Chapter 16

Monitoring Climatic Change Impacts on Protection Forests in Aosta Valley (Italy) and in Drôme (France) Using Medium and High Resolution Remote Sensing and Mateloscopes Plots

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Additional information is available at the end of the chapter

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1. Introduction

Land management in relation to climate change has become a major issue since many studies have confirmed significant changes at local to global scales over recent decades.

At the Alps scale, observations showed an increase in average temperature of 0.9 ° C over the period 1901-2000, and of 0.6 ° C during the last 30 years [1]. In addition, daily maximum temperatures have risen faster: between 0.9 ° C and 1.1 ° C over the same period. The majority of observations converge to an increase in the number of hot summer days and a decrease in the number of frost days. Thus, the years 1994, 2000, 2002 and 2003 were the warmest years since the 16th century [2] [3] [4]. In terms of projections, an increase of 5.5 to 6 ° C in summer temperature and a decrease in summer rainfall of 15 to 20% are expected in the next 100 years (this last prediction is very variable according to altitude)[5]. Some scenarios announce more extreme precipitation events [6] [7].

The impacts of these changes on vegetations' dynamics are extensively studied by the scientific community. These impacts also concern policy makers and forest managers who are trying to find ways to prepare forests to face with the predicted climate changes.

The first consequences of global change on forest habitats have already been demonstrated and reveal two contradictory aspects:

- a positive evolution of species' productivity during the last century;

a probable movement of the spatial distribution of forest species' habitats northward (in our hemisphere) and/or in altitude. For mountainous French forest, the upslope migration of forest species has been estimated to 65 m during the last century. If the projected warming up will be effective, then the corresponding latitudinal shift of forest species' habitats will vary from 250 to 500 km from their current positions.More locally, foresters observe diebacks more or less localized, without knowing their root causes and if they should attribute them to an epiphenomenon related to extreme weather events or to the initiation of a sustainable evolution of climate conditions.

In recent years climate-induced forest stress and dieback have been apparently increasing in Europe [8][9][10]. The two key drivers of climate-induced forest dieback are aridity increasing (e.g., drought intensity and duration) and temperatures warming, resulting in physiological stress that can exceed mortality thresholds for particular tree species. The combined effect of lack of precipitation over a certain period with other climatic anomalies, such as high temperature, high wind and low relative humidity over a particular area may result in reduced green vegetation cover [11]. When drought conditions end, the following vegetation recovery process may last for longer periods of time. The recent availability of reliable satellite imagery covering wide regions over long periods of time has progressively strengthened the role of remote sensing in environmental studies [12] [13]. The use of vegetation index obtained from satellite imagery allows overcoming the limit of discrete point data provided by conventional drought monitoring tools. In recent years there has been a lot of studies dealing with drought events over different regions of Europe or even covering the entire European continent [14] [15] [16] [17] [18] [19]. Summer droughts are the most important in terms of human perception, but water shortages during the remaining seasons may also have significant impacts on vegetation. The spatial distribution and severity of dieback and mortality is not routinely captured and areas affected by dieback often go unreported. Efficient and accurate mapping of disturbances over large geographical areas are possible with satellite remote sensing. This method offers the possibility of time- series analysis given the large quantity of archived data spanning many years.

Recently, forest dieback have been observed in the Southern Alps [20] [21] affecting protection function against rockfalls hazards. High mortality of Scots Pine (*Pinus silvestris L.*) have been observed and studied in large areas of Europe since the early 1980's. The Scots Pine decline is a complex phenomenon that may develop in response a variety of triggering agents (e.g. high temperature and drought) and ecological characteristics related to the stand location. The process can affect single plants or the entire stand and the effects, visible on the crown, may appear both as a discoloration process and as a progressive thinning and loss of needles [22]. In Aosta Valley acute Scots Pine decline events occurred starting from 2005 in large sub-alpine areas located within 650 and 1000 m a.s.l and specifically in North exposed slopes. Several studies on this subject have been conducted in previous years [23] [24], but the causes for these diffusive deaths are not well clarified. It has been argued that the decline process is triggered by several concurrent factors (e.g. drought, land use changes, parasites). Since these forests have a part in protective functions against natural hazards, monitoring the status and the evolution of the decline process is of primary importance to lead decisions on current and future management strategies.

According to these elements, foresters and land use managers can legitimately wonder about the consequences of climate change on forest stands in short, medium and long term. The future of forests in the Alps is a major issue at the the European scale, which requires a high anticipation from managers, policy makers and scientists for understanding phenomena and their evolutions, defining management strategies for risks prevention and mitigation.

In order to help forest managers to cope with climate changes' consequences in protection forests, one of the objectives of the project MANFRED has been to test models, tools and technologies which can be used for diagnoses and for building up forest management guidelines. The contribution of remote sensing techniques has been tested in the Aosta Valley. The contributions of specific training plots (marteloscopes), rockfall protection eco-engineering works and a model for mapping probable rockfall risk below a forest screen have been tested, in the two French case studies (in the Drôme administrative area) for the achievement of a black pine forest new magagement plan. This chapter presents the mains results obtained.

2. The Aosta Valley case study

The Aosta Valley case study had two main objectives:

- to test remote sensing techniques for mapping the degree and the evolution of Scots Pine decline
- to localize and quantify dieback sectors impacts comparing ground measurements and satellite remote sensed data.

2.1. Data

The response of vegetation was assessed with:

- Normalized Difference Vegetation Index (NDVI) as derived from two types of sensors: a medium resolution (MODIS) and a high resolution (Landsat)
- Very high resolution images analysis and field data.

2.1.1. Modis

MODIS is an optical multi-spectral instrument onboard TERRA satellite that performs an almost complete cover of the Earth surface in 8 spectral bands, on a bi-daily basis.

2.1.2. NDVI

Satellite vegetation index (VI) products are commonly used in a wide variety of terrestrial science applications in order to monitor and characterize the Earth's vegetation cover from space. VIs are optical measures of vegetation canopy “greenness”, a composite property of leaf chlorophyll, leaf area, canopy cover, and canopy architecture. Although VIs are not intrinsic to physical quantities, they are widely used as proxies in the assessment of many biophysical and biochemical variables. VI time series data records have played an important role in measuring and characterizing land surface responses to climate variability and change. In our study, NDVI data were extracted from the so-called 16 days Vegetation Index Products (MOD13Q1) with 250m resolution of the MOLT database [25].

The technique of compositing data for 16 days considerably reduces noise in the surface reflection signal including QA data sets with statistical data indicating the quality of the VI product. It makes use of a filter for data dependent on cloud and viewing geometry [26]. This VI compositing algorithm includes the maximum value composite (MVC) and a constraint on view angle – maximum value composite (CV-MVC). The objective of this compositing methodology is to determine a single value per pixel from all the data retained by the filter. This value is assumed to be representative for each pixel over the 16-day period of interest. As a result, the quality of MODIS NDVI data is significantly enhanced [27]. The NDVI, a normalized ratio of the near infrared (NIR) and red spectral light reflected (red) by the land surface back up into space is linked to the presence, density and condition of vegetation:

$$\mathrm{NDVI} = \left[\left(\mathrm{NIR - Red} \right) / \left(\mathrm{NIR + Red} \right) \right] \tag{1}$$

The raw NDVI values are fractional real numbers that range between -1 to +1 units, but when used to define the land cover classes, the values are normally constrained from + 0.1 units in rocks and up to + 0.8 units in dense forest.

First we analyze the intra and inter annual variations of NDVI for protection forests over the period 2000-2011. The temporal evolutions of the VI is bound to the vegetation development phases, the established profiles allow to characterize the specific phenological cycle of the considered stands and to localize keys phenological stages in particular the spring development. Temporal evolution can be defined from « phenologic metrics ». Over a year (Fig. 1), the NDVI time-series shows a typical pattern with three phases: an increase corresponding with the start of vegetation growth (peak),a plateau period of high photosynthetic activity, a sharp decrease indicating vegetation senescence.

The temporal evolution of monthly values of NDVI, spatially averaged over protection forests in the Aoste Valley between 2000 and 2010, is presented in Fig. 2. The general linear trend of the vegetation was plotted to identify trends towards degradation or vegetation recovery.

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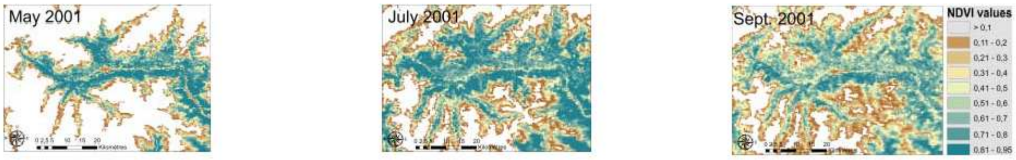

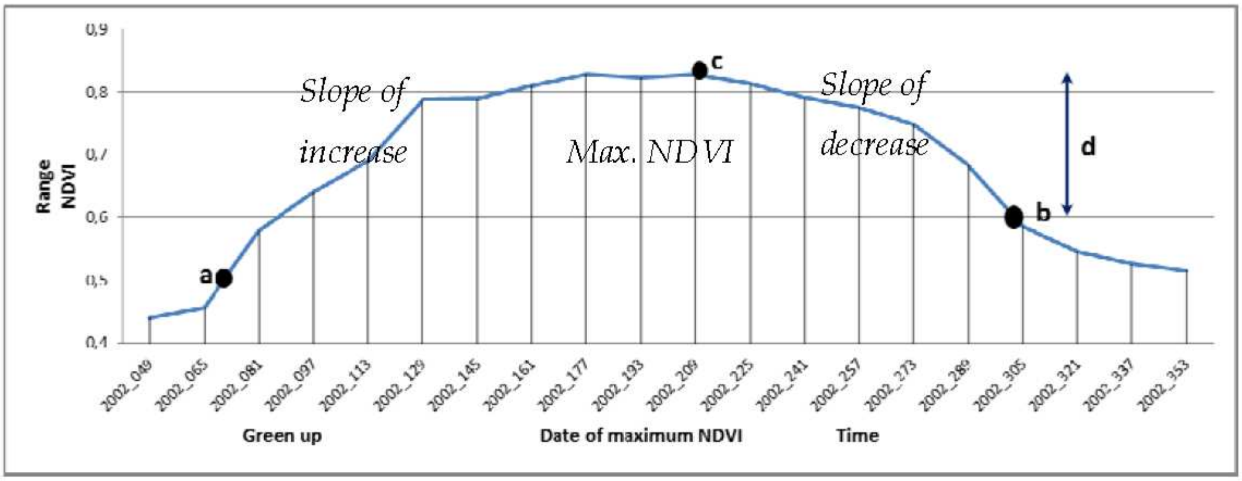

Figure 1. Annual cycle of NDVI in Aoste valley protection forest (year 2002). Points (a) and (c) mark start and end of season, point (c) displays the largest value and (d) displays the seasonal amplitude.

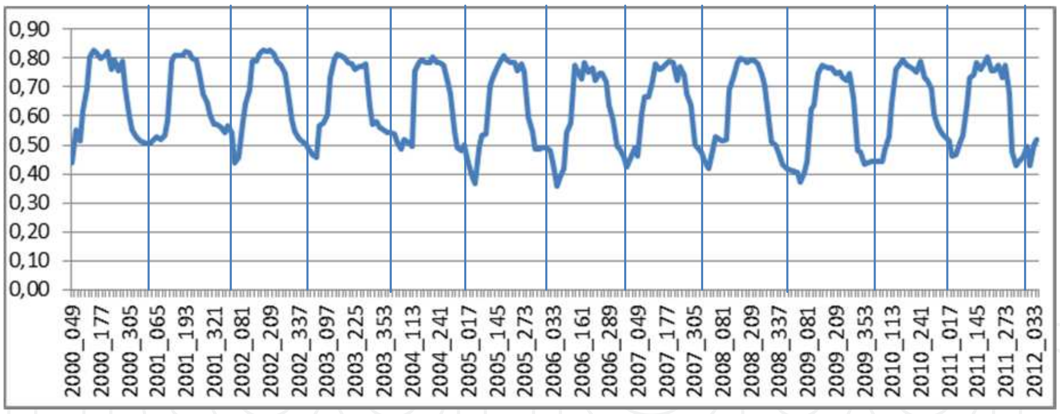

Figure 2. Time-series NDVI data for representative pixels of Aosta valley protection forests observed on a biweekly basis from 2000 to 2012.

2.1.3. VCI

16 days-NDVI composites (250 m spatial resolution) for 2000–2011 were used to calculate the Vegetation Condition Index (VCI) developed to control for local differences in ecosystem productivity [28]. The VCI is a pixel-wise normalization of NDVI accumulated over a long period that is useful for making relative assessments of changes in the NDVI signal by filtering

out the contribution of local geographic resources to the spatial variability of NDVI. The VCI is computed as:

$$VCI=100(NDVI-NDVImin) / (NDVImax–NDVImin) \quad (2)$$

where NDVI, NDVImax and NDVImin are the smoothed bi-weekly NDVI, multi-year maximum NDVI and multi-year minimum NDVI, respectively, for each grid cell. VCI changes from 0 to 100, corresponding to changes in vegetation condition from extremely unfavorable to optimal. Individual years can then be compared and assessed against the 'normal' conditions. The VCI smoothes out non-uniformity in the MODIS data and it indicates how weather conditions have influenced the relative vigor of the vegetation with respect to the ecologically defined limits.

2.1.4. SG Index

We used an annual index of vegetation vigour able to characterize quantitatively the vegetation activity during the period of spring increase: SG phenologic metric. This index corresponding to the accumulation Spring NDVI that can be likened to the net primary production. SG is obtained by making the sum of NDVI during the green up period.

$$SG = \Sigma \text{ NDVI from } 15^{th} \text{ april to } 15^{th} \text{ june} \quad (3)$$

2.1.5. Landsat

Many factors affect NDVI variations within a pixel: plant architectural arrangement, interactions with canopy cover, height, composition of species, vegetation vigour, leaf properties and vegetation stress are some factors that can significantly affect the remotely sensed information. In order to improve the accuracy of the spatial analysis, Landsat data were selected. Spectral and temporal resolution was found to be adequate for vegetation stress detection and a single scene covered a large enough area [29]. 30 Landsat 5 TM and Landsat 7 ETM+ images (Path 195 and Row 28) were provided courtesy of the USGS EROS Data Center. The full scenes (standard L1G product) are available at http://glovis.usgs.gov.

Atmospheric correction of satellite measurements is critically important in remote sensing especially when using multiple images. Most of the radiation detected by a satellite sensor is backscattered from the atmosphere. Therefore, removing atmospheric effects is important [30]. The images were geometrically and radiometrically corrected. First, all scenes have been calibrated into radiance in units of [μW/(cm2*sr*nm)] using sensor calibration coefficients [31]. Later, an atmospheric correction of the images was carried out to minimize the effects of the different atmospheric conditions on the images that should compensate for the "skylight" (atmospheric aerosol scattering) to produce spectra that more truly depict surface reflectance.

The FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) software package in ENVI (by Research Systems) provides an accurate means of compensating for

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atmospheric effects. It incorporates MODTRAN 4 radiative transfer code with all MODTRAN atmosphere and aerosol types to calculate a unique solution for each image [32]. FLAASH includes also a correction for the adjacency effect, provides an option to compute a scene-average visibility (aerosol/haze amount). The method is based on observations [33] of a nearly fixed ratio between the reflectance for such pixels at 660 nm and 2100 nm (FLAASH User's Guide). It includes also the average elevation of the study area, scene center coordinates, sensor type, flight date and time, and information about aerosol distribution, visibility, and water vapor conditions [34]. In this study, model parameters describing a mid-latitude summer atmosphere and rural aerosols together with automatic aerosol retrieval were used in FLAASH to correct the Landsat images.

2.2. Aerial images and field validation

Airborne and satellite remote sensing is a valuable tool for a synoptic view of the terrestrial ecosystems in order to monitor the environmental processes. In particular, in the case of forest decline, the spatial distribution of environmental parameters (such as canopy greenness or species distribution) and their associated temporal dynamics are detectable by remote sensing, allowing understanding, monitoring and predicting the evolution of the process [35] [36].

In detail, the analysis and the numerical classification of digital aerial photographs at high spatial resolution allows understanding the intensity of the decline process. Moreover the availability of several acquisitions is useful to monitor the decline process evolution over time. Aerial images acquired in 2011 (20 cm spatial resolution) were used in order to semi-automatically map the presence and distribution of Scots Pine and to identify the state of canopy decline. The map obtained in 2011 was then compared with digital aerial photographs acquired in 2006 (50 cm spatial resolution) in order to evaluate the evolution of the decline process, in terms of potential reversibility. Finally, the analysis computed on digital aerial photographs have been validated using direct field observations carried out in summer 2011 in six sample areas of the central valley.

The method for the processing of aerial images involved the computation of spectral indices from the digital numbers (DN) values of the images in the red (R), green (G) and blue (B) channels. These indices together with the values of the original DN were used to make a classification of the different images. In detail, 12 spectral classes were identified which were then assigned to 5 information classes : 1) shadows, 2) deciduous tree species, 3) not damaged Scots Pine, 4) damaged Scots Pine, 5) other surfaces (e.g. roads). The two classes of interest (3 and 4) were used to analyze differences between the 2006 and 2011 images.

2.3. Results

2.3.1. Annual cycle of NDVI using Modis data

In order to smooth Modis time-series, we experimented different processing methods in Timesat program [37] (Fig.3). The performance of different processing methods have been evaluated in a recent study by Hird and McDermid [38] „concluding that they are highly competitive and that they preserve the signal integrity". Three different processing methods are experimented: the local Savitzky-Golay filter [39], the asymmetric Gaussian and double logistic model functions that are well suited for describing the shape of the time-series in overlapping intervals around maxima and minima. In our case, fits to the asymmetric Gaussians appeared to be the better choice.

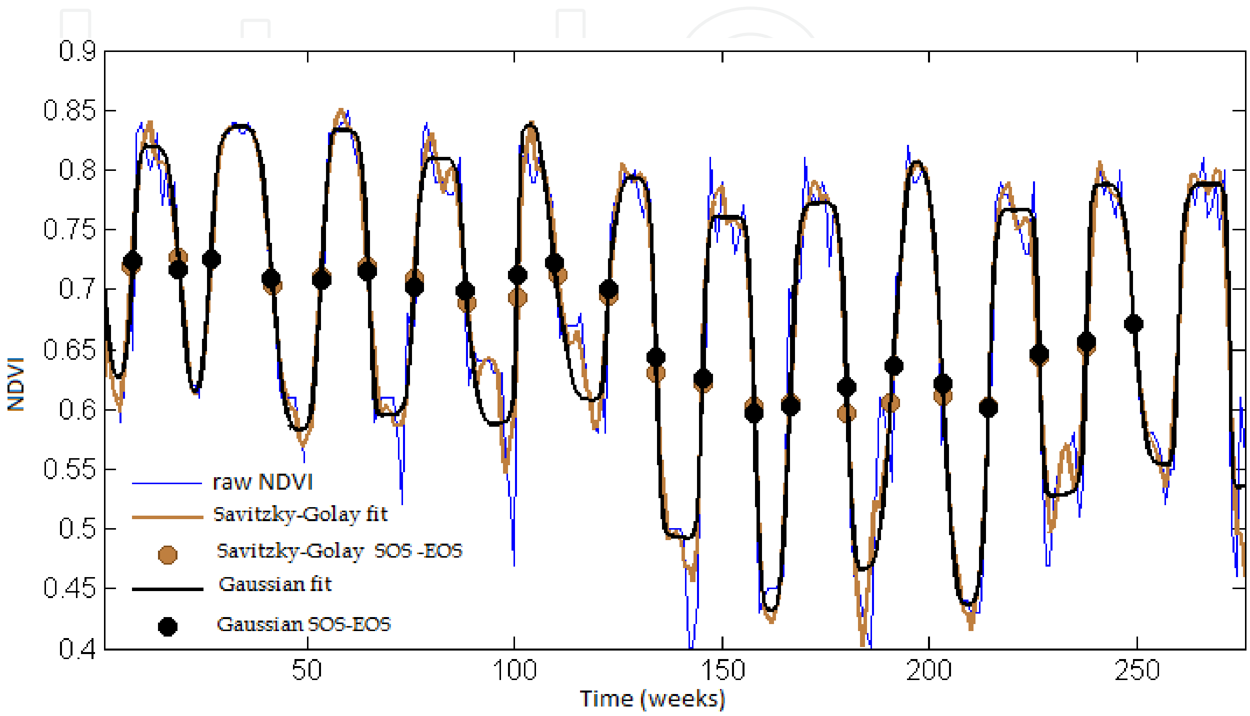

Figure 3. Smoothed NDVI time-series for decade 2000-2010 in Aoste valley protection forests. The blue thin line represent the original NDVI data, the brown thin line shows the Savitsky-Golay fitted function, the black solid line displays the Gaussian fit.

The curve exhibits a consistency both in amplitude and in length of growing season and low peaks values appears in 2006 and 2009.

Some seasonality parameters computed using TIMESAT are shown in Fig.4 and Fig.5:

a. Start of season defined from the fitted function currently set to 10% of the distance between the left base level and the maximum ;

b. End of season show a decay of 15 days for SOS and 10 days for EOS with a trend to occur later over the decade 2000-2010.

c. point with the largest NDVI value during the season

d. Seasonal amplitude during the decade

SOS shows a heterogeneous pattern with high variability from day 105 in 2000 to day 120 in 2010. EOS data indicates a later onset of autumnal phenological events, but these shifts are less pronounced.

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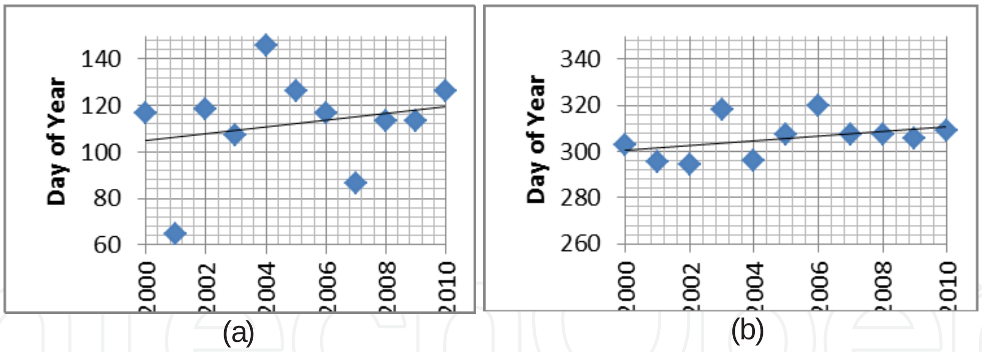

Figure 4. SOS (a) and EOS (b) estimated from fitted functions (Timesat) from 2000 to 2010 in Aosta Valley protection forests.

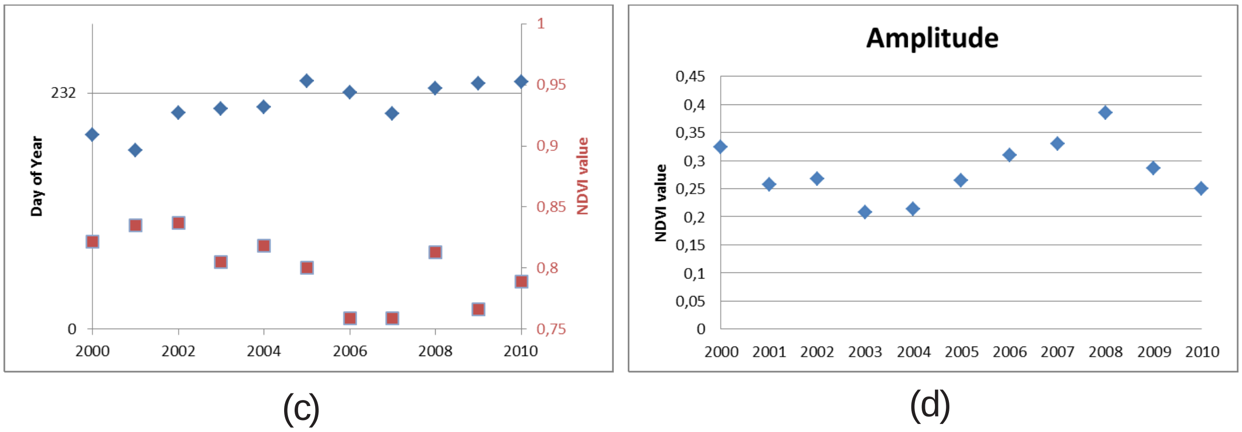

Figure 5. NDVI peaks values (c) and seasonal amplitude (d) estimated from fitted function (Timesat) over the decade 2000-2010 in Aosta valley protection forests.

NDVI peak points over the season with the largest value calculated along the decade begin at day 190 in 2000 (mid June) and day 243 in 2010 (mid august). The mean at Day 232 is situated in 2006 (end of July). We observe a progressive delay of NDVI peak days during the decade, with very low variation of NDVI peak value (around 0, 8).

The seasonal amplitude, reflecting the "biomass production "vary from 0, 21 in 2003 and 2004, to 0,39 in 2008.

2.3.2. Vegetation condition index

The VCI index indicates percent change of the difference between the current NDVI index and historical NDVI time series minimum with respect to the NDVI dynamic range (Fig.6). VCI was calculated by seasons, aggregating values from april to june (spring) and from july to September (summer).

The trend for spring values shows a continuous decrease from 2002 but staying over 70%. Summer vegetation conditions show a decrease over the period 2000-2011 with two marked inflexions (under 60%) for the years 2006 and 2009.

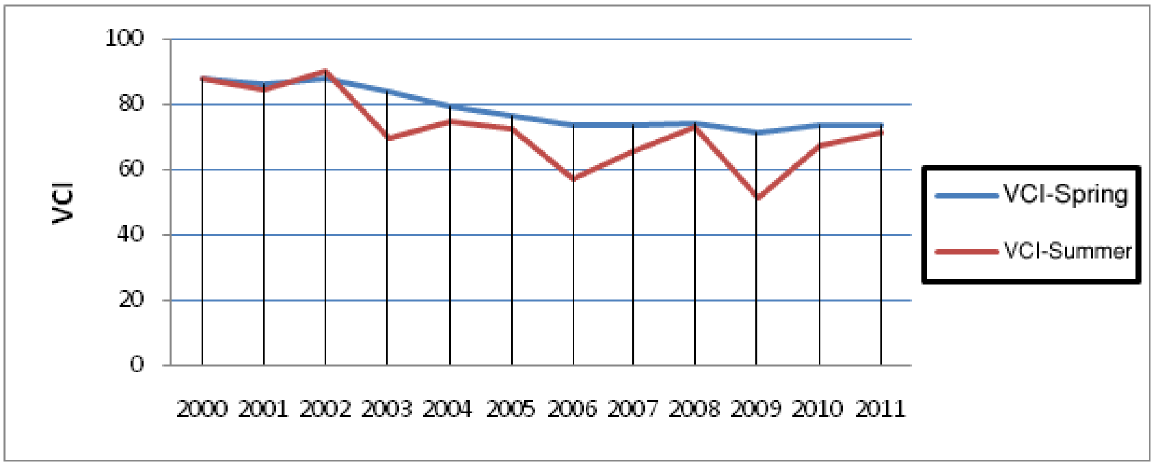

Figure 6. Vegetation Condition Index in Aoste protection forests (2000-2012).

2.3.3. SG index

SG Index values allow characterizing each year and indicating annual fluctuations.

We can highlight and quantify abnormal variations of the vegetation activity over the period of observation. The series of annual SG calculated from 2000 till 2012 can be characterized by a trend which reports the variation of the vegetation activity between two extremes: Downward trend if physiological disturbance or upward if the vegetation increases. A strong fall of vegetation activity, over the period of observation, is to be put in connection with important disturbances which would have occurred within forest stands (Decay or sanitary cutting).

Fig. 7 shows a valuable example of annual SG for all protection forests between 2000 and 2006. The line of trend of the series is characterized by a value of slope (α) which reports the importance of the fall of activity over seven years (2000-2006). The principle to use the slope on series of temporal images was already implemented in the case of analysis of trend to measure variations of behavior of the vegetation [32]. The slope (α) of the trend line, calculated for every pixel, establishes our indicator of "change" or disturbance observed over 2000-2006. This one can be mapped for all the protection forest areas.

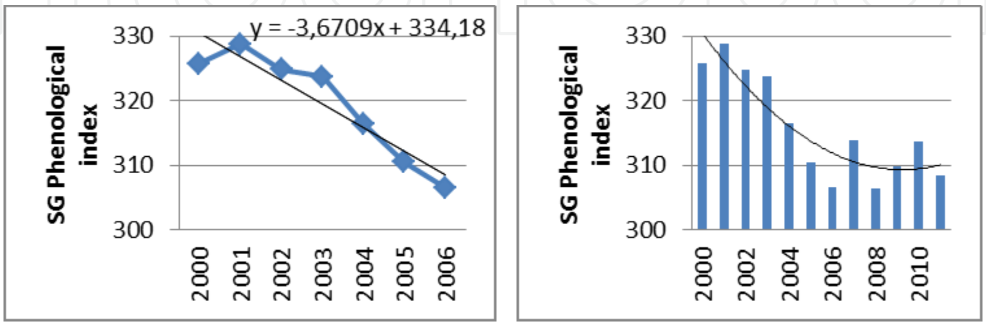

Figure 7. SG index (sum of spring NDVI values) indicating the vigor of vegetation. SG values for all forest protection pixel; slope of trend line (α) =-3.67

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These monitoring tools are able to specifically detect periods of varying drought conditions. Findings indicate a clear trend of decrease starting from summer 2002 and reaching the lowest values at summer 2006.

Further results at finer resolution using Landsat images should confirm and refine these results.

2.3.4. Monitoring impacts at high resolution using Landsat sensors

At the high resolution of Landsat sensor (30m), the objective was to determine the patterns of vegetation variability and change between 1999 and 2011. We took into account seasonal variations in the distributions of different vegetation types. Forests show contrasting seasonal variations in vegetation activity with a peak activity occurring in summer [39].

Landsat 7 ETM+ SLC-off data refers to all Landsat 7 images collected after May 31, 2003, when the Scan Line Corrector (SLC) failed. A hardware component failure left wedge-shaped spaces of missing data on either side of images. The sensor still acquires approximately 75 percent of the data for any given scene (240*240km). The gaps in data form alternating wedges that increase in width from the center to the edge of a scene. In our case study, over the 30 Landsat TM5 and ETM+, we calculate a loss of information between 4 and 6% due to SLC off on protection forest areas (Fig. 8).

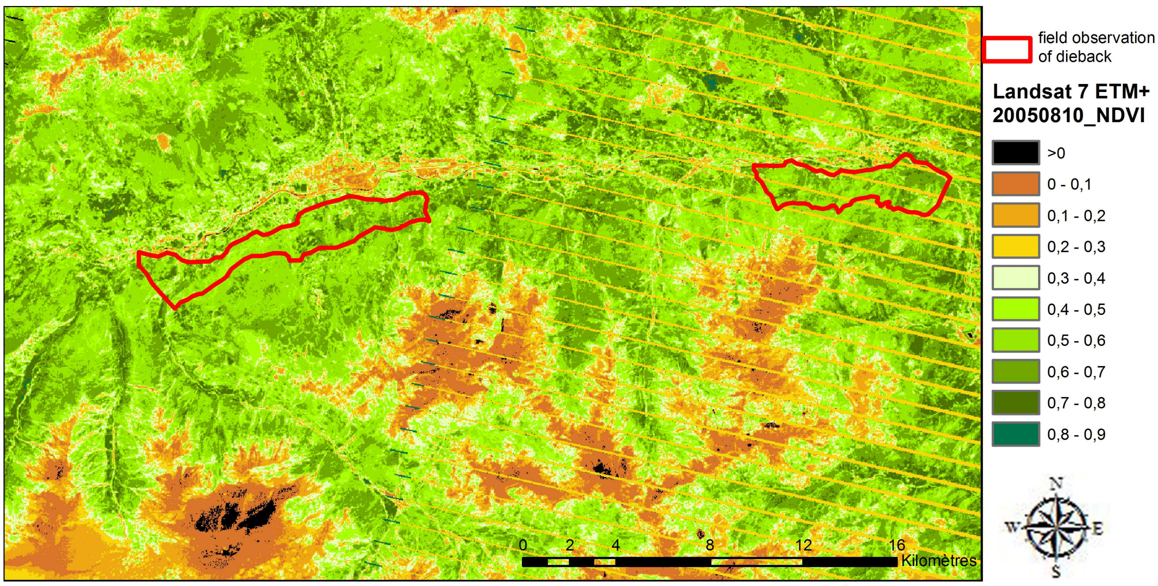

Figure 8. NDVI in Aoste valley 2005/08/10 Landsat 7 ETM+ (SLC off) and localisation of dieback fields observations.

The temporal evolution of monthly values of NDVI (end of july- first days of august), spatially averaged over Aoste region south of river between 1999 and 2011, is presented in Fig. 9.

Time series of monthly NDVI are also shown for three different types of forests (Fig.10 and 11). Information about the forest type associated to each pixel was obtained overlaying the images with the official forestry database: the Regione Autonoma Valle d'Aosta made available

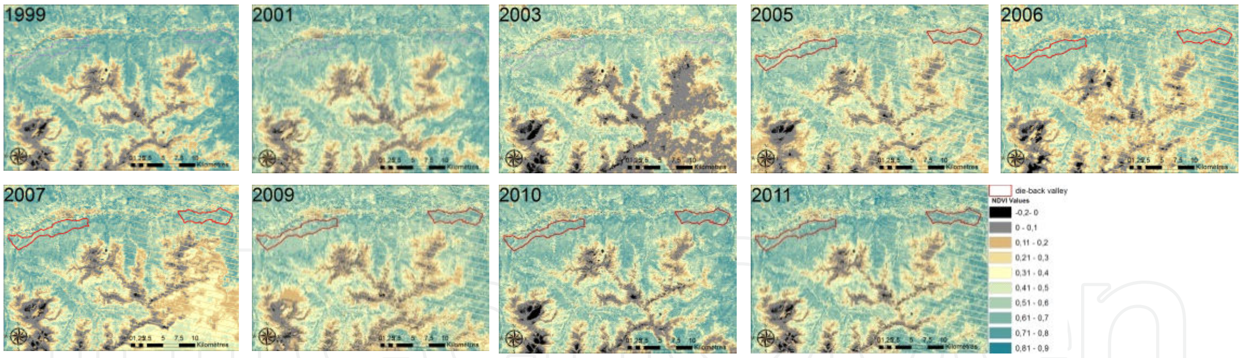

Figure 9. NDVI evolution in Aoste valley 1999-2011 Landsat sensors.

a map of protection forests from the „dipartimento Agro.Selvi.Ter. dell'Università degli Studi di Torino". This map covers the entire regional territory (arround 3.000 km²).

The comparison between the NDVI values obtained from MODIS and Landsat images has shown a good consistency of the temporal dynamics but a systematic error that can be read as bias (MODIS NDVI over estimation). We took NDVI values from end of july-beginning of august images as it was determined as the peak date during the decade using Modis data.

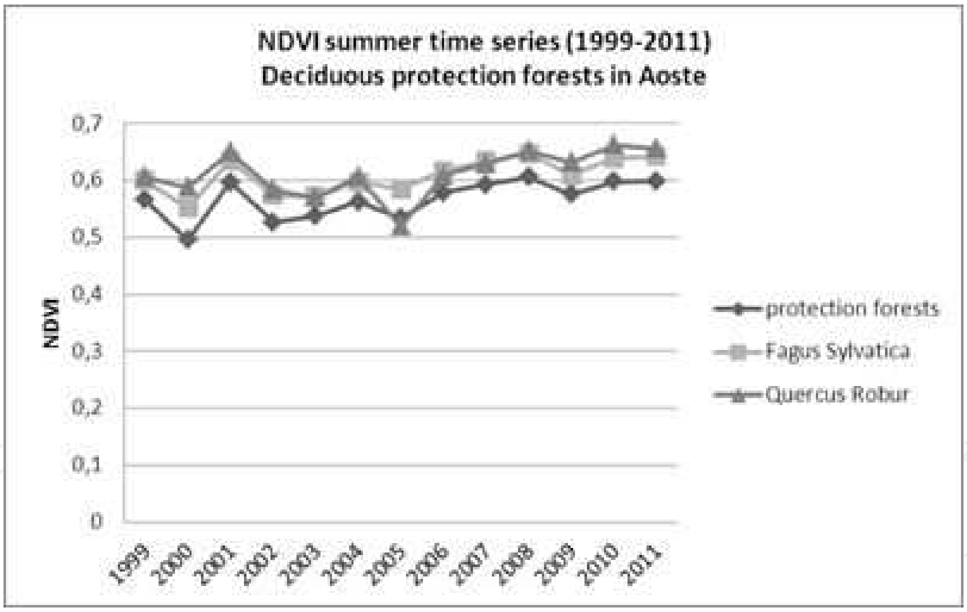

Figure 10. NDVI summer time series (1999-2011) - Deciduous protection forest

Monitoring Time series of summer NDVI values in the area of protection forest in Aosta valley allowed detection of good (2001, 2008) and bad years (2000, 2002, 2005, 2009) relatively to a general increasing trend. Spatial characterization of forest patch (900m2) showed a decrease of NDVI during bad years where trees are affected by drought. At regional scale we achieve a precise localization of die-back and ability to qualify stand types and to separate behavior of coniferous and deciduous forests.

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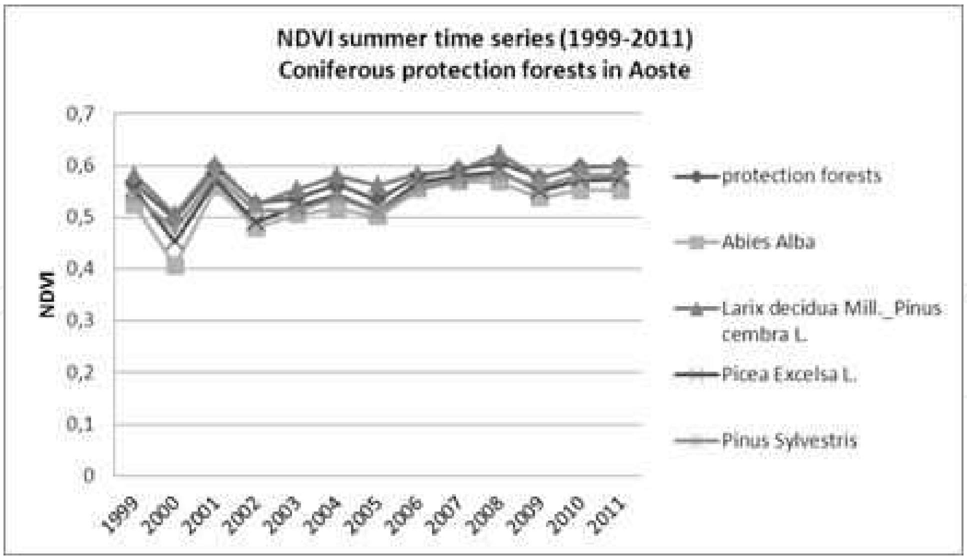

Figure 11. NDVI summer time series (1999-2011) - Coniferous protection forest

2.4. High resolution analysis on ortho-images and field validation

Results of this analysis showed good agreement between the classified images and field data collected (coefficient of determination R2 = 0.74) in the sample areas (fig. 12).

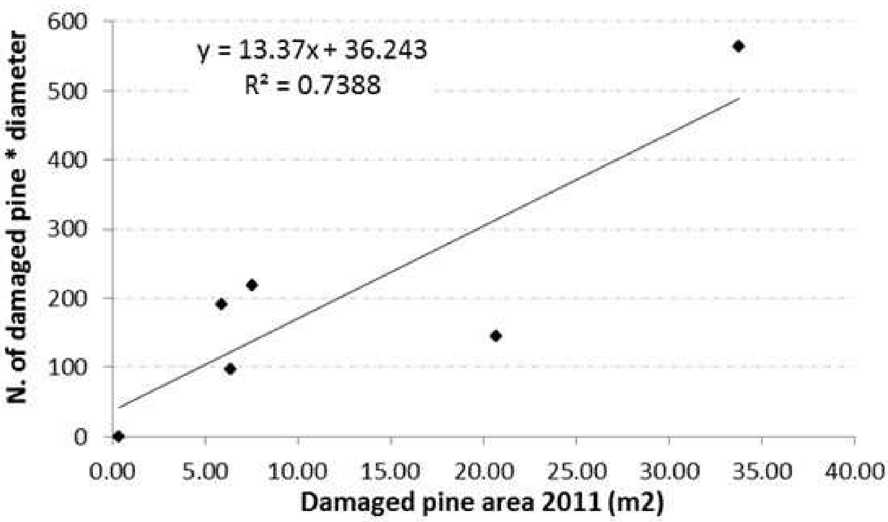

Figure 12. Relationship between the area affected by Scots Pine decline, as classified by the digital aerial photograph processing, and the number of damaged Pine trees observed in the field. The average diameter of trees measured in the sample area has been multiplied by the number of Pine individuals in order to better relate the field observations to the mapped area.

Analysis on images collected in 2011 allowed to distinguish healthy Pine from damaged Pine. The field observations evidenced that damaged pine mapped from 2011 aerial photographs are trees characterized by severe crown defoliation (i.e. needle loss > 60%) or dead trees. On the contrary crown discoloration was rare (discoloration % < 10) in all the monitored areas (percentage of canopy discoloration < 10 %). Images collected in 2006 allowed to distinguish only the damaged Pine, characterized by a brownish colour typical of severe discoloration, while the healthy Pine was not well distinguished from other tree species, probably due to the worse spatial and radiometric image resolution.

Finally, results showed that the area interested by Scots Pine decline in 2006 was higher compared to 2011 as it can be appreciated by Fig. 13 and 14.

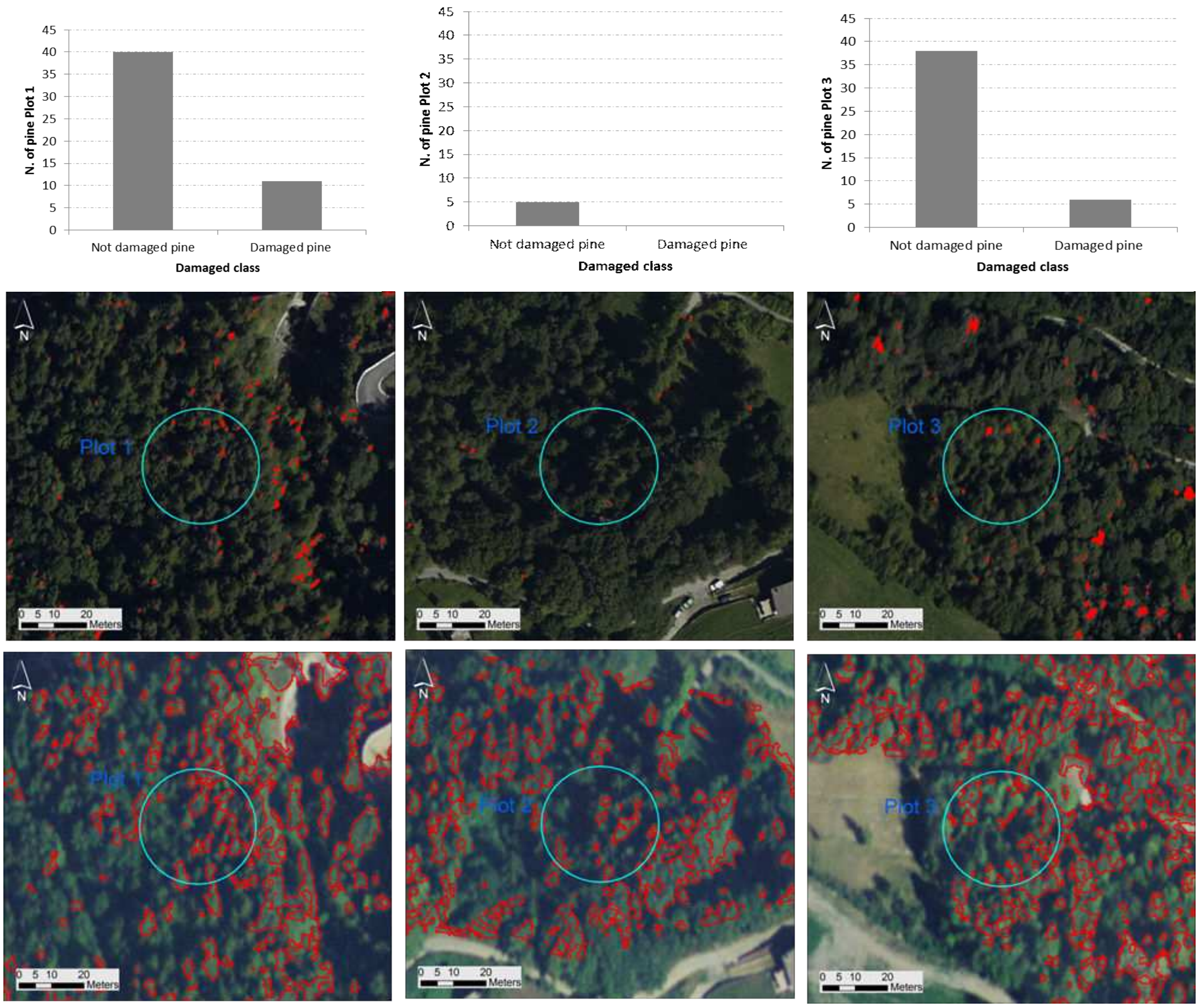

Figure 13. Plots represent the number of pine sampled on field belonging to "not damage pine" (needle loss < 60 % and discoloration < 10 %) and "damaged pine" (needle loss > 60 % or dead trees and discoloration < 10%) classes. The red area depicted on the digital photographs represent damaged pine mapped in 2011 (images above) and 2006 (images below) in plot 1, 2 and 3.

This observation lead to the hypothesis that the stands which experienced the decline observed since 2005 (i.e. severe discoloration) are likely going towards a recovering process. This

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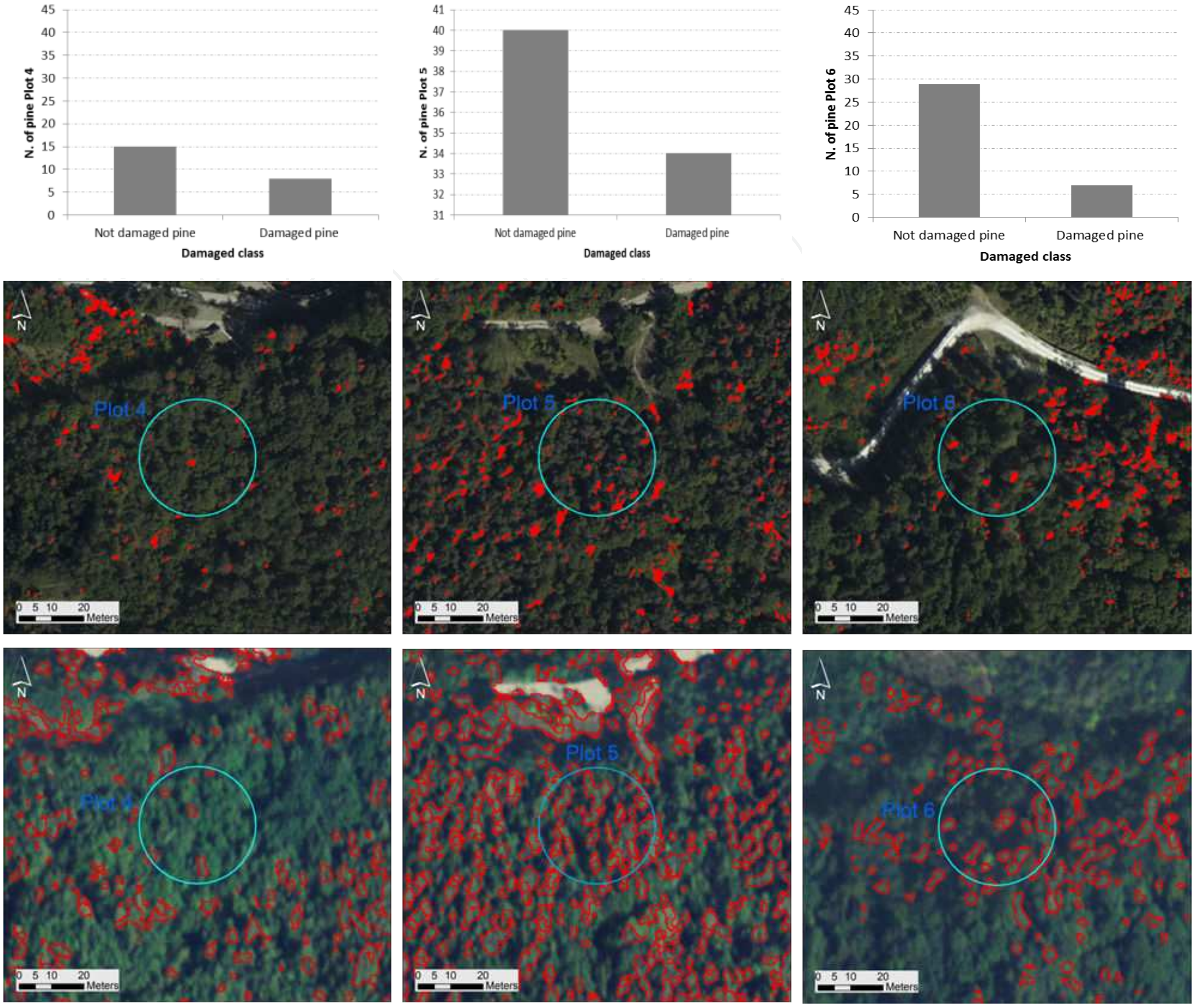

Figure 14. Plots represent the number of pine sampled on field belonging to “healthy pine” (needle loss < 60 %) and “damaged pine” (needle loss > 60 % and dead trees) classes. The red area depicted on the digital photographs represent damaged pine mapped in 2011 (images above) and 2006 (images below) in plot 4, 5 and 6.

hypothesis is supported by field observations conducted in summer 2011: the average discoloration was low (< 10 %) in all the study plots and the average needle loss was moderate (> 25-60 %) or low (< 10 %) meaning that all the plots investigated belongs to the category of forest damage absent or very low [41] [42].

2.5. Spatial analysis of protection loss against rockfall

First we used an energy line model in order to map rockfall hazards in Aosta Valley based on topographic criteria: RockForLIN has been developed by the French research centre IRSTEA and used to develop a method for protection forest mapping using Geographic Information Systems (GIS) [43].

First, all potential release points have to be mapped. 2D GIS models have been developed to localize them depending on topographic conditions: a simple slope threshold is applied to the slope surface raster (computed from the raster Digital Elevation Model [DEM]), according to the equation:

$$\alpha = 55 \text{ x RES}^{-0.075} \quad (4)$$

Where RES is the DEM resolution. All cells with values higher than the threshold α are qualified as potential release zones for rock falls.

Then, from each of the identified potential release points, 2D GIS models simulate the probable run out envelops. RockForLIN is based on the Energy Line principle, which allows relating rockfalls run out envelops to slope angles. The maximal spread of a block is determined by intersecting the ground and an imaginary line drawn from its release point with angle β. Different values for β are used: 32, 35 and 38°. Areas between 32 and 35° have a low but not null probability to be reached by rockfalls ; between 35 and 38°, a intermediate probability ; and higher than 38°, a high probability.

Second we overlayed NDVI data at the two resolutions with Modis (250m) and Landsat (30m) images, representing forest pixels as points (Fig.15 and 16).

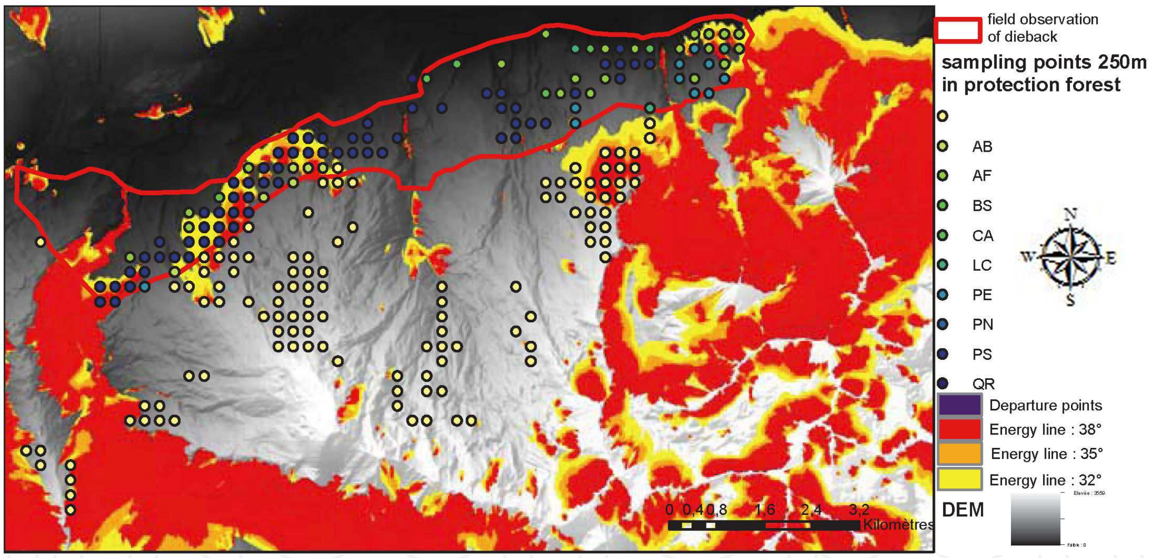

Figure 15. Rockfall mapping in Aoste valley using energy line model created with 5m resolution DEM. Sampling points representing Modis pixels (250m) in the west sector.

The GIS environment alowed us to map the "loss" of protection forest capacity against rockfall, taking into account the values of NDVI decrease at two periods 2001-2005 and 2001-2009 (fig. 17 and Fig.18).

The areas affected by die-back are overlaid with the field plots inside the red polygon defined on the ortho-images. Many affected zones overlay the rockfall hazard mapping calculated with the energy line model.

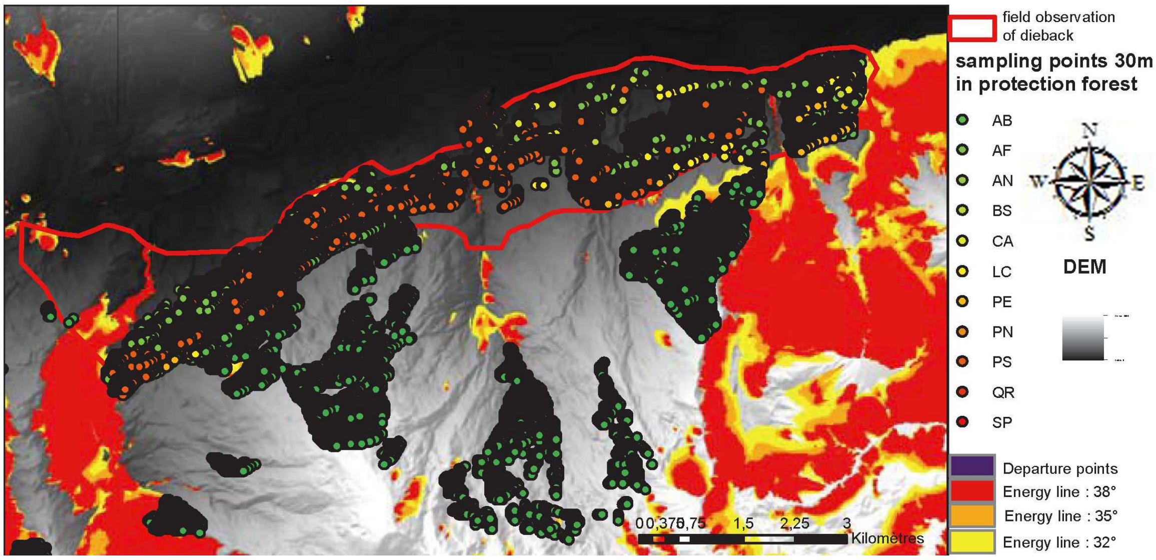

Figure 16. Rockfall mapping in Aoste valley using energy line model created with 5m resolution DEM. West sector. Sampling points from Landsat 30m (1999-2011).

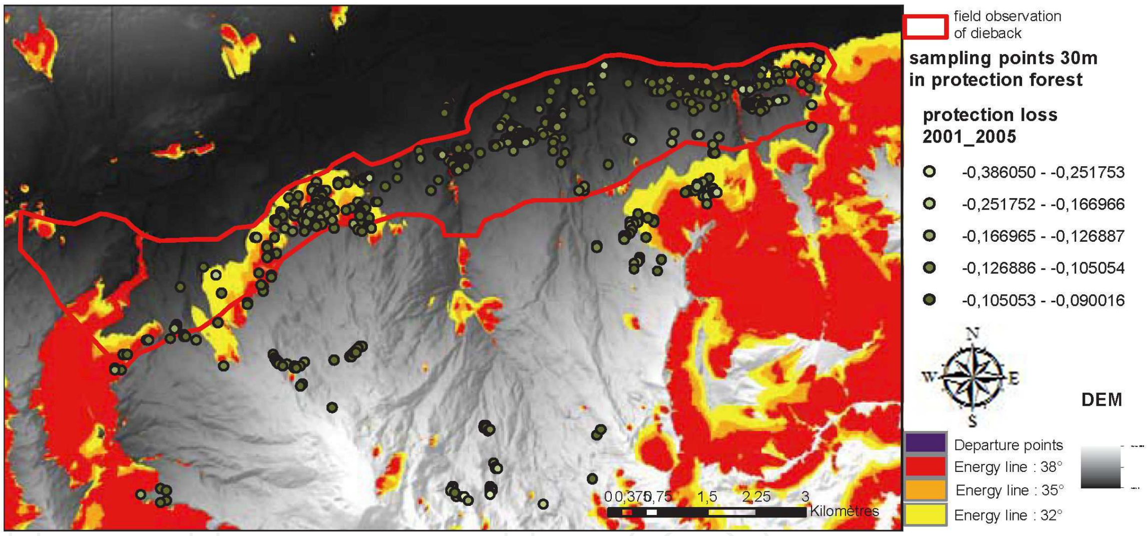

Figure 17. Localization of NDVI loss in protection forest between 2001 and 2005. West sector

2.6. Conclusions

This study takes place in the long series of environmental and risk assessment with a particular focus on spatial methods multi-sensors multiresolution. Satellite-based assessment of die-back have been successfully used and validated. An integrated remote sensing methods has been tested for detection and localization of die-backs in protection forests. It was coupled with a hazard characterization in order to monitor cross-impacts. Method appear to be consistent for detection of phenologic parameters giving indications on forest health at Modis resolution (250m). The use of satellites for vegetation monitoring provides several key advantages over other methods. It can provide near real-time data over large areas at a relatively high spatial

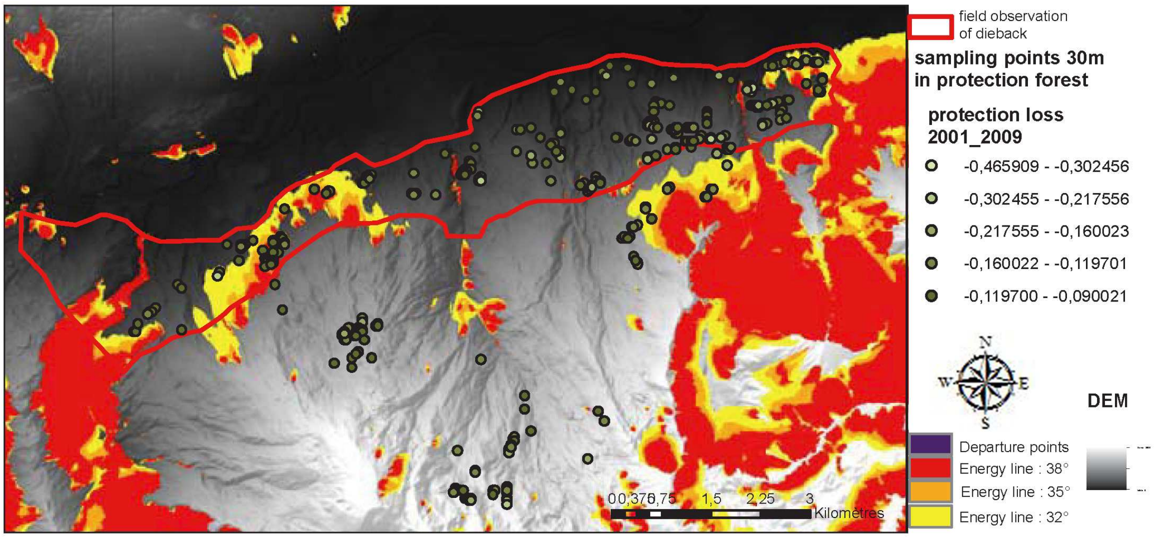

Figure 18. Localization of NDVI loss in protection forest between 2001 and 2009. West sector

resolution. It is often difficult to calculate station-based drought indices in a timely fashion because the required data is usually not available in real-time.This means that satellite-based drought/vegetation indices may able to detect consequences of droughts earlier and more accurately than other methods. The processes identified and localized in this study(die-off and rockfall) would be a first step of diagnosis that allows to develop management strategies able to adapt protection forest to changing environmental conditions. The energy line model is an empirical model which principal bias is the detection of the block departure zone directly linked to the DEM resolution. More calibration work would be necessary which implies more in situ experimentations and field validation of the areas affected by rockfall.

3. The Val Drôme case study and its new rockfall black pine protection forest management plan

One of the MANFRED French case study sites is located in the administrative department of la Drôme. More precisely, it is located in the district of le Diois (administrative district around the town of Die). Within this case study a sylvicultural training plot (also named martlesocope) has been implemented. The main thematic of this case study is an Austrian black pine rockfall protection forest management. The results of the 5 training sessions held on the marteloscope, have been used in connexion with rockfalls propagation modelling results for designing the new forest management plan of this district.

3.1. The historic context of natural risks protection forests in the Diois

Historically, the protection function of the forest was introduced by the "RTM" (Restoration of Mountain Greunds) policy to fight against natural hazards in mountain areas and the

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devastating floods of the XIXth century. This policy was applied in mountain forests especially in Diois, a land next to the town of Die, in the French administrative area of Drôme.

During the Little Ice Age (1450-1850), the Diois district was concerned by an important torrential activity while the watersheds were weakened due to an agropastoral overexploitation and a low afforestation (in the 1850s, forests covered only 30 % of the area in Diois, now 70 %). The torrential activity caused changes in Alpine rivers: beds were very high and large so the risk of flooding and the erosion significantly increased. Due to the lack of forest cover, soil materials were washed away by rain water of heavy thunderstorms, which are frequent events in Diois. Soils were strongly degraded.

Figure 19. An example of the appearance of soil cobber in the early twentieth century in Menglon in the Diois

In this difficult context for local people, the repetition of large floods in the 1840s and 1850s had a decisive impact on public opinion. Decision-makers established different policies: in 1860, a first law has been stated for reforestation of degraded land, in 1882 a law on restoration and conservation of mountain grounds has been voted. All degraded grounds have been identified and included in perimeters of "restoration". These restoration perimeters generally include a large number of villages in the watershed of the torrential river but they only content degraded grounds. The watersheds of the Drôme have been divided into six areas: Basse-Drôme, Haute-Drôme, Roanne, Bez, Eygues, Oule. Then, the state purchased the land perimeter and the Waters and Forests Administration undertook significant work.

The first “RTM” missions done by the Administration of Waters and Forests have been:

- From 1863 to 1867: torrential correction and weeding are common. They increase the soil stability and the proportion of successful planting and seedling.
- From 1887 to 1914: reforestation begins, principally by planting because seeding is too uncertain in these difficult environmental conditions. The main species used are the Austrian Pine and Scots.

Due to these actions, 18 500 ha of Austrian black Pine have been planted in the French administrative area of Drôme between 1860 and 1930.

Figure 20. Water and Forests Engineers in Die, early twentieth century

Figure 21. The effectiveness of the RTM laws, the reforestation of the Marignac and le But St Genis districts between 1900 and 2012.

Nowadays the French Forest Commission (ONF in French) continues the actions by promoting natural regeneration of Austrian Black Pines and by promoting the return of native species such as Beech or Fir, with the aim to protect fragile mountain lands on 40,000 ha of RTM forests in the Drôme. About the rivers, in addition to overseeing the maintenance and up keeping of the torrential works, the ONF provides new missions, for instance, a new management of sediments in the upper watershed as the mobilization of sediment stocks in stable sectors.

3.2. "The rockfall marteloscope" in the Haut Diois

As part of the RTM actions, forest managers must adapt their silviculture in order to sustainably and effectively reduce the consequences of natural risks in mountains by optimizing the protective actions of mountains forests. In mountain area, the predominant natural risk is the

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one generated by rockfalls. All the aspects of human socio-economic activities are concerned: houses, industrial areas, roads, railways, energy transportation lanes… Forest stands can considerably reduce the impact of rockfalls by stabilizing mountainsides, anchoring the rocks, slowing boulders and so imitating boulders kinematics. A forest can play an important role in rockfalls mitigation and its efficiency largely depends on the silviculture used. Thus, to maintain the protective function of these forests, an adapted silviculture anticipating the consequences of climate changes must be applied to them.

In this context, the marteloscope of the Haut Diois (and also all the other ones implemented during the MANFRED project but not presented in this chapter) aims to:

- educate and train foresters to consider this problem of rockfalls into their forest management;
- test virtually different kinds of sylviculture in order to select the most adapted one to the local problems and conditions.

3.2.1. General data

The marteloscope is located in the French administrative area of Drôme (26), in the Haut Diois, France. Its surface area is 1 ha. It settles on the parcel 2 of the «forêt domaniale du Val de Drôme". This forest is classified as RTM forest, with a status of protection forest. The marteloscope is on the South-West facing slopes in the upper valley of the Drôme, at an average altitude of 700m. The average slope of the versant is about 40%.

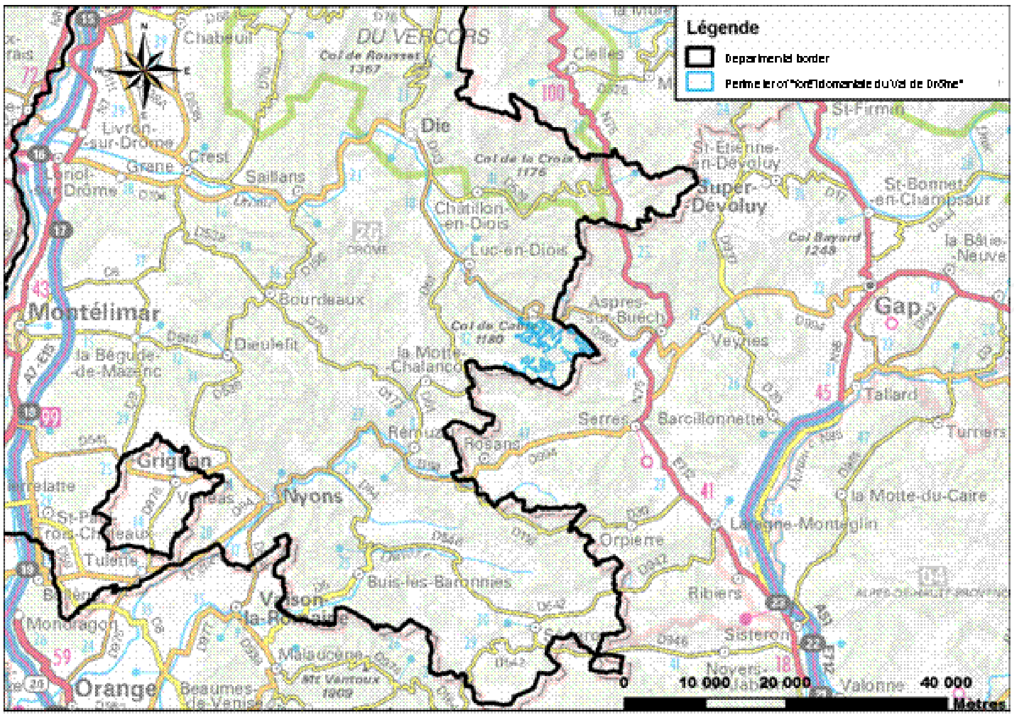

Figure 22. The state forest of Val Drôme and its localization in the "départment de la drôme"

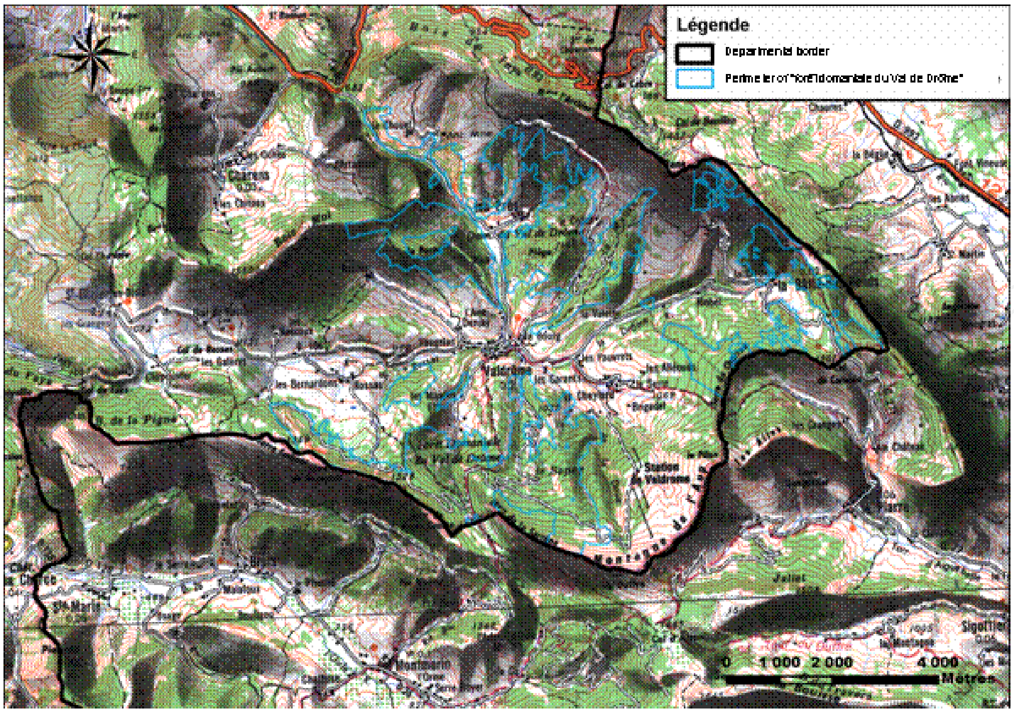

Figure 23. The state forest of Val Drôme and the localization of the marteloscope.

The climate is mountainous, with a Mediterranean influence. The annual average temperature is 10-11 ° C and the annual precipitation is of 1000 mm. The marteloscope is on a warm slope (South-West facing, annual average temperature is high) with enough water for the vegetation but with a significant risk of summer drought. Late frozen are common. Seasonal and annual variations are very important. But generally, summers are short, very hot and stormy, while the winters are long and cold.

The soil comes from massrocks. It is deep, not compact and composed of many limestone disorganized elements. Some places are less deep with a marly limestone cracked rock in surface, which gives rendosols or rendzines. The marteloscope is located on a soil of good quality for a forest soil with high slopes, well drained and offering a good prospection for the root systems.

3.2.2. Marteloscope's stand description and historical overview on the forest management

The stand of the marteloscope is composed at 100% of Austian Black Pines, planted in 1902 in the framework of the application of the RTM laws. This forest is managed into even-aged forest (" futaie régulière " in French). The distribution of tree by classes of diameters is represented by the following histogram. This graph shows that all classes of diametres are present; the average diameter is 22 cm. It is a dense forest stand, with 1026 stems/ha. The marteloscope is belonging to the parcel number 2 of the state forest (Forêt domaniale in French) of Val Drôme.

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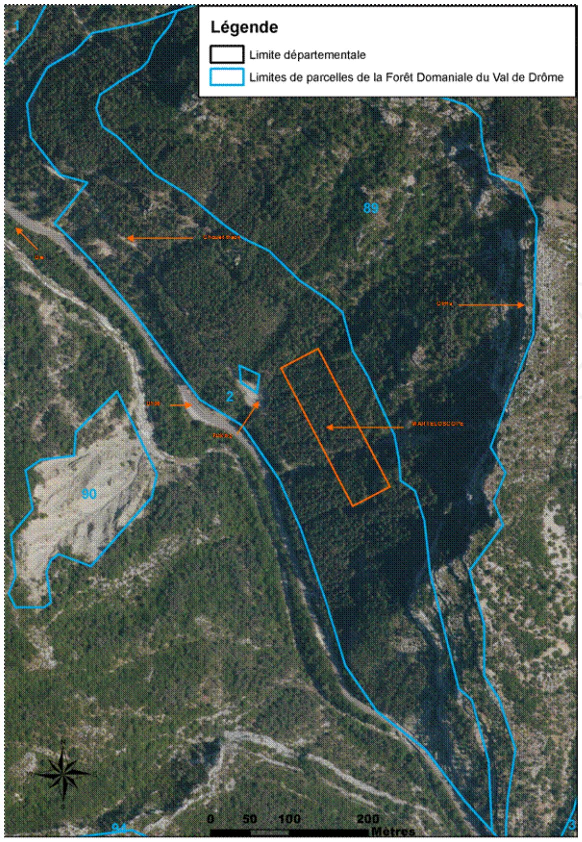

Figure 24. A general overview on the slope on which the Val Drôme marteloscope is located.

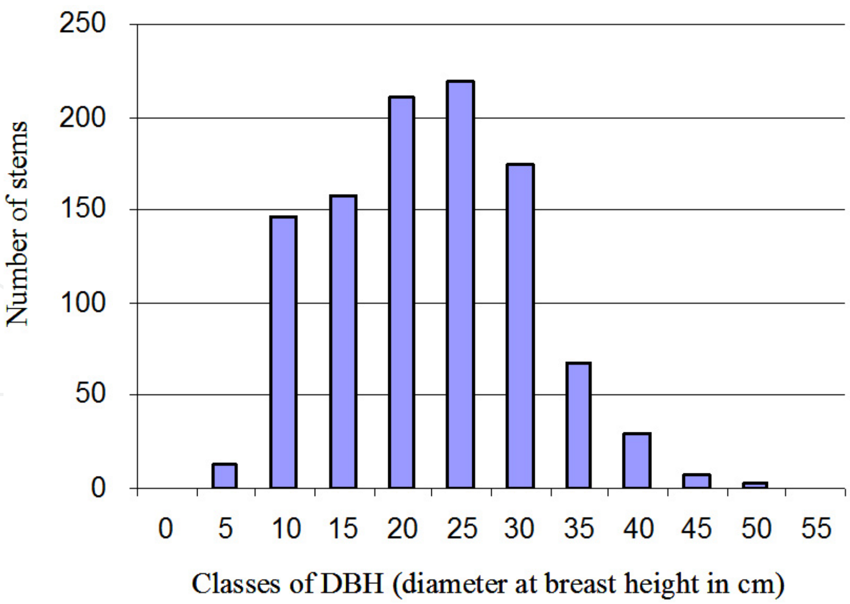

Figure 25. The DBH distribution of the martelsocope's Austrian black pine stand.

The parcel 2 of the forest « Val de Drôme » is bounded by 10 m high cliff upstream, and by a departmental road D106 (previously D306) downstream (cf. Figure 23). This road allows users from Valence, Die, or other towns to reach Valdrôme and its ski resort or to reach Baronies at the South and East. It is usually quite busy. Moreover, traffic is still increasing during winter and summer with the arrival of tourists (Valdrôme ski resort, hiking, biking...). However, this parcel is located on a steep slope (between 35-40%) and the cliff represents a potential starting zone of rockfalls. Indeed, the rocks became dislodged because of climatic constraints (alternating freezing and thawing, erosion...). Many impacts on the trees have been identified in the marteloscope (cf. Figure 26). The average size of the block is 60cm × 60cm × 60cm. Some trees have big impacts. Two ravines, located on either side of the marteloscope in the direction of the slope, are natural ways often taken by the falling blocks. In this context, rockfalls are a real risk for the user of the departmental road below this forest screen. Up to now no catastrophic events occurred but each year at least one rock is reaching this road.

Figure 26. Photo of the marteloscope's stand.

All the trees have been mapped in x, y, z using a theodolithe. The figures below present a 2D and a 3D maps of this plot.

According to the forest management plan for the period 1975-1994, the parcel 2 is a part of the series in «even-aged forest " whose vocation is Austrian Black Pine forest, with a production target, like most of the Val de Drôme forest (70% surface) at that time. Therefore, improvement cuts were made: a first thinning was conducted in 1986 with 3726 trees cut which represents a total volume of 706 m^3 and a density of 190 stems/ha on this 19.6 ha parcel. Thinning should be "fairly light", even possibly restrict the natural regeneration. In addition, the final cutting was prohibited by this plan. Then, a second thinning was conducted in 2006 (rotation of 20 years) with 760 trees cut, for a total volume of 276 m^3. This cutting is located on the downstream portion of the parcel to limit potential damage caused by rockfalls. Few trees have been cut in order to respect the protection forest function and their branches were cut and arranged along the path for retaining the falling rocks.

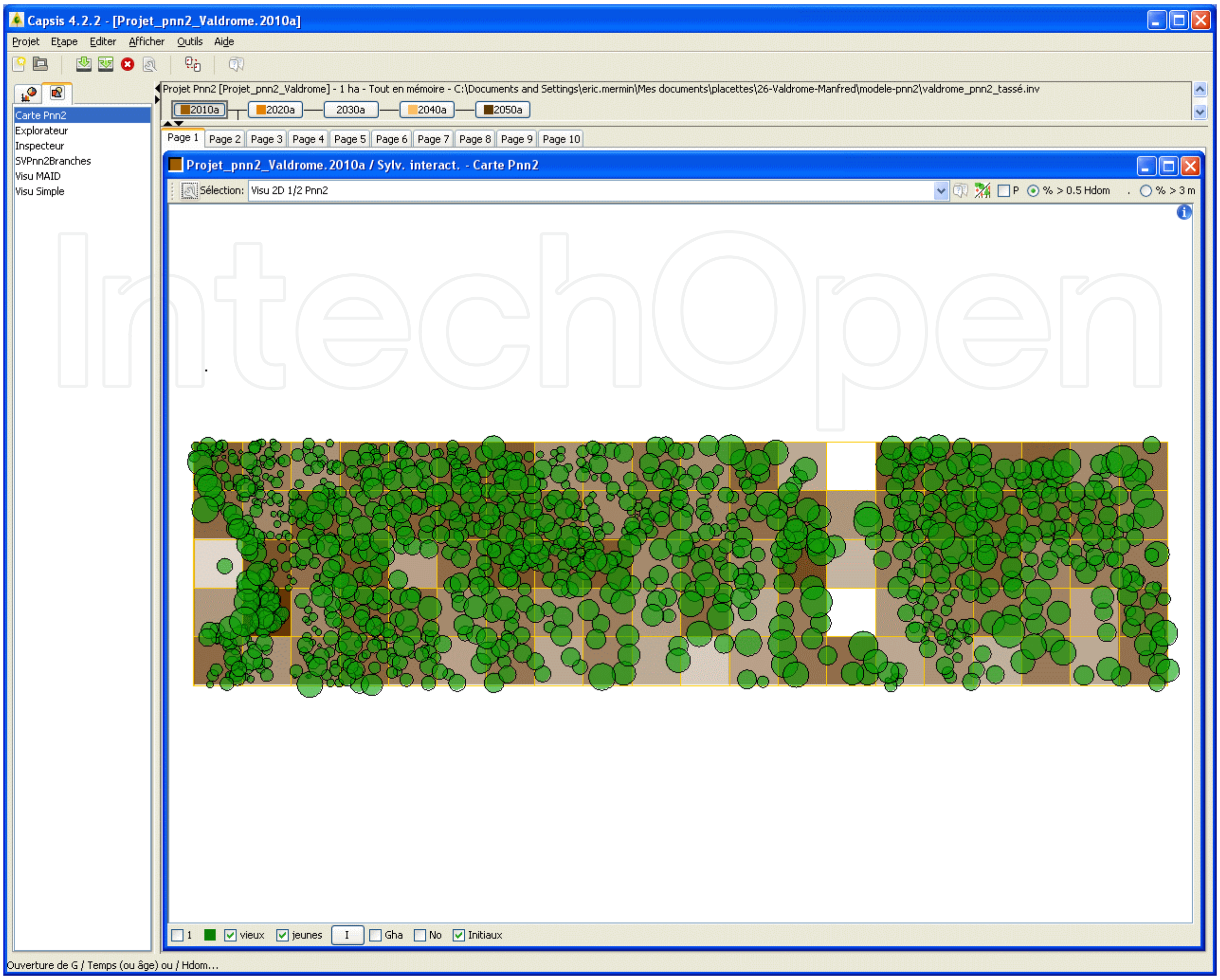

Figure 27. The trees' position map of the marteloscope of Val Drôme. A green circle represents the position of a tree and it is proportional to the tree's diameter.

The current forest management plan of this parcel, according to the high risk of rockfalls, avoids logging operation. But silvicultural interventions are now necessaries for improving and helping natural regeneration dynamics.

3.3. Rockfalls risks assessment using the modelling tools: Rockfor^{LIN},Rockyfor3D and Rockfor^{NET}

The rockfalls risk assessment in this case study has been done using tree scale modelling tools. The first one used has been the model Rockfor^{LIN}. The advantage of this empirical model is that only the Digital Terrain Elevation model is required to perform the analysis. This model has been built up using the energy line principle and the notion of mobility index [46]. This model allows having a first overview on the probable maximal envelop of rockfalls propagation areas with and without taking into account the forest stands. The map below presents the results obtained with this model without taking into account the presence of forest stands.

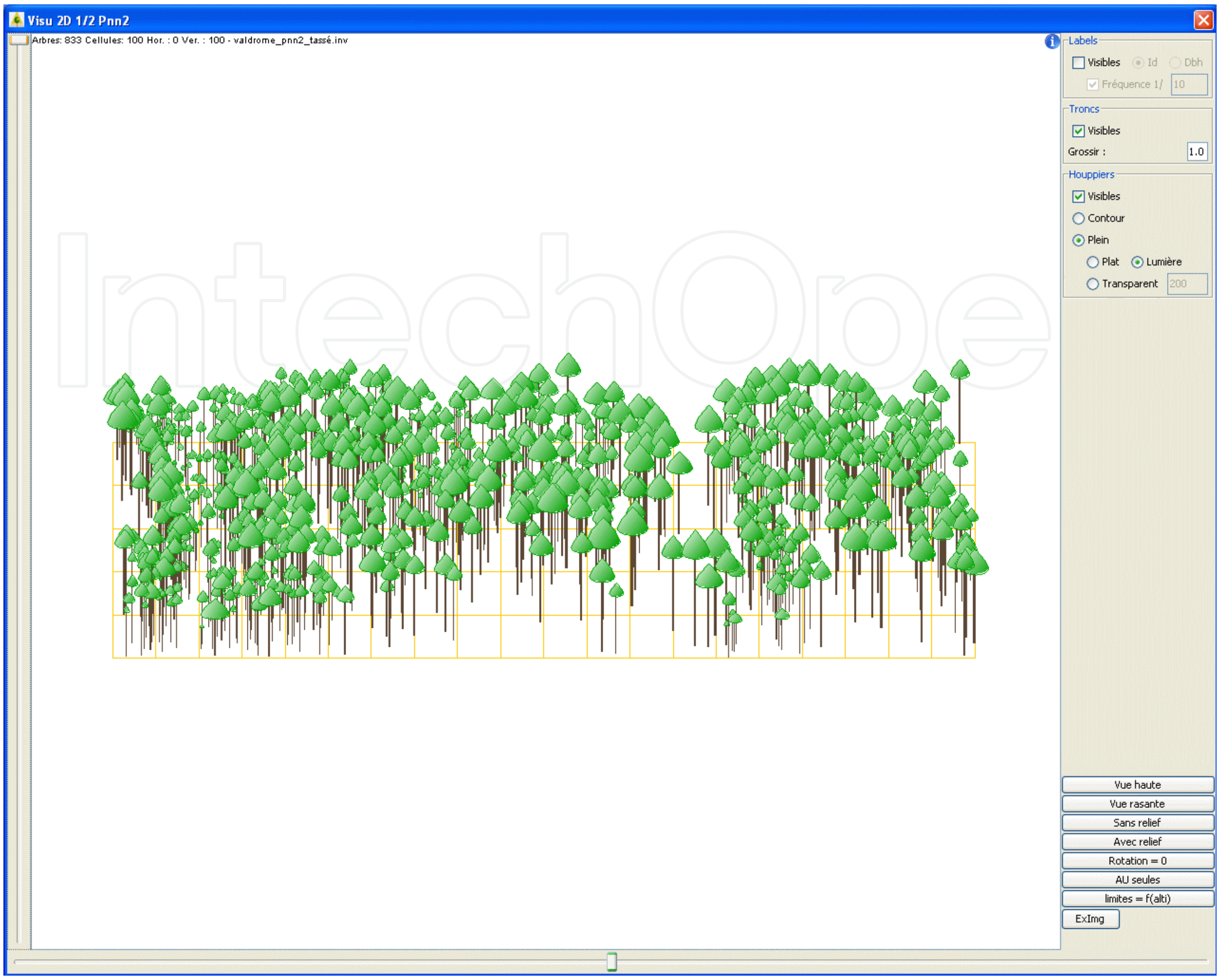

Figure 28. A 3D view of the marteloscope's stand of Val drôme.

According to the figure 27, the rockfall risk on the road below the martelsocopes will be very high if the forest stands will disappear one day.

To confirm this first analysis, the 3D trajectories simulation model Rockyfor3D has been used. To use this model, the following data are needed:

- the Digital Terrain Model with the highest accuracy and resolution available. For this case study the LiDAR data (with 5 points/m^2) has been acquired
- the map of the geomorphological units : it classifies areas according to specific soils' characteristics (topographical and geological parameters, soil roughness...)
- the map of the current deposit rocks: all rocks landed in the marteloscope are spatially represented. From this map an average volume of the largest block is defined
- impacts data : the impacts on trees due to rockfall are analyzed (location, height, dating by analysis of tree rings)

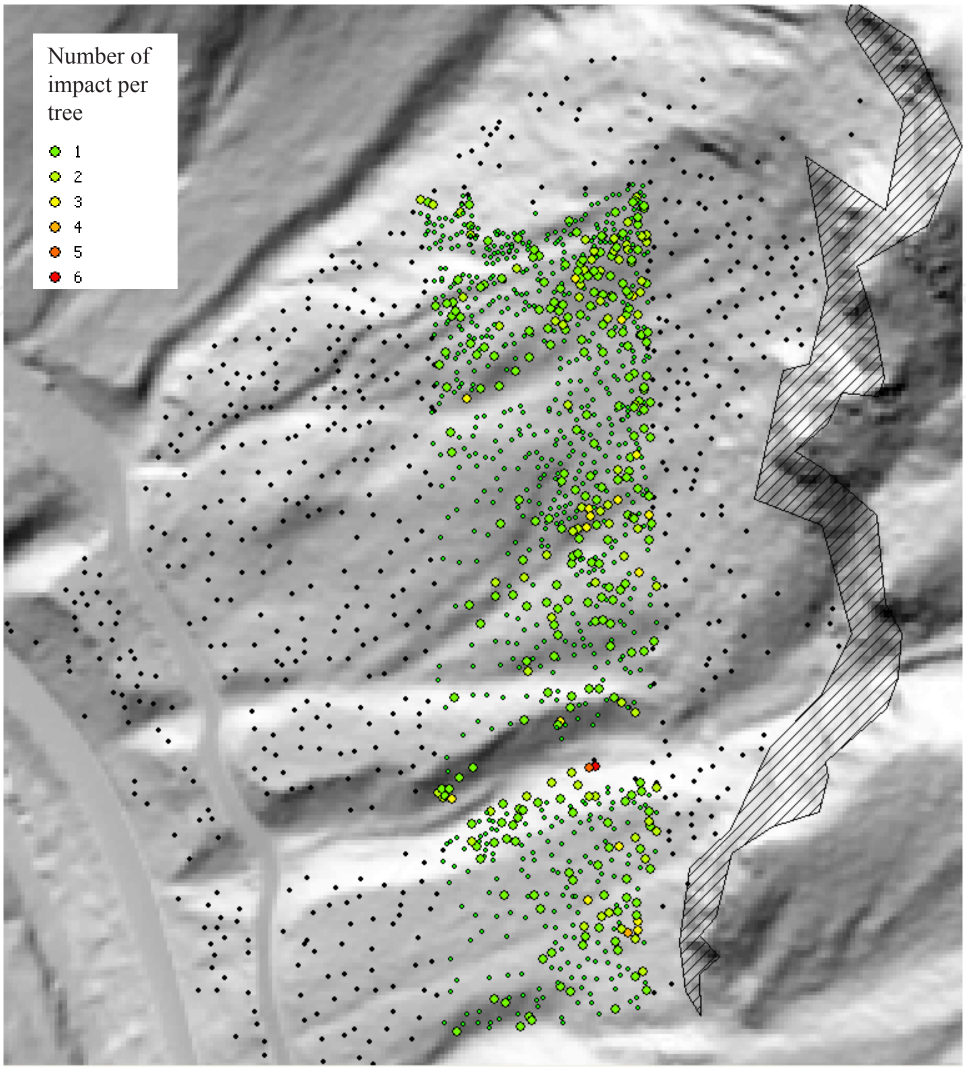

Figure 29. Map of the number of rockfall impact per marteloscopes's tree.

- the map of release areas : a linear symbol drawn thanks to the DEM and an informatics program shows the cliffs where rockfalls come from
- the map of forest stands according to the the main dendrometrical parameters : the mean DBH with its standard deviation, the stem density and the species distribution.

All these input data are used by Rockyfor-3D for simulating rockfalls trajectories. The user has to select a number of simulations. 500 simulations for each release points is a good compromise for having results in both reliable and fast.

The software allows:

- a visualization of all the simulated trajectories
- a display in each points of the DTM of the main statistics of these trajectories : passing frequencies,..

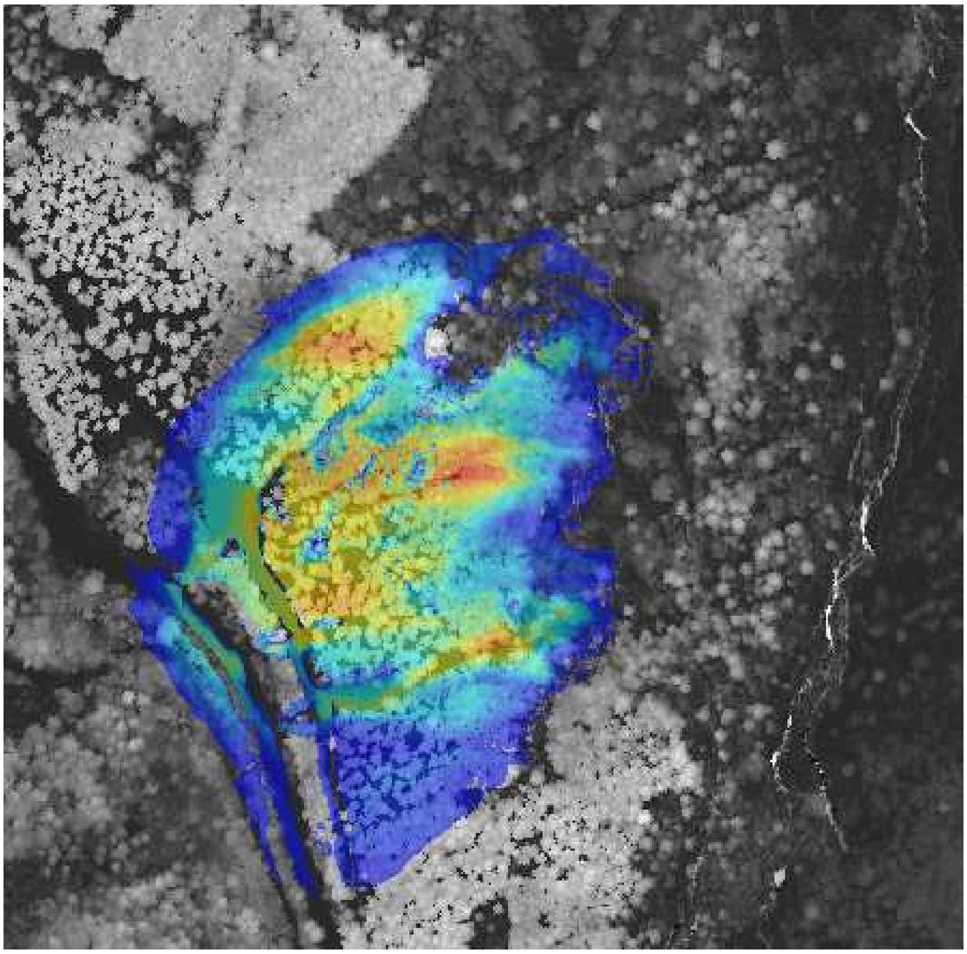

Figure 30. Map of the maximal envelop of probable rockfalls propagation areas obtained with the empirical model Rockfor^{LIN}. The difference of colour represents the rockfall passing frequency: Blue = low frequency, Red = high frequency. The results are expressed on the LiDAR Digital Surface Model.

- an estimation of the kinematic parameters in each point of the DTM.

With all these calculated output data the user can provide the map of the endangered areas, It is also possible for the forest manager to test if his silviculture has effectively strengthen the protection function by comparing before and after tree marking, all trajectories and their frequency and the value of the kinematic parameters of boulders in each point of the DTM. The maps below present the results (passing frequencies) obtained with Rockyfor3D for 3 different rock volumes and taking into account the role played by the current forest stand.

The results obtained with Rockyfor3D confirm the first ones obtained with Rockfor^{LIN} interm of potential endangered areas. But Rockyfor3D allows the forest manager to go furthermore in the protection forest assessment. For rocks having a volume less than 0.5m^3 the current forest stand offers an efficient protection : none rocks is able to reach the road. For rocks of 0.5m^3 the current forests stand is only able to limit the number of boulders able to reach the road. This action of clipping can be expressed using the concept of Probable Residual Rockfal Hazard (PRH). The PRH represents the percentage of rocks which are able to surpasse the forested

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area of a slope. What has also to be noticed is that the results obtain with Rockyfor3D fit perfectly with the map of the observed rockfall impacts on trees.

According to these results, it appears that the upslope part of the forest has a very important role for all the categories of rocks' volumes. This forested strip of 50m is one of the key components of the protective action of the current forest stand.

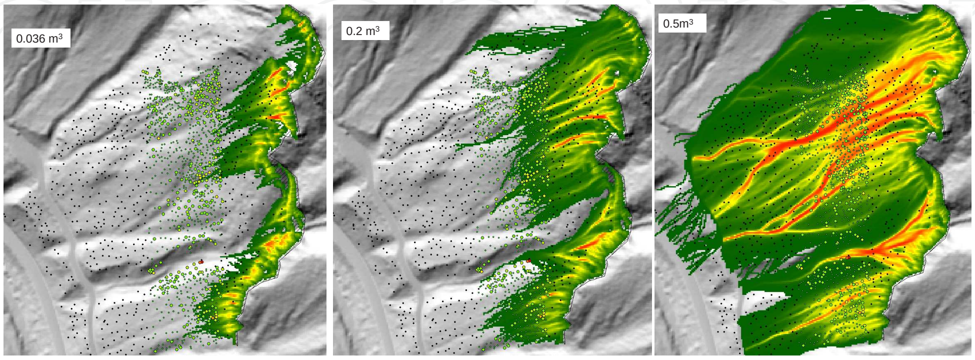

Figure 31. Maps of rockfalls propagation areas, for boulders of 0.036, 0.2 and 0.5 m^3, obtained with Rockyfor3D and taking into account the role played by the current forest stand. The difference of color represents the rockfall passing frequency: Green = low frequency, Red = high frequency. The results are expressed on the LiDAR Digital Terrain Model.

The last modeling tool which has been used is Rockfor^{NET}. This tool is specifically dedicated to the Probable Residual Rockfall Hazard assessment. The PRH is a synthetic indicator of the level of protection that a forested area can provided. This probabilistic tool also provides theoretical stand density intervals and Mean Stem Diameter value in order to have a PRH less than 1%. This tool is described and freely usable via the web site: www.rockfor.net. The input parameters are presented in the figure 29.

Before making a silvicultural treatment in a rockfalls area, this one can be tested in term of consequences on the rockfall risk using Rockfor^{NET}. This tool is usable for checking: if the PRH has been increased after the realization of the planned silvicultral treatment and if this increasing is acceptable or not, if the theoretical stand density and average DBH are realistic or not, and if not then the question of using civil engineering works has to be asked. So this tool has to be used as expertise support to evaluate, via the quantification of the PRH, the protective role played by current forest stands and to adapt in consequences the forest management.

Rockfor^{NET} has been used in the Val Drôme case study for displaying the current PRH before any silvicultural operations (cf. figure 30). The results obtained with Rockfor^{NET} are also fitting with the ones of Rockyfor3D and Rocfor^{LIN}.

3.4. The new forest management plan elaborated using Rockfor^{NET}

According to the results of the workpackage 4 of the Manfred project, the probable consequences of climate changes in the region, in which the Val Drôme case study is located, are a

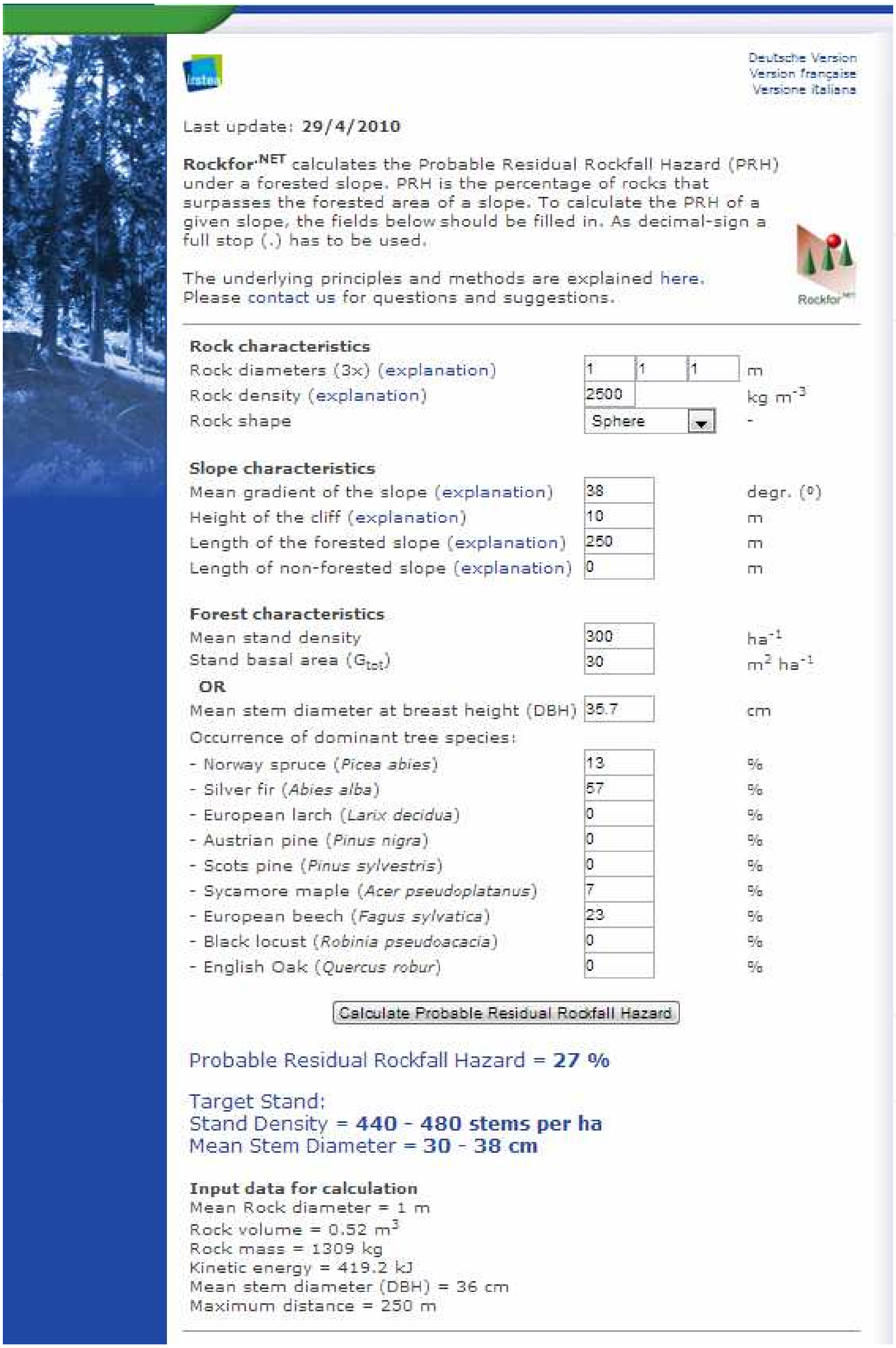

Figure 32. The tool Rockfor^{NET} freely usable via the web site www.rockfor.net

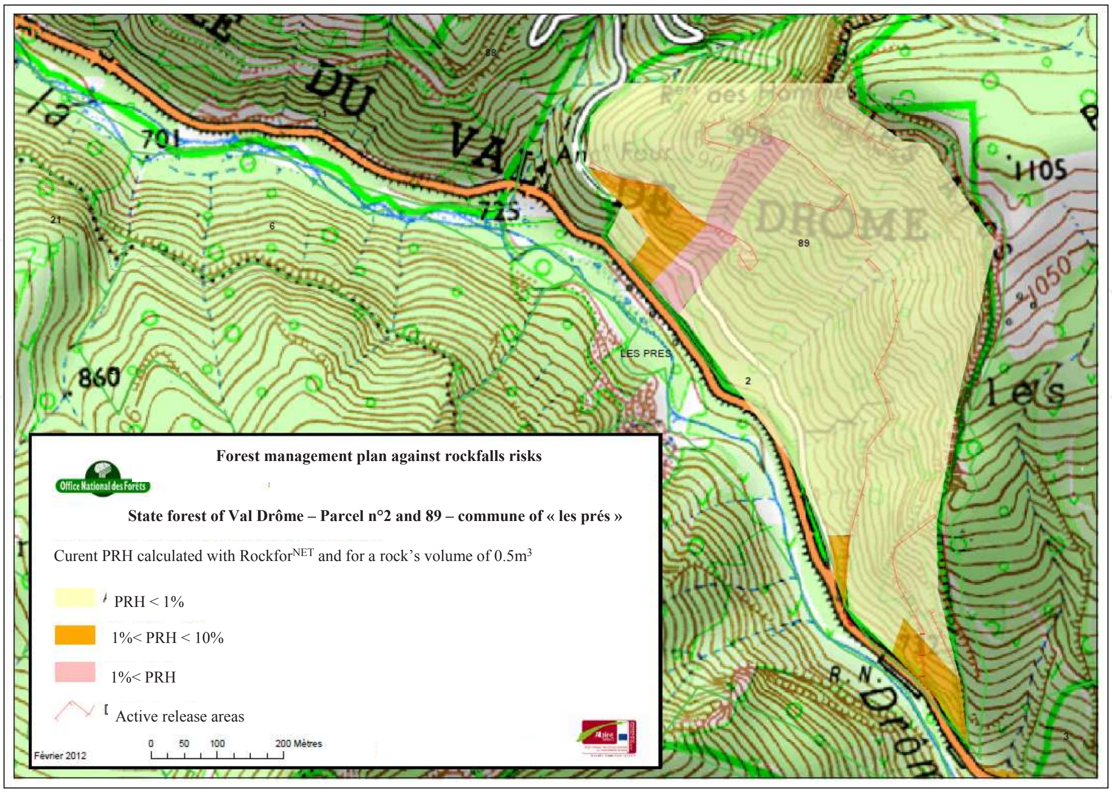

Figure 33. Map of the current PRH obtain with Rockfor^{NET}

migration up slope of the broadleaves species and the maintenance in the next 100 years of Austrian black pine in this area. These two situations are currently observed in this case study: broadleaves trees are settled in the understory of the present Austrian black pine stand and in open areas the Austrian black pines are naturally regenerating.

So, local forest managers have decided to: shift from an even-aged structure to an uneven-aged one, promote the current settlement of broadleaves trees in the understory and to develop the natural regeneration of Austrian black pine by opening or promoting regeneration gaps. Due to the important protective effect of the 50m width forest strip just below the release areas, it has been decided to ban any logging activities in this zone. In this forest strip the natural regeneration is the result of the "cutting" activities of the falling rocks on mature trees.

Rockfor^{NET} has been used for the dimensioning and spacing of the regeneration gaps to be opened. It has been decided to make the regeneration gaps without any complementary eco-engineering works, only in the areas where the PRH after the opening will be still of less than 1%. The other driver for the implementation of regeneration gaps has been to promote the current and viable regeneration patches. According to these drivers the final planning is the following one:

- The maximal length of a regeneration gap in the direct down slope direction could not exceed 30m
- The shape of the gaps will be a circular one

- The distance between to gaps (from centre to centre) will be at minima of 140m
- The spatial distribution of the gaps will follow up a quinconce pattern on the slope
- The gaps radius will be increase of 10 m each 20 meters if and only if the regeneration development will be efficient and viable
- All the slashes due to the silvicultural interventions will be used for increasing the roughness of the slope. They have to be positioned diagonally to the slope on the upslope part of each gap.

If regeneration gaps have to be implemented in areas where the current PRH is higher than 1%, then specific eco-engineering works have to be used. This specific eco-engineering works are:

- Trees felled diagonally to the direct slope and anchored on other trees or stumps (cf. Figure 31).
- Obligation to cutting trees leaving high stumps: at minima the height of the stump has to be equal to 1.30m, measured upslope (cf. Figure 31).
- To use Treenet or Fasnet works in thalwegs in order to promote the settlement of natural regeneration and the development of vegetation works (plantation of broadleaves trees).

Treenet (cf. figure 32) are eco-engineering works based on the use of mature trees as support poles of rockfall nets, and Fasnet structures are based on the use forest exploitation products as trunks and branches for making fascines (cf. figure 34) which are also anchored on living trees. These two eco-engineering have been experimentally tested within the Manfred project and are able to dissipate kinetic energy less than 100 kJ.

Figure 34. Examples high stumps and felled trees diagonally to the direct slope and anchored on high stumps in the case study Val Drôme

Figure 35. Examples of uses of Treenet eco-engineering works in the case study Val Drôme

Figure 36. Example of use of a Fasnet eco-engineering work in the case study Val Drôme

The figure 34 presents the map of the future PRH after the implementation of the new forest management plan elaborated using the support expertise tool Rockfor^{NET}.

In parallel to these eco-engineering technics, all the unstable deposit rocks on the slope have been anchored using metallic cable (Cf. Figure 35).

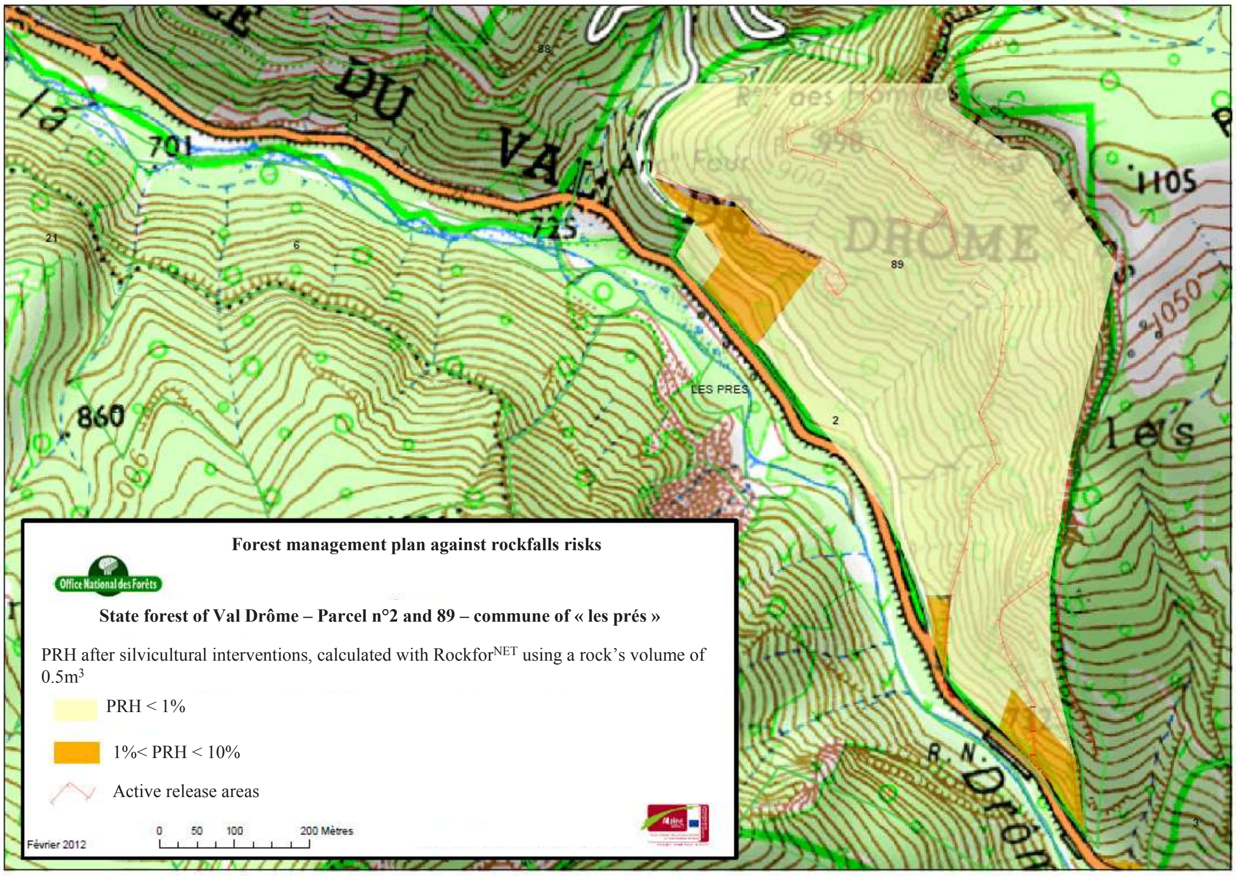

Figure 37. Map of the future PRH after the implementation of the new forest management plan and using Treenet and Fasnet eco-engineering works.

Figure 38. Example of anchorage of an unstable deposit rock in the Val Drôme case study.

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3.5. Technical and financial report of the implementation of the new forest management plan of the Val Drôme case study

The new forest management plan of the Val Drome case study is dedicated to the regeneration of a rockfall protection Austrian black pine forest which covers a surface of 36 ha. The forest interventions have been targeted on a forested strip of 6 ha and they have been defined using the expertise support tool Rockfor^{NET}. The following table gives the main technical items and their associated costs.

Type of intervention	Details of the intervention	Duration man.day	Staff costs	Consumable costs	Total costs
Forest management plan elaboration	Diagnoses on the site Definition of the interventions Public presentations	7	3000 €	0 €	3000 €
Project management	Technical preparation of the site	6	3000 €	0 €	3000 €
	Administrative preparation of the site	1	500 €	0 €	500 €
	Monitoring of the works	3	1500 €	0 €	1500 €
Logging, revegetation and eco-engineering works	Regeneration gaps opening	24	9120 €	996 €	10216€
	Revegetation of one thalweg (plantation of 300 trees and associated digging in works)	8	2240 €	600 €	2840 €
	2 Treenets structures (2 * 25m) 1 Fasnet structure (1*25m)	16	4480 €	2000 €	6480 €
	Total	65	23840€	3696€	27536€

Table 1. Technical and financial report of the implementation of the new forest management plan in the Val Drôme case study.

For this site the elaboration and realization of an adapted to climate changes forest management plan dedicated to the optimization of the protection role of a Austrian black pine forest has cost 765 euros per ha. For only the elaboration phase of the management plan the cost is 84 Euros per ha. The cost of the eco-engineering works is 86.4 Euros per linear meter. For the same condition, a protection strategy based only on civil engineering works will have cost about 1000 Euros per linear meter of rockfall defense structure. For this site the total cost of a pure civil engineering strategy is estimated to 75000 Euros.

3.6. Conclusions

The set of modelling tools Rockfor^{LIN}, Rockyfor3D and Rockfor^{NET} is perfectly adapted to the building up of protection forest management plan. At minima forest managers have to use Rockfor^{LIN} and Rockfor^{NET}. The first model is able to give an accurate evaluation of the maximal probable envelop of rockfalls propagation zone. The second one helps managers to 1) provide a quick and efficient analysis of the protective effect of forest stands and 2) display the results via the mapping of the values of the Probable Residual rockfall Hazard. The use of these expertise supporting tools is optimized if accurate and high resolution geographical data are available like LiDAR ones.

The probable consequences of climate changes trends on forest stands dynamics has to be taken into account for producing a long term efficient forest management plan. In the field of protection forest management, the main objective is to promote the tree species both adapted in term of climatic conditions and risk mitigation. In the case of rockfalls protection, broad-leaves tree species are the most adapted ones. That's the reason why, forest managers have to promote in coniferous stands the natural settlement of broadleaves trees.

The costs associated to the implementation of an adaptive forest management in rockfall protection forests, based on a technical approach coupling eco-engineering technics and regeneration by gaps, are 3 times cheaper than the ones associated to a pure civil engineering protection strategy. The magnitude of the difference of these two categories of costs is: the cost of 1 linear meter of a classical rockfall net (not ones like Treenet) is equal to one at three times the cost management of 1 ha of a protection forest. If forest stands are able to offer an efficient protective function then their management is much more sustainable and cost effective for the society then protection strategies only based on civil engineering technics. But if some subventions exist for civil engineering building up, this is not the case for protection forest management. For subventionning protection forests maintenance, which have to be considered as natural protection works, the most efficient solution is to fix a subvention per hectare and for a certain period. According to the results obtained within the Manfred project the minimal amount of the subvention should be of 150 Euros/ha/year for a period of 5 years. As the objective is to maintain protection forest, any benefits coming from the sale of timbers have to be subtracted from the subvention. This subventionning will be fully effective if a map of protection forests has been firstly done.

4. Conclusions

Forest managers have now a set of efficient tools for expertising gravitational risk protection forests. Depending on the available data, this expertise can be provided using the last development in remote sensing technic for assessing the evolution of dieback in protection forest and their consequences in term of natural risk activity. The minimal set of data to be used is at least an accurate digital terrain model and a forest stands description map. For rockfalls protection forest assessment the main modelling tools are usable or available via the web sites : www.rockfor.net and www.ecorisq.org. The assessment processes presented in this chapter are easy to reproduce in any other sites.

The valorization of protection forest stands as real natural protective works, needs to firstly produce on large scale the map of localization of protection forests and secondly to develop an adapted financial support for covering the specific costs associated to protection forest adaptive management plan. The MANFRED project offers, via the models developed and the case study examples, adapted and efficient solutions to these questions.

Acknowledgements

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