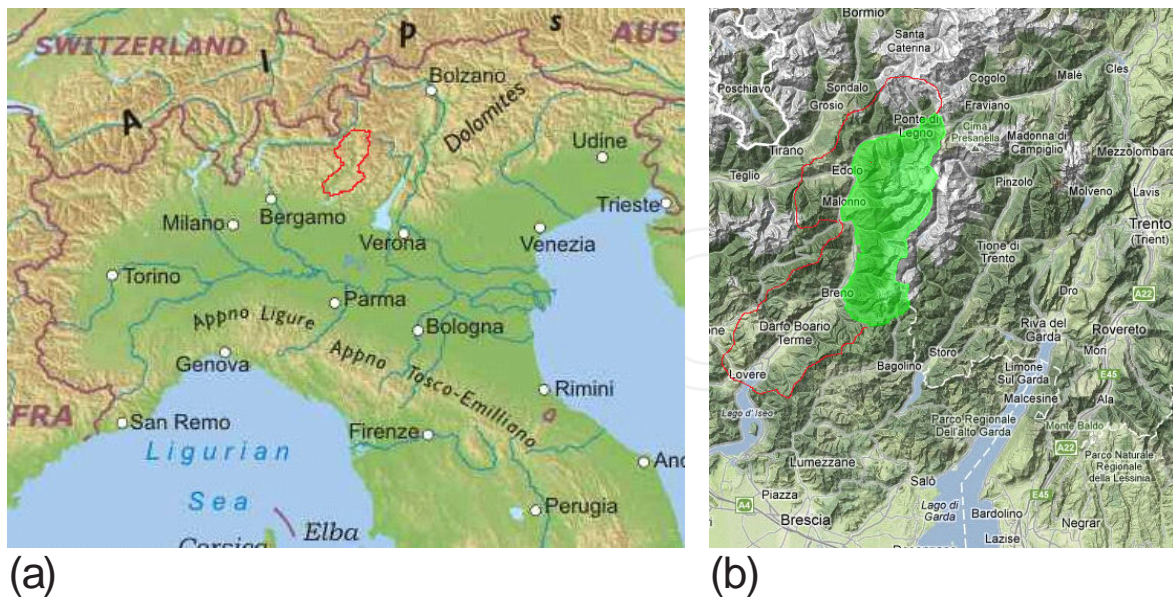
Figure 1. a) Localization of the Valle Camonica in the Lombardy region, Northern Italy. b) Localization of the Adamello park (green area) inValle Camonica (red borders)

1.2. Climate

The climate of the region corresponds to a tempered sub-oceanic type. The rainfalls ranges between a yearly minimum of 900 mm in the valley floor of the southern part of the domain and a maximum of 2.200 mm in the northern part of the Valley. The pluviometric regime show two rain peaks in spring and autumn, and two minima in summer and winter, with an absolute minimum in winter (mainly snow above 1.100 m a.s.l.).
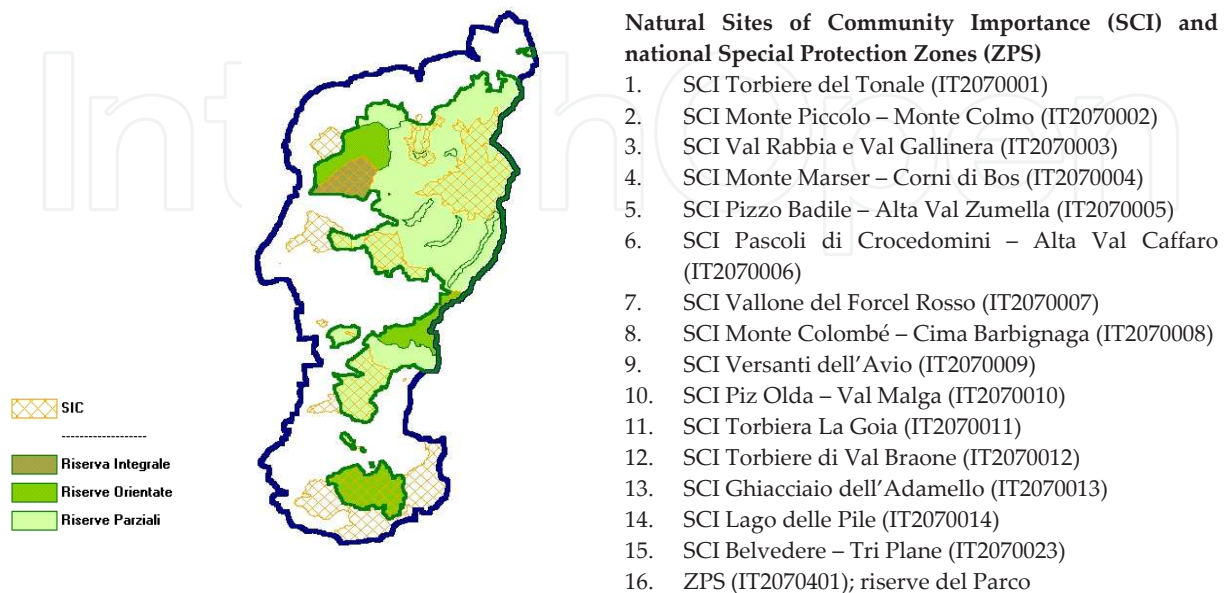
The thermal regime is characterized by an average yearly temperature of 12.5 °C in the valley bottom. The average minimum temperature is registered in January about +2 °C), while the average maximum temperature is recorded in July (around 20 °C). The Iseo lake provides remarkable thermal influence over the southern part of the valley.

Winds have no peculiar characteristics, following the typical breeze regime of a normal alpine valley.

1.3. Vegetation and natural reserves

Following the common italian typological classification, up to 74 forest ecosystem types are represented in the area, classified into 21 wood categories: *Quercus spp.* (oak woods), *Fraxinus ornus-Ostrya carpinifolia, Castanea sativa* (chestnut woods), *Acer psseudoplatanus and Fraxinus excelsior, Tilia cordata, Corylus avellana, Betula pendula, Larix decidua, Pinus cembra, Pinus sylvestris, Pinus mugo, Picea excelsa* and *Fagus sylvatica, Abies alba, Fagus sylvatica, Picea abies, Alnus viridis, Alnus glutinosa e Alnus incana, Robinia pseudoacacia, Salix spp.* and *Populus spp., Laburnum alpinum, Populus tremula, Sorbus aucuparia e Sorbus aria*, plus anthropogenically promoted formations with exotical species and artificial coniferous plantations.

Many Natural Reserves are included in the Park (Figure 2), among which there are fifteen Sites of Community Importance (SCI) plus a national area of special protection for birds (ZPS) which cover approximately 50% of the territory.

Natural Sites of Community Importance (SCI) and national Special Protection Zones (ZPS)

1.   SCI Torbiere del Tonale (IT2070001)
2.   SCI Monte Piccolo – Monte Colmo (IT2070002)
3.   SCI Val Rabbia e Val Gallinera (IT2070003)
4.   SCI Monte Marser – Corni di Bos (IT2070004)
5.   SCI Pizzo Badile – Alta Val Zumella (IT2070005)
6.   SCI Pascoli di Crocedomini – Alta Val Caffaro (IT2070006)
7.   SCI Vallone del Forcel Rosso (IT2070007)
8.   SCI Monte Colombé – Cima Barbignaga (IT2070008)
9.   SCI Versanti dell'Avio (IT2070009)
10.   SCI Piz Olda – Val Malga (IT2070010)
11.   SCI Torbiera La Goia (IT2070011)
12.   SCI Torbiere di Val Braone (IT2070012)
13.   SCI Ghiacciaio dell'Adamello (IT2070013)
14.   SCI Lago delle Pile (IT2070014)
15.   SCI Belvedere – Tri Plane (IT2070023)
16.   ZPS (IT2070401); riserve del Parco

Figure 2. The natural reserves of the Adamello Park (green lines in the map) and list of the SCI and ZPS included in the Park (right).

1.4. Forestry

The forest surface of the Park is mainly covered with coniferous stands or mixed stands with a coniferous prevalence (more than 70% of the forest surface).

Picea excelsa is clearly dominant, with a standing volume of approximately 1.200.000 m³. Then *Larix decidua* represented with 320.000 m³, *Abies alba* with 25.500 m³ and *Pinus sylvestris* with 16.500 m³ (less relevant amounts are assigned to *Pinus cembra*, *Pinus mugo* and *Juniperus communis*).

The volumetric estimate of broad-leaved species (synthetic estimate) gives back a stock value of 350.000 m³ with a prevalence of *Castanea sativa*, *Fraxinus ornus* and *Ostrya carpinifolia*.

These data witness a strong characterization of the local forests to a secondary type. Most of the main broad-leaved species are in fact not significantly present and this is certainly due to an intensive management of the woods carried out in the past.

The average offer of timber available from the Park is about 10.000 m³ per year of industrial wood and nearly 500 tons of broad-leaved timber (mainly for fuelwood or poles). The industrial wood is then mainly destined to local lumber mills, which usually sell it as unique assortment (44,8%), saw lumber (20,3%), packaging wood (32,9%) and pulpwood (2%). Coppice wood is on the other hand mostly sold on the local market.

On the whole, the level of the offer of timber is probably under its potential, thus implying the need for an improvement of the system in the area.
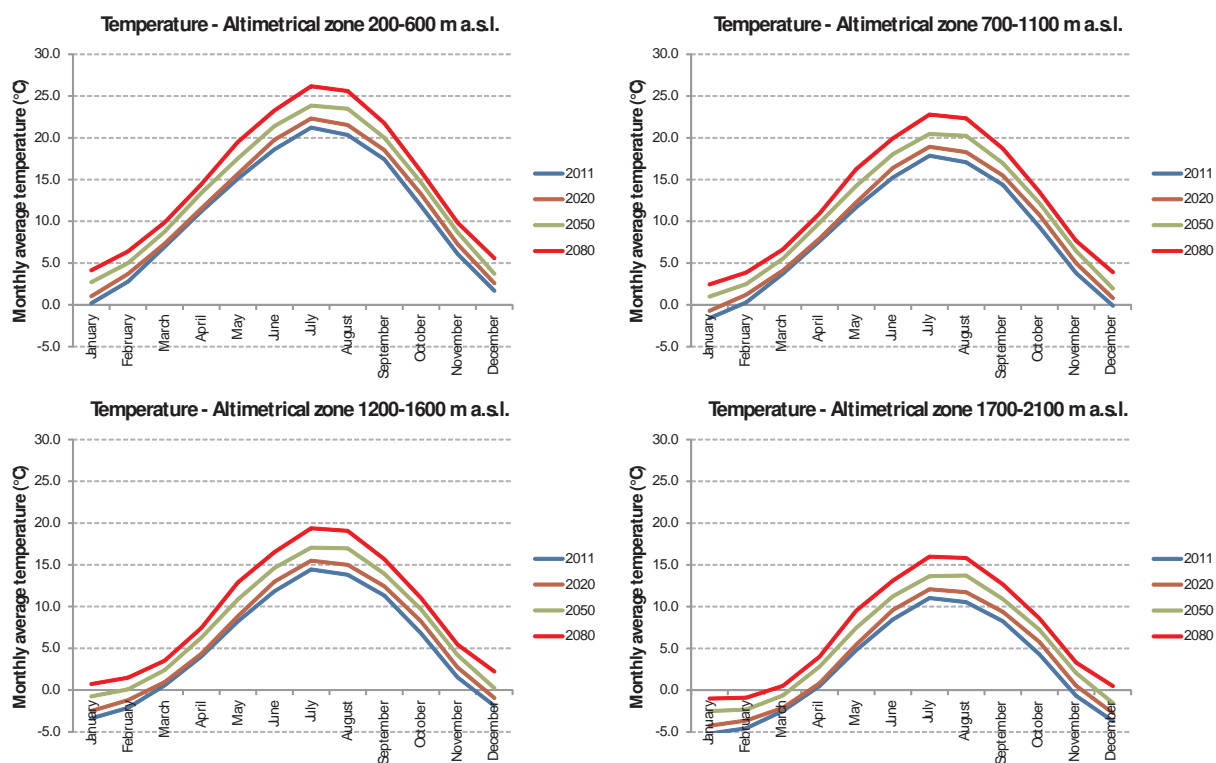

Figure 3. Annual course of monthly averaged temperature for different altimetrical zones. The blue line corresponds to year 2011, the dark red line to year 2020, the green line to year 2050 and the bright red line to year 2080

2. Future scenarios for Valle Camonica and the Adamello Park

2.1. Expected climate

IPCC climate change scenario A1b [1] have been downscaled to the Valle Camonica domain within the framework of the MANFRED project and the results are showed hereafter. All the scenarios foresee a remarkable temperature increase and an overall yearly precipitation decrease in this Alpine area.

The scenario A1b, assumed as a reference since it is an intermediate one and it is the most likely for this area, predicts a temperature increase of 4.0 °C for the lower altimetrical zone (200-600 m. a.s.l.) and an increase of 4.1 °C, 4.2 °C and 4.3 °C for the higher altimetrical zones corresponding respectively to 700-1100 m. a.s.l., 1200-1600 m. a.s.l. and 1700-2100 m. a.s.l. (Figure 3). The highest temperature increase is predicted for August 2080 when the average daily temperatures will likely rise by 5.3 °C over the corresponding values of 2011.
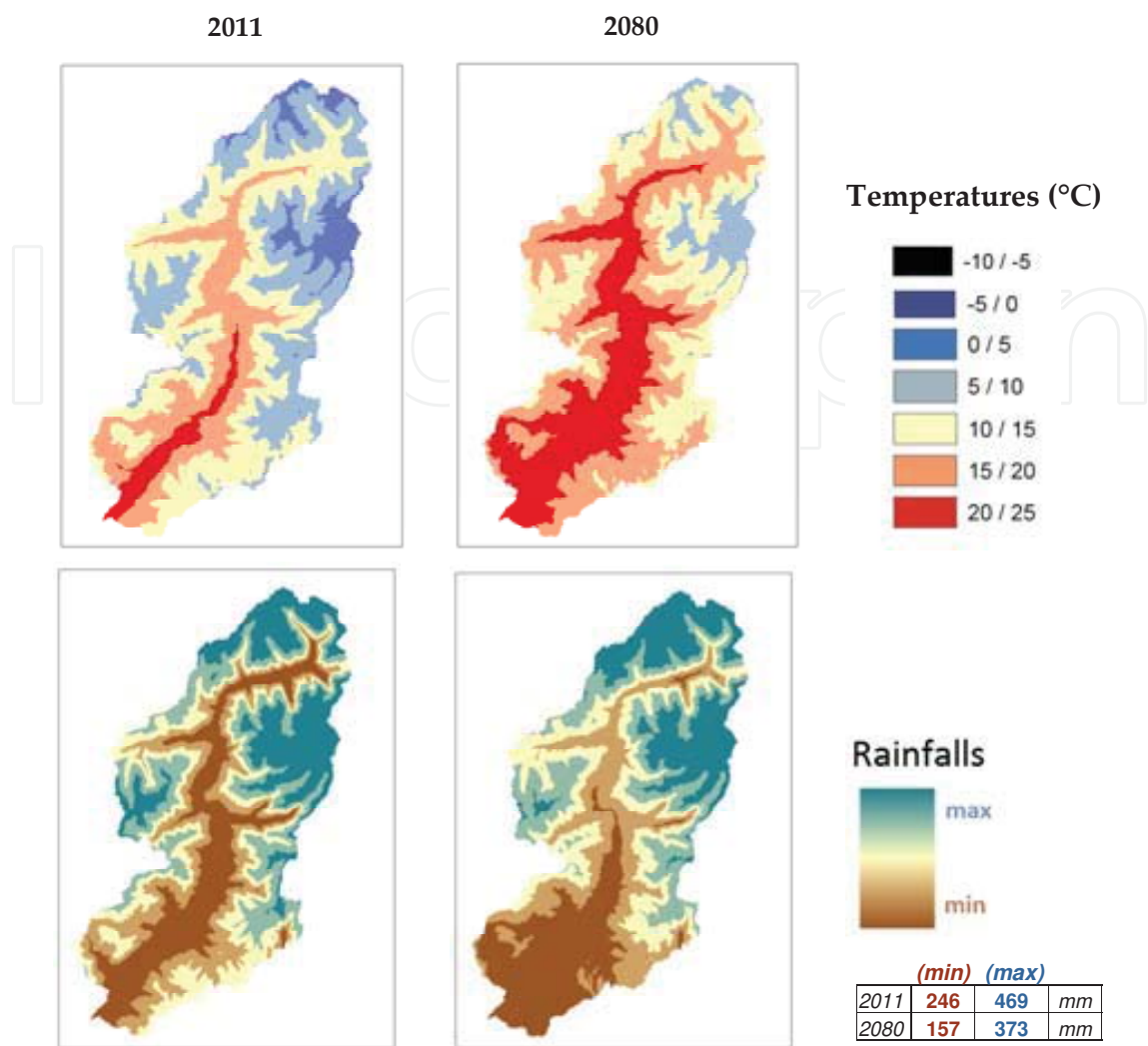
Figure 4. Distribution of the climatic variations in the Summer season in Valle Camonica. Top two maps: summer average temperature for present (year 2011, left) and for future (year 2080, right). Bottom two maps: summer rainfalls distributions for present (year 2011, left) and for future (year 2080, right)

The geographical distribution of these temperature changes can be appreciated in Figure 4 which compares the maps of the the average temperatures in the summer 2011 with their predictions for the summer 2080. While a sensible temperature increase is observed throughout the whole valley, in the year 2080 the highest temperature range (20/25 °C) will be experienced by nearly the half of the southern part of the valley and by the valley floor of the northern part and of the side valleys.

Besides temperature the other parameter which will be significantly affected by climate change in this area is rainfalls. Comparing the future prediction of rainfalls (30 year period between 2071 and 2100) with the present situation, taken as the rainfalls average of the past 30 years (1971-2000), two main facts can be highlighted: a slight increase of rainfalls will characterize the first months of the year (+20%) and the late autumnal period, while a very strong reduction of rainfalls (- 40%) will affects the whole summer period (Figure 5)

Deepening this seasonal trend of rainfalls it can be observed that the increase in the first months is substantially the same for all the altimetrical zones, while the summer decrease will more affect the less elevated areas (Figure 6). Furthermore this decrease will be significantly different throughout the valley. In fact, while on the southern part of the valley less rainfalls will be expected also at high elevation, in the northern part the valley floor will experience an increase in rainfalls (Figure 4).

The decrease in rainfalls will lead to a further consequence, that is the considerably increase of the number of dry days in summer (+ 21 %) and to a lesser extent in autumn (+ 6 %) (Figure 7).
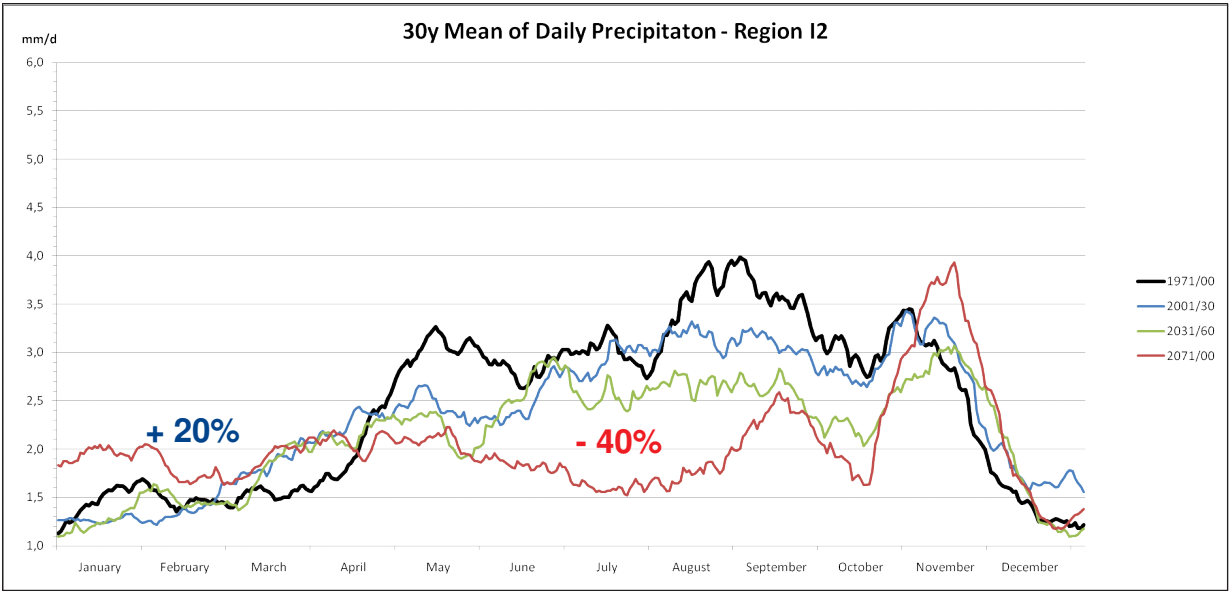

Figure 5. Thirty years mean of daily rainfalls from present to 2100 in Valle Camonica. The black line shows the present situation calculated as the average of the period 1971-2000, the blue line is the 2001-2030 average, the green line is the 2031-2060 average and the red line is the 30 years average between 2071 and 2100. (Elaboration of Zueger and Gebetsroither on downscaled data from Zimmermann)

As a consequence of the increased temperature and of the decreased rainfalls the evapotranspiration of vegetation is expected to decrease. Figure 8 shows the future potential evapotranspiration calculated for the altimetrical zone where higher is the forest coverage (700-1100 m a.s.l). In that zone, at the present, the vegetation will experience only a very slight water shortage in the half of September. But in the future the water shortage will start earlier, in the mid of June when the plants transpired all the water they received in the previous months (the yellow area in the graph), and it will last until the end of September. After mid June the water supply by rain will not be able to sustain the plants' evapotranspiration demand, and then an increased stomatal control on water losses and a reduced overall actual evapotranspiration could be foreseen.
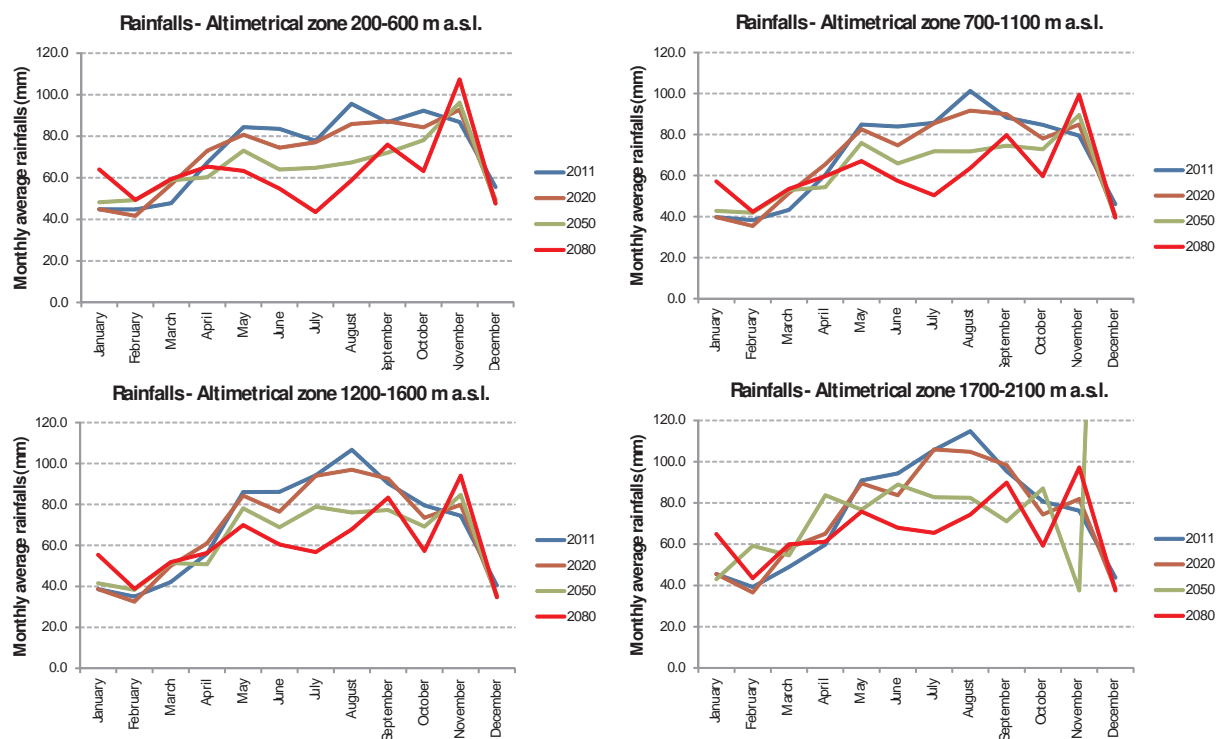
Figure 6. Annual course of monthly averaged rainfalls for different altimetrical zones. The blue line corresponds to year 2011, the dark red line to year 2020, the green line to year 2050 and the bright red line to year 2080
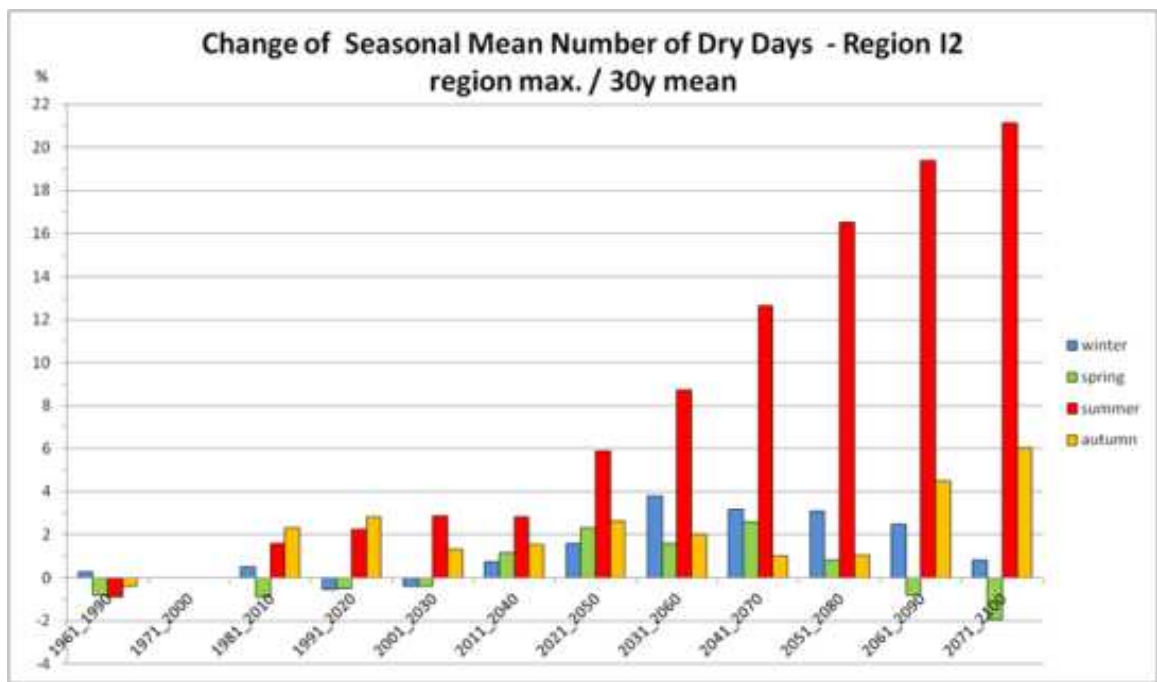
Figure 7. Change of seasonal mean number of dry days. The mean was calculated on a 30 years basis. Blue histograms are winter, green ones are spring, red ones are summer and the yellow ones are autumn

2080 - Rainfalls balance
700-1100 m slm
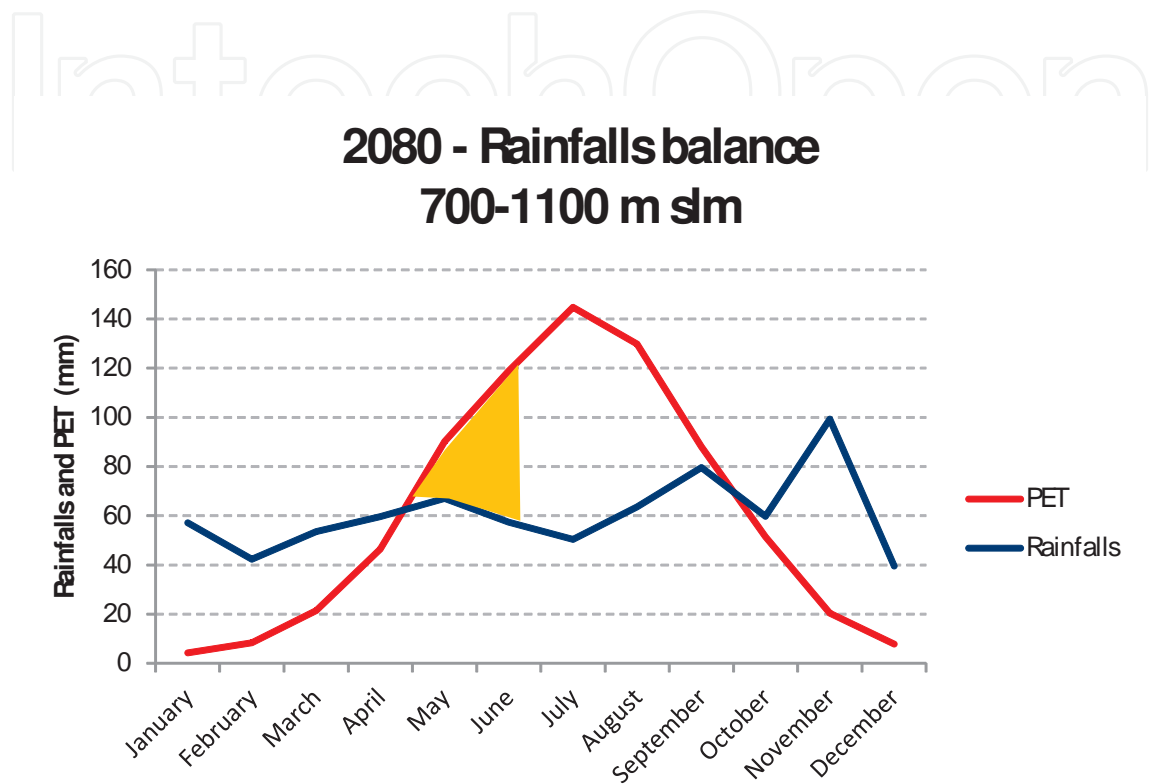
Figure 8. Pluviometric balance for the year 2080 between 700 and 1100 m a.s.l. Rainfalls and potential evapotranspiration (PET) are represented. The yellow area represents the water reservoir which compensates the water deficit when the evapotranspiration demand is higher than the water received with rainfalls.

2.2. Expected shift of potential vegetation

In a recent study G. Pignatti [2] proposed an interesting methodology for analyzing the possible effect of climate change on the composition of the Italian forests. All the Italian forest areas were screened by forest type and local climate. Pignatti found that the distribution of the different forest types can be described by taking into account a simple climatic descriptor: the average temperature of the coldest month of the year.

Based on the average temperature of January, six different climatic zones were defined (A to E: <8°C, -8°/-4°C, -4°/0°C, 0°/+4°C, 4°/8°C and >8°C) to which correspond a different class of forest type (*Alpinetum, Picetum, Fagetum, Castanetum, Cold Lauretum* and *Warm Lauretum*).

The employment of the Pignatti's methodology gives an idea of the potential distribution areal of the different forest types, and by using the temperature forecasts of the climatic models it allows to realize whether new types of vegetation might find a suitable climate for them in a given area. It must be remarked that these results does not necessary mean that these new types of vegetation will onset in that area at the given future year, but that a vegetation migration process will start and that the given specific area will be a future destination of those vegetation types. However the process can be very slow, and it could be further slow or even stopped by the competition with the pre-existing vegetation which – within certain limits - could adapts to the new climatic conditions.

This methodology was applied to the Valle Camonica domain using the temperature distri‐ bution predictions of the years 2011, 2020, 2050 and 2080 (Figure 9). It can be observed that in 2080 the climatic area corresponding to the spruce (*Picetum*) should almost disappear, while the beech climatic area (*Fagetum*) will shift to higher elevations. The climatic area of chestnut (*Castanetum*) will significantly expand throughout the whole valley, particularly in the valley floor, and the warmer climate will create a suitable areal for the evergreen oak *Q. ilex* (*Lauretum*) in the valley bottom of the southern part of the Val Camonica domain.
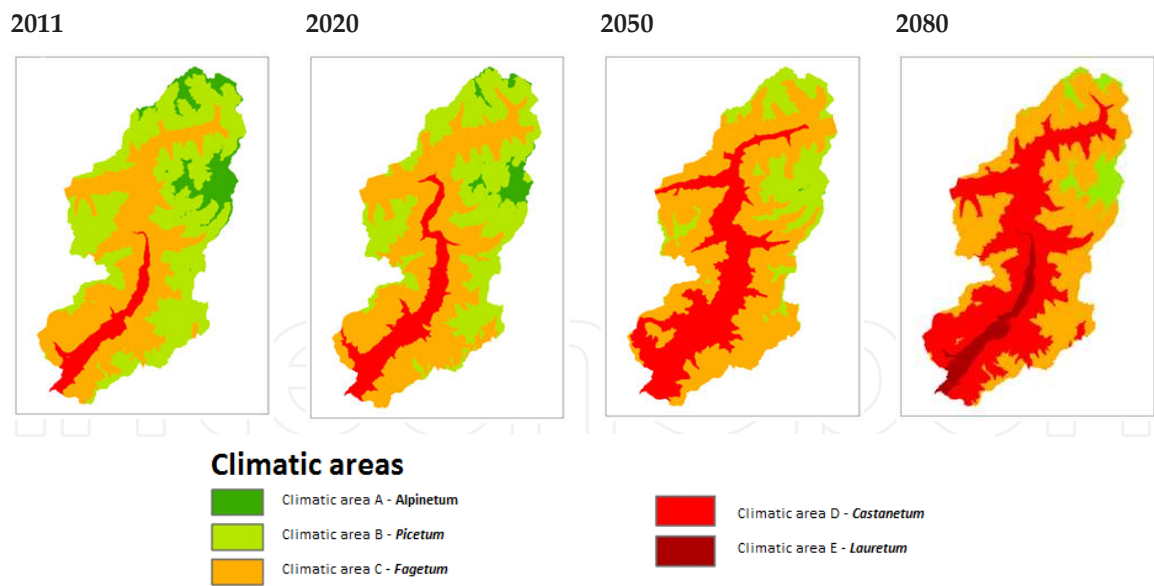
Figure 9. Climatic areas for the reference years 2011, 2020, 2050, 2080 following the methodology proposed by Pignatti
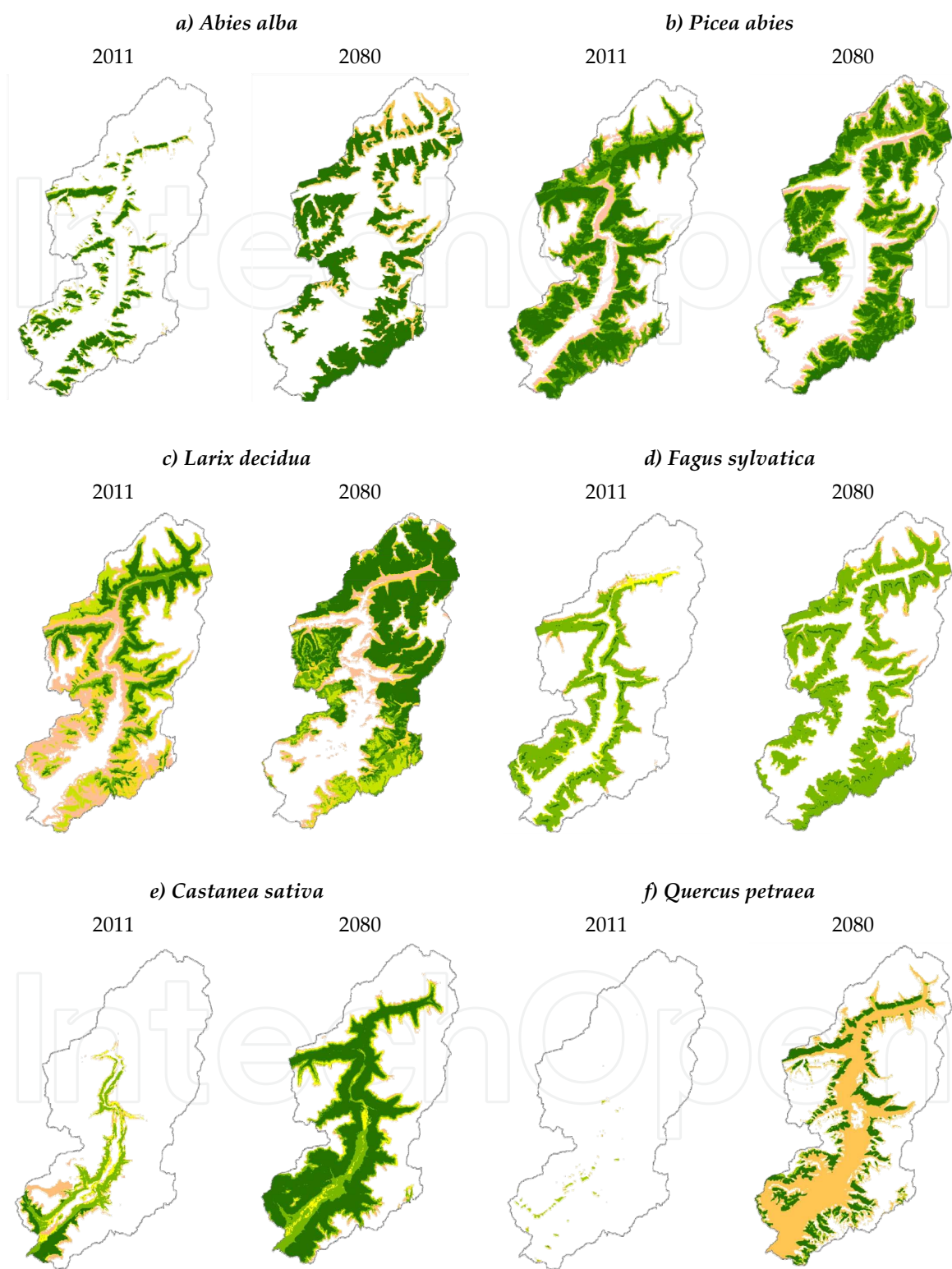
Figure 10. Areals evolution of six different tree species from present (2011) to future (year 2080): a*) Abies alba*, b) *Picea abies*, c) *Larix decidua*, d), *Fagus sylvatica* e) *Castanea sativa*, f) *Quercus petraea*. The greener the color the higher the probability to find the species in each point; lighter areas are less suitable for the species and white areas are not suitable areas.

These results are substantially confirmed by a more detailed climatic envelops forecasts performed by Zimmerman within the MANFRED framework for the 6 main forest tree species of Europe. Using ecological and climate models, Zimmerman downscaled to the valle Camonica domain the future potential areals of *Abies alba, Picea abies, Larix decidua, Fagus sylvatica, Castanea sativa and Quercus petraea* and, which are showed in Figure 10.

It was worth noticing, again, that the areals does not represent the future spatial distribution of the species, but only a region where climatic conditions will be suitable for their growth, regardless of the ecological competition with the pre-existing species. Figure 10 shows a vegetational shift towards higher elevation for *Abies alba* and *Fagus sylvatica*, with a slight expansion of the present coverages. *Castanea sativa* will spread throughout the whole valley floor and in the mountain areas of the southern part of the valley, and *Quercus petraea* might significantly increase its presence in the valley. *Larix decidua* and *Picea abies* will decrease in the southern part of the valley (which will be hotter and with less rainfalls), but these two species will find a better and expanded habitat in the northern part of the valley and at higher elevation.

Where the Zimmerman's and Pignatti's predictions differ are on *Picea Abies*. Even if both predicts an altitudinal shift and a restriction of the spruce areal, Zimmerman does not foresees a disappearance of this species form the Val Camonica domain, but only a slight reduction of it.

3. Climate change impacts: fire and ozone hazards

The predicted pattern of future CC (increasing in summer temperature and winter precipitation) is accounted to produce a shift of conditions (both in time and space) leading to a more severe exposure to natural hazards than present. In this study, current (2011) and future scenario (2080), have been compared analyzing the influence of CC on fire ignition risk and ozone exposition in Valle Camonica.

3.1. Forest fires — 10-years' trend in Valle Camonica (2002-2011)

In the Valle Camonica during the last decade (2002-2011) a total of 246 fires caused a forests loss of about 160 ha/yr^{-1}. Number of fires and burned area were particularly high in hot and dry years (e.g. 2002 dry winter and 2003 hot summer) resulting also in much larger fires. Winter and spring are the season mainly affected by the phenomenon both in terms of number and burned hectars (Figure 12). The majority of fires are caused by human action, mostly related to crime acts and negligence whilst natural causes represent only a small percentage of the overall amount. Since the beginning of 2000 thanks also to the National Law on forest fires (L. 353/2000), protective and preventive measures have significantly reduced the number and the average size of fires in respect to the past.
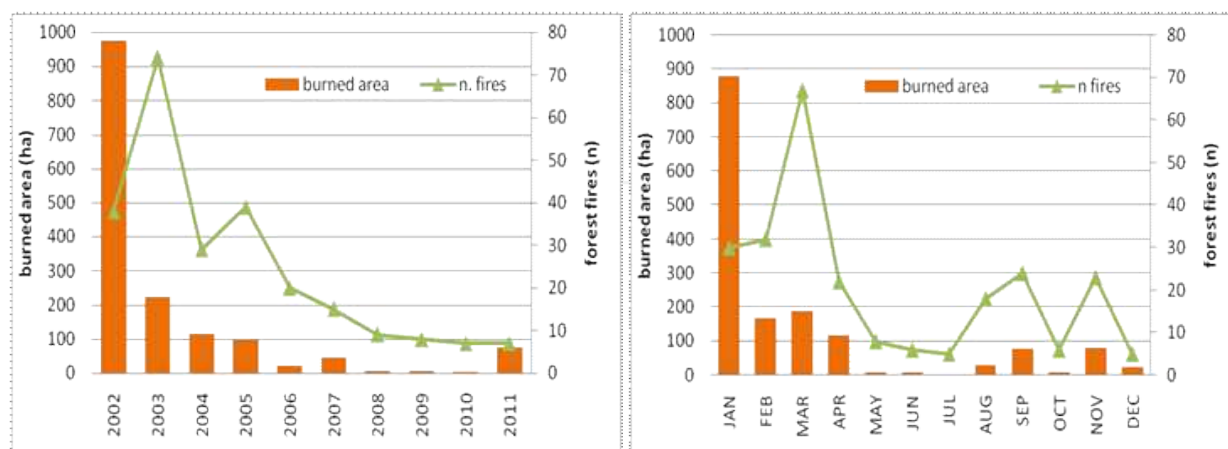
Figure 11. Frequency of fire events and burned area per year (right) and month (left) over the period 2002-2011

3.2. Forest fire risk in Valle Camonica

In this study fire risk has been considered as composed by two parts: hazard and vulnerability. The relationship between the two components is defined as follow:

Risk= Hazard * Vulnerability

According to the fire regime present in Valle Camonica, and in particular the monthly pattern (Figure 11), in our analysis, we evaluated the evolution of fire risk for the so called "fire season", from January to April, where the most part of fires occurred and assumed to occur also in the future. Fire hazard and fire vulnerability have been evaluated by the means of a tool (4.FI.R.E. - FORest FIre Risk Evaluator) developed in the framework of the MANFRED project by ERSAF (*cfr* Chapter 6). The tool, composed by two main modules (4.FI.R.E.- Hazard and 4.FI.R.E.- Vulnerability), allowed us to generate hazard and vulnerability maps for current and future scenario, then combined to achieve the final risk map.

3.2.1. Fire hazard

Current and future scenario were produced by using the module 4.FI.R.E. - Hazard. The methodology for hazard calculation provided in the tool is based on [3]. Conceptually, the production of the hazard map is made of three simple steps (Figure 12): i) Layers pre-processing; ii) Monte Carlo simulations to produce Monte Carlo scores maps and lookup tables; iii) Layer overlay.
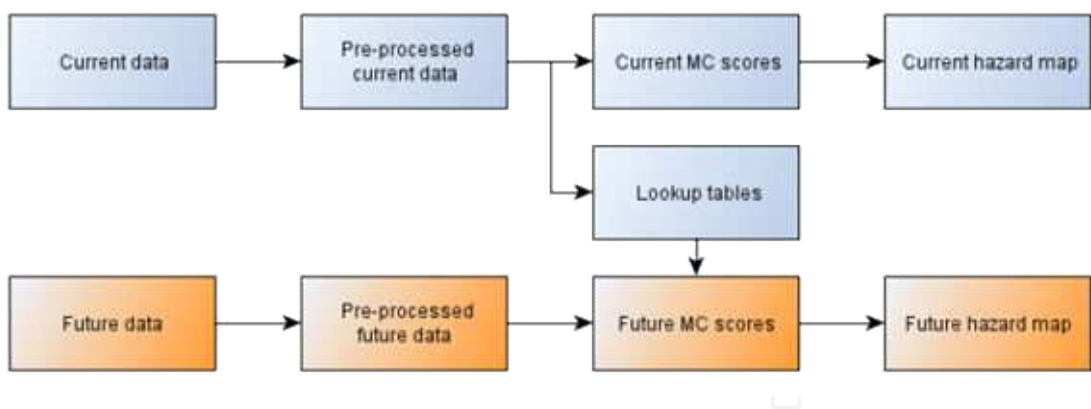
Figure 12. R.E. - Hazard. Workflow

4FI.R.E.–Hazard has been designed to allow the creation of hazard maps both for current and future scenarios. In the first case, the Monte Carlo scores maps are calculated straight from the input layers. In the second case, the Monte Carlo scores maps are calculated using lookup tables derived by comparing the current input layers and their Monte Carlo score maps. Input data consist of a broad set of variables accounted for influencing the proneness of a specific area to forest fire events (i.e. morphological features, climatic conditions, anthropic elements, Table 1).

| List of input variables	Variable used in the model
Map of ignition sources	Yes
Digital Elevation Model	Yes
Land use map	Yes
Roads map	No
Forest map	Yes
Precipitation (interpolated map)	Yes
Temperature (interpolated map)	Yes

Table 1. R.E. – Hazard. List of input variables.

Road map was not included in the final model due to the lack of information for future trends in space and time. Topographic attributes (i.e. elevation, slope and aspect) were derived from a Digital Elevation Model provided by the cartographic service of Lombardy region. In this work we assumed that morphological features will not be subjected to significant changes for the future. Therefore, the same raster datasets have been included in both the model runs (2011 and 2080). Site-specific climatic data (temperature and precipitation) and land use map at 2011 and 2080's scenario provided by WSL were included in the final model. In order to characterize the territory with meteorological variables representative of the fire season, average temperature of March and total precipitation within the period January-April were considered as input data.

Results for the current scenario showed a clear decreasing trend, where the area tends to decrease moving from the lower to the highest hazard classes. The results of the model for the future scenario indicated a potential decrease especially in the middle classes (2-4, 4-6, 6-8) whilst for the lowest and highest classes (0-2 and 8-10) an increase is expected (Figure 13). These findings are consistent with the hypothesis that future climate changes will drive changes in the magnitude of forest fires. In the analysis we carried out, meteorological variables are the most important factors leading the change in fire hazard. It is likely that fire regime of Valle Camonica will face a new situation with an increased likelihood to have a potential shift in the seasonal distribution of forest fire occurrences. Increased temperatures and a net decrease of precipitation, in fact, can result in drier fuels increasing the likelihood of fire ignitions. According the future trend of temperature and precipitation, we can speculate that hotter seasons (e.g. spring and summer) will face in future an higher probability of fire events.

Figure 14 illustrates the hazard maps for 2011 and 2080. Considering the spatial distribution of the phenomenon, the hazard increases is more evident at the lower altitudes where the higher class (8-10) tends to replace the lowest ones.

This result is not surprising, since it is straightly leaded by land use and climate change (in particular temperature) which will cause the treeline shift toward higher altitudes. This process is well documented and many studies [4, 5] reported as alpine ecotones are assumed to be particularly sensitive to altered temperature regimes. and climate warming is expected to drive treelines upslope. As a consequence species more sensitive and prone to forest fires (e.g. chestnut and oak) are expected to extend their spatial range at higher elevations increasing the likelihood of having forest fire occurrences.
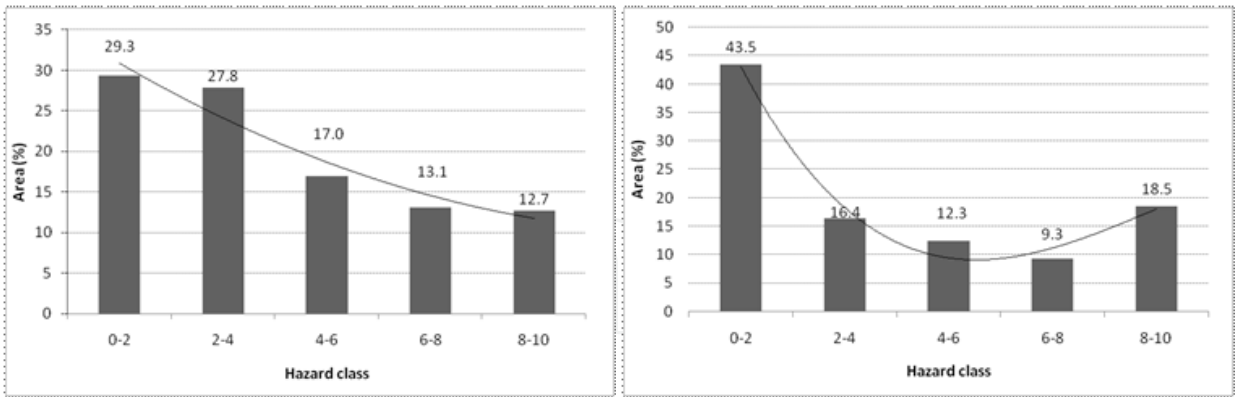

Figure 13. Territorial distribution (%) for each hazard class at 2011 (left) and 2080 (right)

3.2.2. Fire vulnerability

Fire vulnerability for 2011 and 2080 were calculated by using the second of the modules of the tool (4.FI.R.E. - Vulnerability). The process of vulnerability modelling builds on a 4-step design method: i) input selection; ii) layer pre-processing; iii) layer overlay; iv) output creation.

The final output consists of a map resulted from the simple sum (i.e. linear model) of the input layers rescaled to defined vulnerability classes. In the final vulnerability maps (2011 and 2080) percentiles were used to define the reference intervals. As for the hazard model, some variables were not accounted in the final model due to the lack of information for future trends in space and time. Input variables considered in the tool and those included in the model are reported in Table 2.

Protective, productive and naturalistic functions were implemented by using proxy variables (respectively slope, slope and accessibility, presence of protected areas).
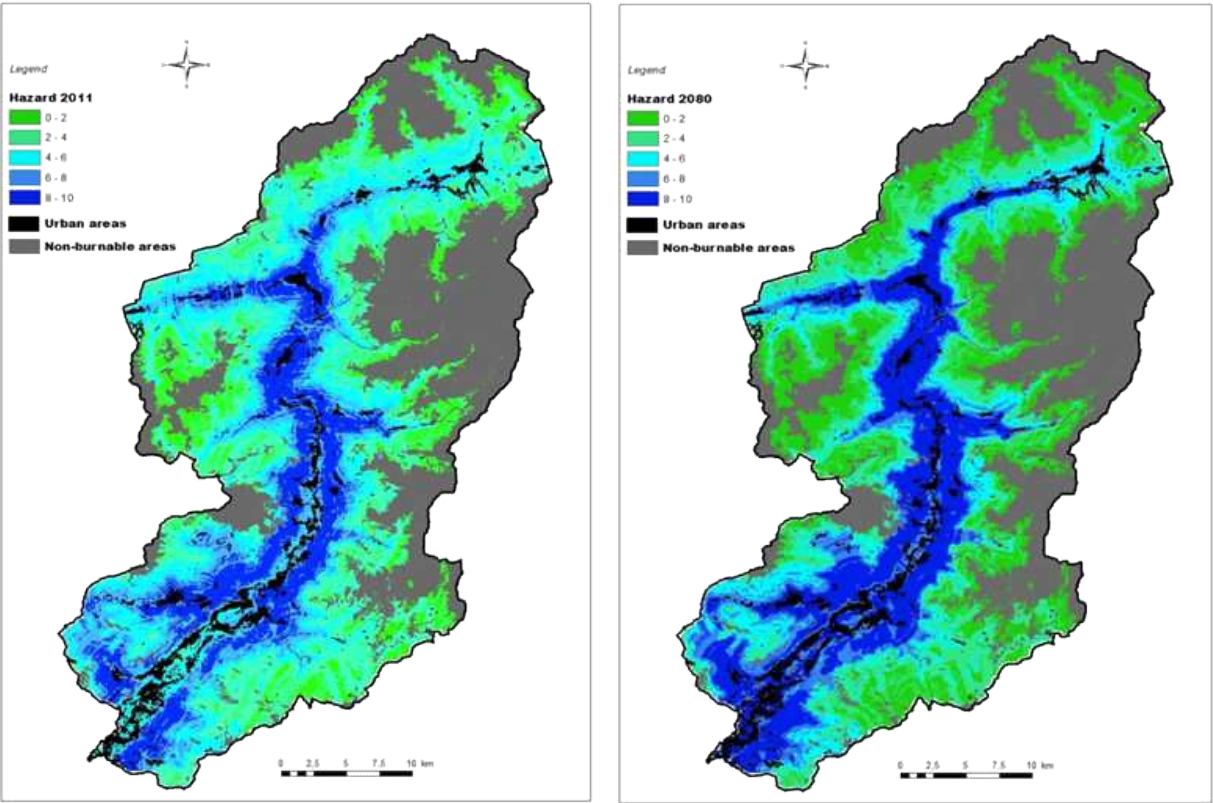
Figure 14. Hazard maps for current (left) and future (right) scenario

The final maps for Valle Camonica (Figure 15) shows the significant vulnerability along the valley bottom given to the presence of areas more accessible and characterized by anthropic presence (urban areas). The scenario for 2080 depicts small changes for vulnerability of urban elements. It is important to notice that the results of the analysis are affected by the input data. In this sense, it is expected that urban areas (the most vulnerable landscape elements) will not be subjected to significant changes during the analyzed time span. The map for 2080 reflects this small change in the highest class. It is also possible to appreciate, for the future scenario, the pattern of vulnerability increase for protected areas. These areas are expected to face an increase of vulnerability probably due to the expansion of forest within those regions currently occupied by non-forest habitats (e.g. meadows and pasture). The natural afforestation and/or

re-afforestation of areas currently not covered by forest will increase, in the future scenario, the vulnerability of the territory.

3.2.3. Fire risk

The fire risk was calculated by combining the two maps resulted from the analysis of hazard and vulnerability for current and future scenario. As for vulnerability, percentiles were used to define the risk classes for 2011 and 2080.

List of input variables	Variable used in the model
Forest types resistance	No
Forest types resilience	No
Protective function (proxy slope)	Yes
Productive function (proxy slope and accessibility maps)	Yes
Naturalistic function (proxy protected areas)	Yes
Touristic function	No
Carbon stock function	No
Presence of vulnerable elements (urban areas)	Yes
Exposition (potential damage level of due to the distance from the forest areas)	Yes
Resident population map	No

Table 2. FI.R.E. - Vulnerability. List of input variables

The final risk maps of Valle Camonica (Figure 16) follow the results of hazard and vulnerability. Risk is higher for those areas located at the bottom of the valley and along the mountainsides where the forest are likely to increase their presence in the future.

The major consequences at territorial level are related to the increased safety risk for people, structure and infrastructure. Forest fires in Valle Camonica, as in the most part of the Alps, have a limited direct impact in respect to others natural hazards (e.g. debris flows). On the other hand, forest fires could lead or favor important secondary consequences. In mountainous areas severe forest fires, damaging the forest canopy as well as the soil, could result in increased runoff or sudden snowmelt, which can put homes and other infrastructures below a burned area at risk of safety. Many authors [6, 7] reported how debris flows can be one of the most hazardous consequences of rainfall on burned slopes.

Therefore, the future increase of fire risk should not be considered only for its direct impact but to the future impacts on the overall territorial system of Valle Camonica. Appropriate management strategies for forests and preventive measures for forest fire fighting must be addressed to reduce the risk of fires but bearing in mind also other fire-related or post-fire effects.
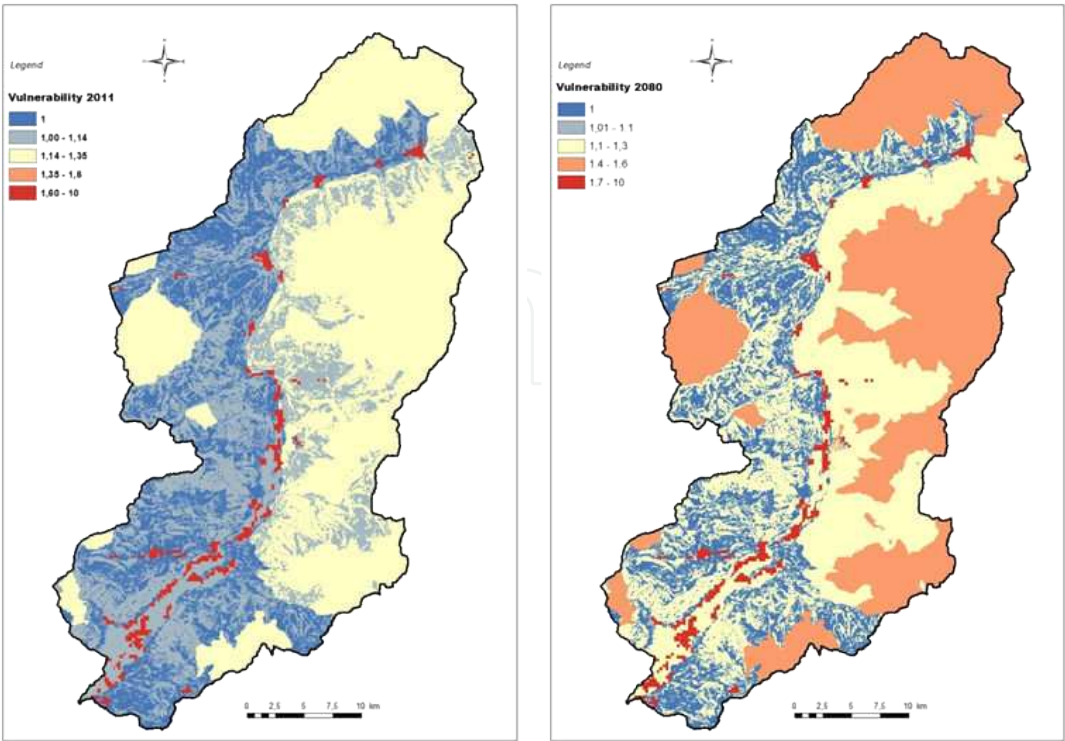
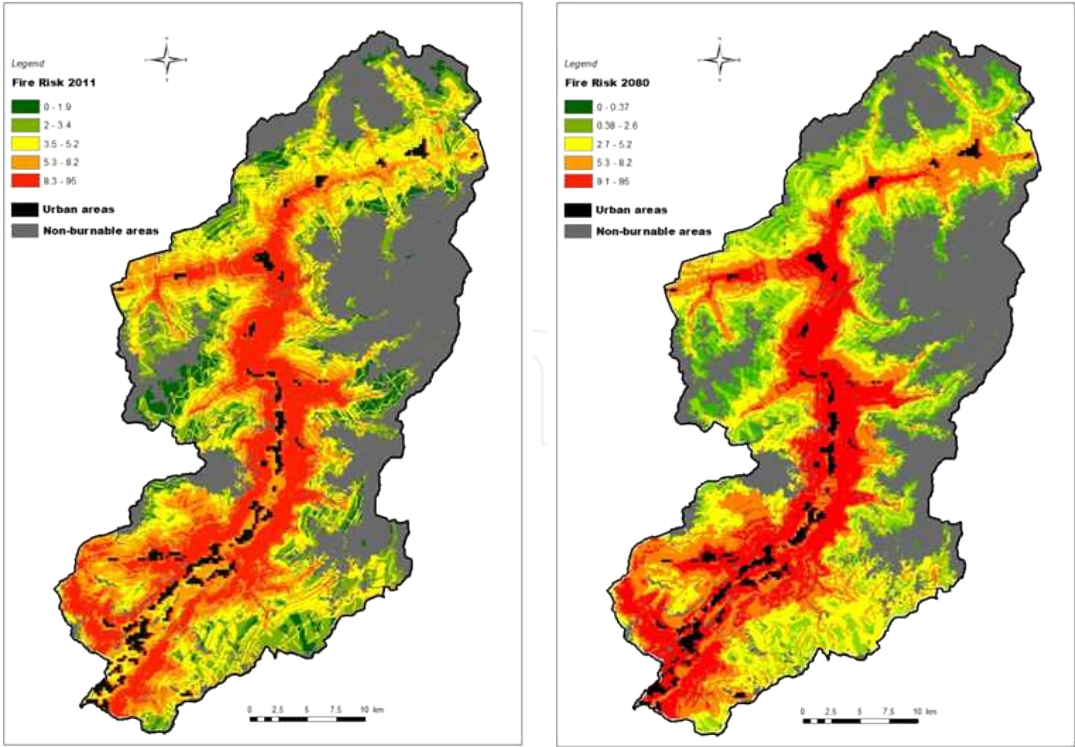**Figure 15.** Vulnerability maps for current (left) and future (right) scenario

Figure 16. Risk maps for current (left) and future (right) scenario

3.3. Ozone

Ozone is a secondary pollutant produced by photochemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOC). No direct ozone sources, both anthropogenic and natural, exist. The photochemical reactions that produce ozone are burst by UV radiation, leading, as a consequence that ozone concentrations are typically higher in summer and in mountain regions, where the breeze cycle can transport the ozone precursors from much polluted areas, like it usually happens in the Southern side of the Alps.

Ozone phytotoxicity for vegetation is a well-known problem [8]. The penetration of ozone through stomata is the most harmful way to which the vegetation is exposed. In fact, once ozone enters the substomatal cavity, it quickly reacts and oxidative radicals like hydrogen peroxide, superoxide and similar compounds are produced. These compounds produce many injuries like the membranes disruption through the peroxidation of the membrane lipids and the oxidation of the reduced groups of biomolecules [9, 10].

All these microscopic effects can produce, in sensitive species, visible injuries at leaf level, such as bronzing, chlorosis and necrosis, increased transparency at crown level, a reduced root growth and an increased susceptivity to both biotical and abiotical stresses. Both ozone sensitive and non sensitive species to ozone can experience a productivity reduction as an ozone effect.

At ecosystem level ozone can cause a change in species composition being disadvantageous to the more sensitive ones; furthermore functional changes like a reduced carbon storage capability, an increase in water loss and a reduction of the forest capability of stabilizing mountain slopes can be observed.

3.3.1. The ozone risk assessment procedures: Level I and Level II assessment

The ozone hazard for vegetation had been widely studied since several decades. The United Nations Economic Commission for Europe (UN/ECE) gave birth in 1979 to the Convention on Long-range Transboundary Air Pollution (LRTAP). In the LRTAP framework the Gothenburg protocol (1999) was approved, fixing the critical levels of ozone for vegetation with target values for the following years. A following EU directive (2002/03) acknowledged the Gothenburg protocol, introducing the AOT40 (Accumulated Ozone Exposure over a threshold of 40 ppb) index. The AOT40 is defined as:

$$AOT40 \; := \sum_{\substack{[O_3]_i > 40\,ppb \\ RadGlob > 50W/m^2}} ([O_3]_i - 40) \cdot \Delta t \tag{1}$$

that is the sum of the ozone concentrations (when they are above 40 ppb) minus the threshold of 40 ppb multiplied by the concentrations evaluation time, which is usually one hour [11]. This sum is calculated only during daylight hours in order simulate the stomatal behavior of vegetation.

AOT40 is employed to map ozone hazard. Then the hazard map is overlapped with the vegetation coverage map (i.e. a vulnerability map) to obtain the so called Level I risk assessment for ozone.

The AOT40 critical level was set by EU for vegetation is 18000 µg m^{-3} h over a period of six months, from 1st April to 30th September. This critical level can be expressed also in terms of ppb h, and its value is 9000 ppb h.

The EU directive gives recommendations to the member state about how to measure ozone and how to calculate AOT40 but, since the monitoring networks are mostly dedicated to estimate the risk for the human health rather than vegetation, ozone data in mountain regions are not so often available, leading to a not proper evaluation of the ozone hazard for forests. Three main measuring options are available to fill this knowledge gap on ozone hazard: mobile laboratories (Figure 17a), passive samplers (Figure 17b) and modeling predictions. All these approaches have their pros and cons: mobile labs can collect hourly data but they require high electric power so they cannot be easily employed in remote areas; passive samplers can be easily employed in remote areas but their time resolution is too coarse, usually one week; modeling predictions are necessary to spatialize the data but they require several measurements to validate the model outputs.

From a regulative point of view AOT40 is, at the moment, the only adopted index to evaluate the ozone hazard, but its scientific soundness is under criticisms. Being a mere exposure index, AOT40 does not take into account the physiology of the vegetation which is exposed to ozone. The ozone damages to vegetation are produced by the molecules entering the plants through the stomata, but plants can regulate stomatal opening as a response to different environmental conditions. The magnitude of the negative effects on vegetation is related to the real amount of this pollutant taken up through stomata, i.e. the dose or stomatal flux, and not simply to the ozone molecules which are surrounding the plants. So high ozone concentrations in the air do not necessarily lead to high ozone doses, thus representing only a potential risk for plants (more correctly an hazard).

The UN/ECE scientific community is hence moving toward a Level II approach based on stomatal fluxes. The Level II approach overpasses the pure risk concept leading to the direct estimation of the negative effects on plants and allowing an evaluation of the related economical losses.

The level II risk assessment requires both models and (better) measurements. Direct measurements of ozone fluxes can be performed by means of the eddy covariance technique, which at the moment is the best available one. Nevertheless these measurements allow to estimate only local ozone risk, but they are of capital importance to parameterize and validate the models, which, once all the input data are available, allow to estimate ozone risk at regional, national or continental level.

The eddy covariance technique is based on the atmospheric turbulence and it requires specific instrumentation, which must be able to measure at least ten times per second the three wind components, the air temperature and the ozone and the other gases concentrations. This instrumentation is mounted above the studied ecosystem.

The ozone fluxes are calculated from the rapid measurement by the following Eq. 2:

$$F_{O_3} = \overline{w'O_3'} \tag{2}$$

where w is the vertical component of the wind intensity and O_3 is ozone concentration; primed variables mean the fluctuations around their 30 minutes averages which is represented as overscript bar. Additional meteorological measurements are useful for a better comprehension of the stomatal ozone uptake process.

In order to estimate how much ozone enters through plant stomata (the most harmful pathway) water fluxes are used as a tracer, assuming that ozone can enter through plant stomata only when vegetation is transpiring. So the stomatal flux $F_{O3,stom}$ is derived from F_{O3} by using the evapotranspiration data and the Penman-Monteith equation [12] following the procedure described by Gerosa et al. [13].

The calculation of the stomatal flux allows then to estimate the ozone dose (which is 'simply' the sum of the stomatal ozone fluxes $F_{O3,stom}$) and the Phytotoxical Ozone Dose (POD_1), which is the cumulated dose over an instantaneous flux threshold of 1 nmol O_3 m^{-2} s^{-1}:

$$POD_1 = \sum_{\forall F_{O_3,stom} > 1} (F_{O_3,stom} - 1) \cdot \Delta t \tag{3}$$

The POD_1 have been introduced in the UN/ECE scientific community because it takes into account the internal capability of the vegetation to detoxify part of the ozone entering through the stomata. Furthermore, many experiments have showed that the POD_1 is better correlated with the biomass reduction than the simple ozone dose, allowing thus to estimate the harmful effects of ozone on vegetation.

(a)   (b)
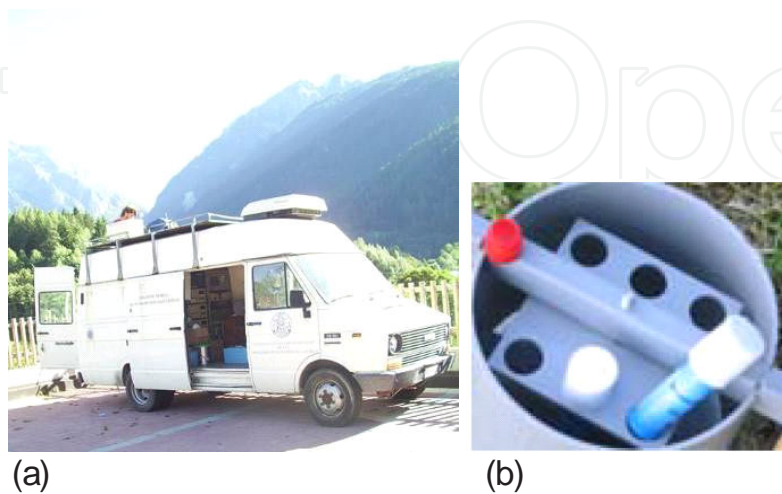
Figure 17. The Mobile Laboratory (a), and Passive Samplers for ozone (b) employed in the MANFRED project

3.3.2. Ozone risk assessment in Valle Camonica

Even though ozone concentrations have been estimated to be quite high in the whole mountain areas of the Lombardy region, as reported for instance by Gerosa et al. [14], only since 2007 an ozone monitoring station had been running in Valle Camonica, in Darfo. Furthermore, this station is located at a position which is not very suitable for the ozone hazard assessment for vegetation (low elevation and nearby a crowded main road). The lack of information on ozone hazard for forest in Valle Camonica, one of the widest forested area of the Region, lead to the choice of this valley as a focus for this topic.

In this project both Level I and II approaches were performed in Valle Camonica, and several measurements had been running in 2010 and in 2011.

The results from an extensive ozone monitoring campaign throughout the valley and the following mapping exercise and some results from the micrometeorological tower installed in Paspardo over a *Larix Decidua* forest are presented in this section.

Level I risk assessment had been realized by running a six month field campaign with a mobile lab and passive samplers (Figure 17) located in 11 sites throughout all the valley (Table 3): 10 of them were placed in remote forest areas while the remaining one was placed in Darfo, near the only automatic monitoring station available in Valle Camonica (Regional environmental agency, ARPA). The sites elevation ranged between 300 m and 1800 m a.s.l. spatially covering all the forest areas of the valley. Table 3 shows the coordinates of the sites and other additional data. Two passive samplers were exposed for one week in each site, inside a protective shelter, the first exposure began at 6th April 2010 and the last one (the 26th one) ended at 6th October 2010. The exposed samplers were analyzed and weekly averages of ozone concentration were obtained.

In order to calculate the AOT40 it was necessary to estimate hourly ozone concentrations starting from the weekly averages following the methodology proposed in [15] and reported in chapter 9.

Then, weekly values of AOT40 were mapped on the Valle Camonica domain using a geostatistical technique known as ordinary kriging, which requires a model of the spatial data variability estimated from the semivariogram plots. Details on all the applied methodology, as well as the resulted AOT40 map for the whole summer semester, can be found in chapter 9 (*cfr* Figure 10).

The map of the ozone risk for forests in Valle Camonica (Figure 18a) has been obtained by overlapping the AOT40 map (Figure 10 in Chapter 9) to the forest covered areas in the valley.

It can be observed that all the valley forests resulted under ozone risk because the AOT40 was almost everywhere well above the EU critical level for forest protection (9000 ppb h). The lowest ozone exposure was experienced by the forest located in the central part of the valley and in the southern part of the valley floor. In the southern mountain areas the critical level was exceeded from two up to five times in the conifer forests (Figure 18c) and up to four times in the broadleaves ones (Figure 18a), with the highest exceedances in the most elevated areas.

ID	Site name	Latitudine	Longitudine	Municipality	Elevation [m asl]	Relative Elevation within 5 km
1	Borno	45°56'36.79"	10°10'59.86"	Borno	1000	750
2	Crocedomini	45°56'30.34"	10°19'29.59"	Breno	800	550
3	Mortirolo	46°13'08.14"	10°19'36.67"	Monno	1300	650
4	Gavia	45°17'15.64"	10°31'08.16"	Ponte di Legno	1780	600
5	Darfo	45°52'29.64"	10°10'41.58"	Darfo Boario Terme	320	20
6	Malonno	46°05'30.97"	10°18'41.49"	Malonno	800	400
7	Montecampione	45°49'24.61"	10°09'52.19"	Piancamuno	980	680
8	Temù	46°14'07.94"	10°28'25.20"	Temù	1380	240
9	Pescarzo	46°02'02.08"	10°19'37.19"	Capo di Ponte	640	300
10	Mù	46°10'57.92"	10°20'19.75"	Edolo	800	340
11	Niardo	45°58'1.69"	10°19'31.11"	Niardo	600	280

Table 3. Passive sampler location in the valle Camonica campaign.

The northern part of the valley experienced the highest ozone exposure which ranged between four to eightfold the critical level.

Figure 19 summarizes the ozone risk for the valley forests by reporting the distribution of the broadleaves and conifers areas as a function of the AOT40 values. It can be realized that 98% of the forest areas experienced an ozone exposure between one and five times the critical level set by EU.

Higher exposures are experienced almost only by conifers since so high AOT40 values are typical of the high elevations sites where the high UV intensity strongly influences the ozone formation. Two third of the conifers stands (67%) suffer an ozone exposure above two times the critical level (CL), and the more represented exposure classes for conifers are those between 2 an 3 time the CL. Compared to the conifers, only one third of the broadleaves stands (exactly 40%) falls in ozone exposure classes above two times the CL, and the more represented exposure class for broadleaves is exactly the AOT40 class equal to 18'000 ppb h.

The magnitude of the exceedances from the critical level could be taken as an indicator of the level of ozone risk for the vegetation growing in a given area. From this point of view it could be concluded that the forest vegetation of Valle Camonica is subjected to a significant ozone risk, particularly the conifers. However, again, it must be remembered that AOT40 represents only a potential damage and a more appropriate ozone risk assessment should take into account ozone fluxes [11], as highlighted by UN/ECE.

Ozone risk was thus evaluated also with a Level II risk approach, by running a micrometeorological tower in Paspardo (Figure 20) in the summer periods of 2010 and 2011. This allowed, for the first time in the Alps, to study the ozone uptake of a larch forest using the eddy covariance technique.
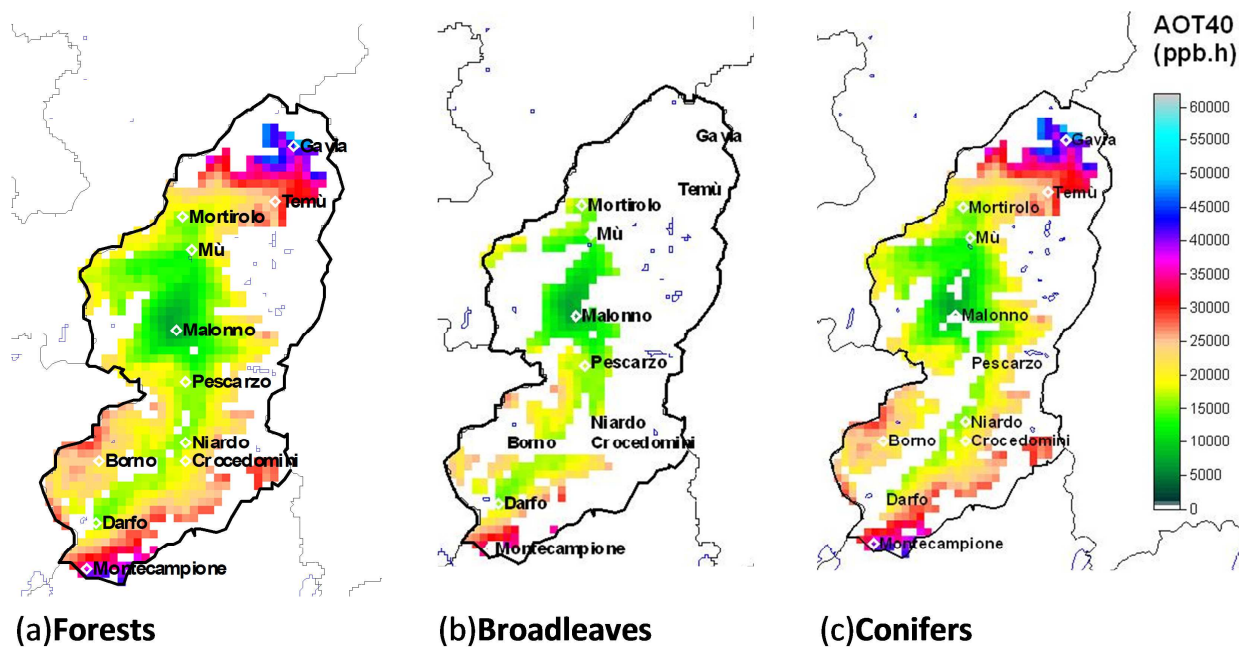
Figure 18. Ozone risk maps for forest vegetation in Valle Camonica. The AOT40 of daylight hours measured in the summer semester 2010 has been reported for each valley area of 1x1 km² where a forest greater than 1 hectare were present. The sites where the passive samplers were located are also indicated. a) All forest areas; b) Broadleaves forests; c) Conifers forests
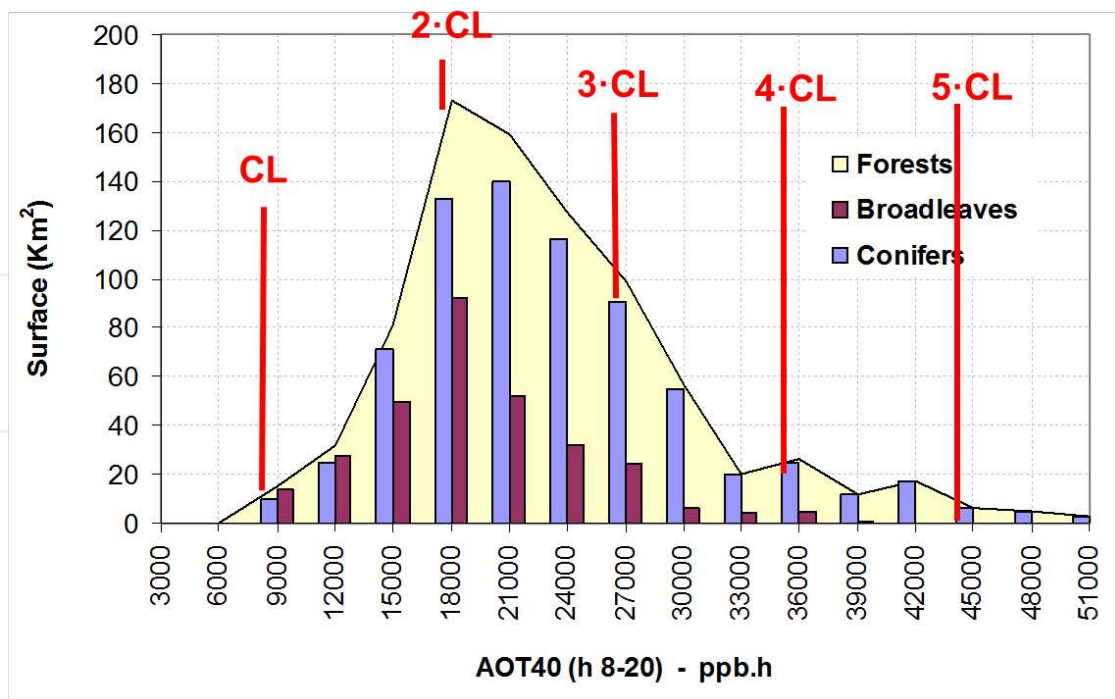
Figure 19. Distribution of forest, broadleaves and conifers coverage as a function AOT40 values. The red lines indicates the times of the exceedances of the critical level

The data processing methodology followed to get to the stomatal flux of ozone is almost complex and has been described in Chapter (8). It included a careful flux partition among the different ozone sink processes, either stomatal uptake and deposition on non-transpiring surfaces or removal by gas-phase reaction in the trunk space, and a separation of the larch uptake from the ozone uptake by the understorey grass.

The result is the cumulated ozone stomatal dose, calculated as POD_1 according to the recent UN/ECE recommendations, reported in Figure 21. The graph compares the accumulation dynamics of POD_1 and AOT40 along the 2010 summer season. The different behavior of these two indexes highlight the criticisms moved to the AOT40. While the POD_1 grew almost linearly for all the measuring period, following the physiological activity of larch, the AOT40 grew more irregularly following the alternation of the photochemical episodes. For example AOT40 had a almost negligible increase in July when ozone was low, but greatly increased in August in concomitance with some photochemical episodes, and then had a very slight increase in the last weeks of the measuring period.

The final POD_1 reached 17.9 mmol m^{-2} while the AOT40 increase stopped at 5150 ppb h. Since the final AOT40 did not overpass the critical level for plants, no risks for plants could be concluded adopting a Level I approach for the studied forest. However, these conclusion differ from how could be argued looking at the stomatal dose of the Level II approach.

Hypothesizing that the dose-effect relationship for larch - which does not yet exist - was the same of the POD_1-effect relationship described for Norway spruce, a loss of biomass increase of -4.5% could be estimated for our larch ecosystem in the measuring period. This relationship published in the UN/ECE mapping manual, in-fact, reports a decrease of 2% of biomass growth every 8 mmol m^{-2} of POD_1 received by trees, and this compared to the growth exhibited by trees which did not receive ozone at all. Further details on these measurement can be found in Chapter 8.

This means that our larch ecosystem had grown a 4.5 % less because of the ozone uptake in the measuring period. This could appear a small ozone effect, but considering that larch has low growing rates the effects could be significant on long term. Moreover the less energy available for growth imply a possible enhanced vulnerability of larches to other stress factor, both biotic or abiotic.

Coming to the future, any performed attempt of estimating future ozone fluxes was almost impossible. The time scale of the output of climatic and chemical scenarios (one day for meteorological data and one month for ozone concentrations) is too coarse to allow any significant estimate and only some general remarks can be given.

The two scenarios used to estimate the future AOT40 levels, substantially foresee no significant increase in future ozone concentrations. But the climatic changes is expected to affect the ozone-plants interactions, and thus the ozone uptake. The strong decrease of summer rainfalls, for example, will cause a reduction of the stomatal openings due to the water shortage, thus preventing the vegetation from ozone damages.

On the contrary the increase in winter and spring rainfalls may cause an increase of the ozone uptake in evergreen species.
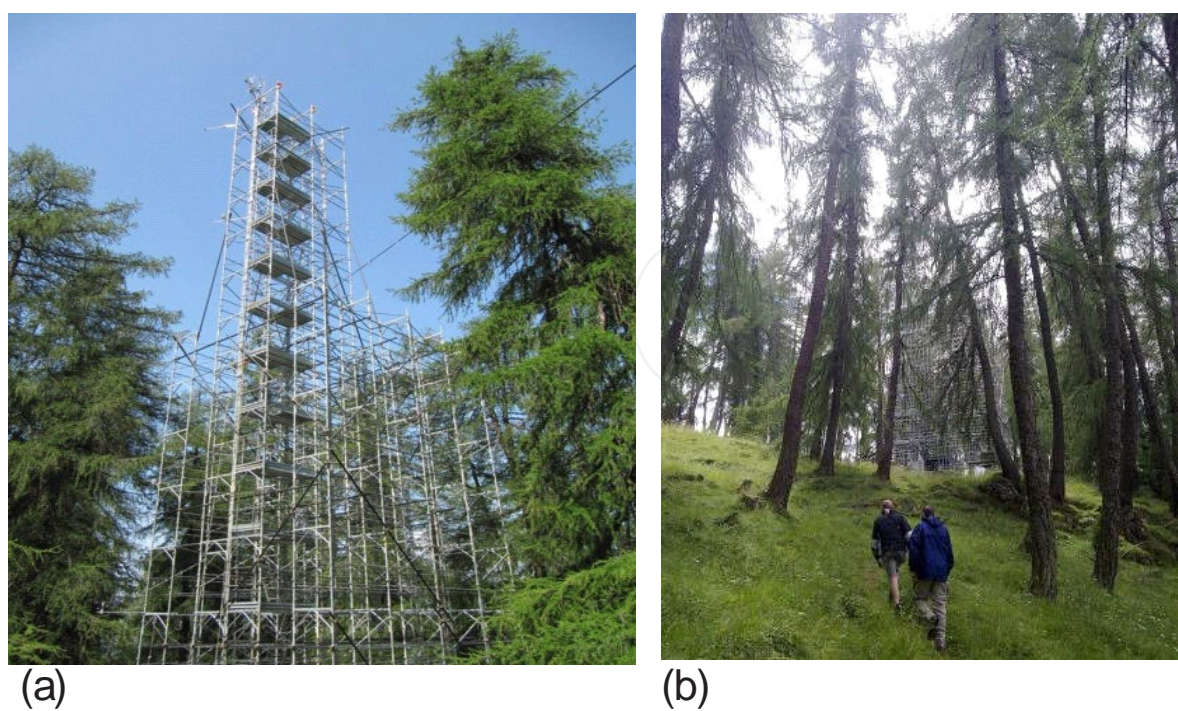
Figure 20. The micrometeorological tower running in Paspardo in 2010 and 2011 (a), and a view of the larch forest around the tower (b)
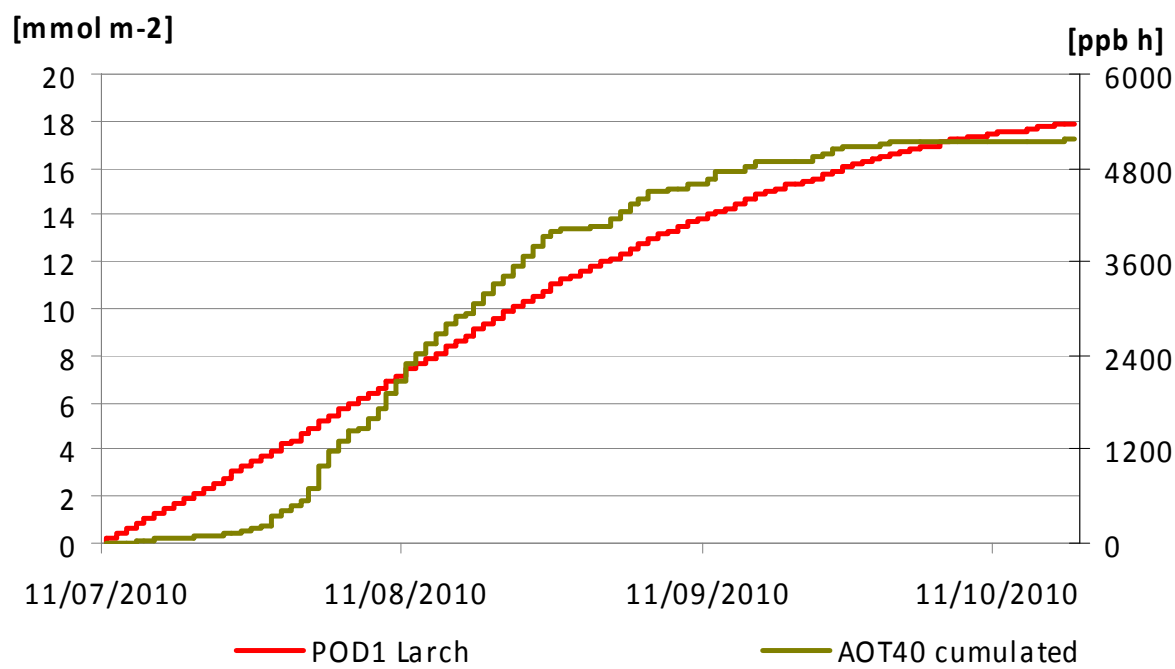
Figure 21. Cumulated POD_1 (red line, left y-axis) and AOT40 (green line, right y-axis) in the measuring period (three months) of the summer 2010.

4. Forestry towards the climate change scenario: dealing with uncertainties

The uncertainty that characterizes the approach to forest management for the next century requires a profound revision of the proven strategies of European forest policy. The trends in climate change are among the main factors of this uncertainty, but not the only ones.

At least two more factors should be considered:

• the enhancing in the magnitude of extreme events: both for the presence of more favorable conditions for pest outbreaks and for augmented vulnerability and stress conditions for the trees;

• the evolution of timber and forest products market: it is hard to foresee the future behavior of BRIC countries about this specific market and what the global response will be.

Some elements that could support the development of a new forest policy course, able to deal with the uncertainty, are here indicated.

It is at present a widespread opinion that forest policy should proceed towards open management systems and provide methods and programs that shall be flexible and easily adaptable to rapid changes in context.

On the other hand temporal coherence and transparency in the goals are strongly required. The decisions taken today have to be supported by continuity. Once established, the objectives of the national forest planning should be absolutely clear and rapidly adaptable to the current focus. Obviously this possibility is ensured by a strongly efficient monitoring system.

A full transparency in the goals should also be in the future a requirement for every subsidiarity intervention, configuring every investment into a rational and coherent scheme.

Moreover we need the full coordination of all matters dealing with territory (agriculture, construction, facilities, tourism, industry, etc.). Forest governance forms that have not been adequately harmonized and integrated with other soil-consuming activities might in fact prove themselves meaningless and totally ineffective.

Finally a further admonition has to be done, concerning illegal forms of forest exploitation (currently available data indicate that at least 50% of withdrawals in the tropical area are illegal).

Initiatives such as codes of regulation and certificated partnerships are just a few examples of good and effective practices developed to cope with illegality through responsibility.

It is also desirable to amend some existing criticality that could exacerbate as the climate scenario gets more and more constraining.

First of all, a situation of high uncertainty urge for a more accurate monitoring system and conditions which are easier to keep under a continuous control.

For this reason it should be promoted the bundling of the properties against the widespread fragmentation of forest parcels, both in the case of private plots and in public ones and to limit

forest utilizations carried on without technical address. In this context, the Park can represent the meeting point between the different realities that operate in forest management.

Moreover all the situations that imply a non-ordinary management should be accurately monitored. Where programmatic choices provide free natural evolution (integral reservoirs, peculiar formations, inaccessible stands, etc.), an adequate system of phytosanitary and hydrogeological monitoring must be implemented.

5. Present and future trends in the technical management of Adamello Park and Valle Camonica Area

The management lines currently implemented in Valle Camonica can already help in facing a situation full of uncertainty as that prospected by the predicted climate change scenarios in the valley, since they are oriented to strengthen the forest formations and make them more stable in terms of specific composition through adequate treatment forms and the corrections of some critical situations.

5.1. Specific management indications

The specific management indications can be summarized in three main issues, as follows.

a. To address forest policy giving priority to naturalistic and landscaping functions to mountainside forest management, promoting at the same time timber production encouraging conversion towards high-stand forests.

While preserving a production management for forests on a large surface of the Valle Camonica, a policy of re-naturalization of the areas, with a multifunctional approach, has already been carried on by the Park administration in the last decade and should be further improved.

It is believed moreover that the same policy should be adopted at the EU level, though it is clear that such a shift of orientation would require a significant change in the administrative and managerial approach to forestry; nevertheless, although not backed by direct economical evaluations, it would be the most reasonable way to be pursued.

b. To evaluate the situation of those formations and species that are the most exposed to climate change.

The forecasts suggest a very significant extension of warm phytoclimatic ranges; therefore the species and formations more susceptible to water stress (for instance, gorge and crags formations) will be vulnerable and will trend to thin out, not necessarily replaced by thermophile species.

Going along with the climate change scenarios, which show a contraction and an shift towards higher altitudes of Norway Spruce (*Picea abies*) and Chestnut (*Castanea sativa*) range, it is desirable:

- to keep on removing coniferous from lower-medium mountainsides and to renaturate secondary woods of Norway spruce and chestnut;

- to improve the treatments in chestnut abandoned formations. In the last years these kinds of woods lacked of the traditional active management: as a result of the consequent chaotic growth, these aged chestnut coppices are characterized by a high risk factor, mainly for what concerns fire risk. It is advisable therefore to facilitate the conversion towards high forests and the changeover towards oak and maple.

Also for what concerns Scots pine, it is reasonable to expect a significant shrinking of the species range, especially in gorge and crags situations. Also in this case, the most recommendable substitute is the oak.

c. Reduce the compositional and structural trivialization of mountainsides promoting and increasing biodiversity. Extreme events increase, induced by biotic and abiotic factors, implies the addressing of proper treatments for mono-cultural and mono-structural forests

5.2. Hints on vegetational composition

From the point of view of the biodiversity and of the composition in species, forestry measures should be addressed in order:

- to promote the conservation species with auxiliary or faunal roles: *Prunus avium, Crataegus monogina, Acer campestre, Betula pendula, Juniperus communis, Laburnum anagyroides, Cornus sanguinea, Cornus mas, Morus alba, Populis tremula, Quercus pubescens, Salix caprea, Taxus baccata, Ulmus glabra, Sambucus nigra, Sambucus racemosa, Sorbus aucuparia e Sorbus aria, Mespilus germanica, Malus sylvestris, Prunus sp., Pyrus pyraster, Quercus pubescens*

- to promote the conservation and diffusion of target species, in order to limit the extreme semplification of the crops and especially to preserve the least competitive species. Specific conservation measures are to be adopted, eventually considering also the total prohibition in use. For what concerns the Adamello Park, target species are: *Quercus sp., Carpinus betulus, Acer pseudoplatanus, Tylia cordata, Fagus sylvatica, Abies alba e Pinus cembra*. As for target forest tipologies, in addition to those representative the single target species (Oak woods, Beech woods, Oak-Hornbeam woods, Sycamore-Lime woods, Fir and Cembran pine woods), it is also recommendable to promote the protection and safeguarding of minors and/or relict species.

For what concerns beech, Oaks and other noble species, it should be noticed that especially Beech range might find benefits from the expected scenario. Since in the territory of Valle Camonica, there is a general lack of seed-bearing trees, the implementation of protection policies to preserve these subjects is essential. *Tilia cordata* and *Acer pseudoplatanus* show greater capacity of seed dispersal. Specific management actions must be addressed to overcame the difficulties of oak regeneration (seed-bearing trees protection, conversion of coppice to high forest for *Quercus robur* x *pubescens* hybrid).

Common Hornbeam *(Carpinus betulus)* and Hop Hornbeam *(Ostrya carpinifolia)* might prove particularly important in limiting the further spread of *Ailantus altissima* and *Robinia pseudoacacia*, possibly fostered by the progressive withering of the valley bottom.

5.3. Hints on technical management

- **High stands management.** It is recommendable to promote the form of high stand management and at the same time the conversion to high stands of coppices no longer actively run or older than 40 years.

- **Coppice management.** Coppice form is advisable only in those cases in which the technical and coltural care are guarantee. A minimum number of sapling has to be assured, but the a priori defined threshold for each species has to be critically revised. In fact, the application of this minimum quantity not always resulted in the best technical option.

- **Natural evolution.** Natural evolution has to be encouraged in those forest types showing structural attributes suggesting the need for treatments despite of hydro-geological and/or topographic concerns (protection forests). The natural evolution is also suggested for those formations having greater bio-ecological value (new formations, riparian formations, primitive formations, rupiculous and ravine formations, scree slope formations).

- **Site-adapted silviculture.** Promote the adoption of extensive silvicultural practices oriented to the raising of forest variability in terms of composition, structure and cover (selective cutting, seeding cutting patch cutting); intensive practices could be implemented in those situations showing perturbed forest ecosystem (e.g. phytosanitary issues), anthropic composition (artificially afforested plots), hydrogeological instability.

- **Seasonality of forest cutting (treatments).** Forest structural management needs to be tailored on specific objectives accounting for the presence of endangered species (e.g. IUCN red list); preventive measures could be addressed to exclude potential and actual nest sites for birds or core areas for vertebrates (e.g. borrows, breeding areas, lek sites, wetlands, ecc.)

- **Forest fire fighting.** Promote actions and ad hoc forest management practices to reduce forest susceptibility to fire. 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 chestnuts 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: cutting of burned trees: cutting of burned trees and release of subjects with the highest survival probability; direct seeding: seeding of herbaceous and woody species to prevent surface run-off; 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

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

Acknowledgements

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