Chapter

Baronnies Provençales Regional Nature Park Pilot Action Region: The Benefit of Large-Scale Rockfall Modelling for Developing Efficient Forest-Based Integrative Management of an Alpine Territory

Frédéric Berger, Benjamin Einhorn, Jessica Jarjaye, David Toe, Jean-Baptiste Barré and Sylvain Dupire

Abstract

The choice of a natural risk prevention strategy must be considered at the scale of a territory in order to take into account all its components. Since 2015, France has developed integrated natural risk management (INRM) approaches in Alpine territories. The challenge of INRM lies in the definition and implementation of innovative projects for initiating synergies with respect to natural risks while seeking to increase resilience through the new and different involvement of the territorial actors. The Baronnies Provençales Regional Nature Park is one of the pilot territories for the operational implementation of this approach, with a particular focus on forest-based solutions. For this reason it has been chosen as the French Pilot Action Region (PAR) of the Interreg Alpine Space project GreenRisk4Alps. In this article we present an example of good practice related to the benefit of large-scale rockfall risk modeling, the analysis of potential cascading effects and the added value of a territorial perspective.

Keywords: protective forest, protective function, risk plan prevention, mapping, modeling, rockfalls, forest fire, integrated natural risk management

1. Introduction

Natural risks in mountains combine multiple hazards and specific vulnerabilities, including a high dependence of socio-economic activities on transport networks (risk of isolation). These risks, which are already omnipresent, also tend to increase under the combined effect of human activities and the rapid changes in the mountain environment brought about by climate change.

The nature and diversity of the phenomena (rapid kinetics, strong impacts, unpredictability, accumulation of hazards, domino effects), but also of the vulnerabilities (material, organizational) and impact scenarios, lead to particular difficulties in terms of detection, monitoring, anticipation, evaluation and prioritization of risk situations associated with strong uncertainties.

These challenges make it difficult to take decisions concerning the choice, sizing or prioritization of interventions. These decisions must also establish a compromise between the socio-economic elements to be protected and the generally limited resources of mountain communities. Risk prevention in these territories therefore requires specific management methods that respond to these geographical particularities through approaches that are both global (multi-risk) and adapted to the local context.

For increasing the competence of the Alpine territories in terms of risk management and adaptation to climate change, it is not only necessary to mobilize a wide range of interdisciplinary scientific and technical skills, but also specific resources dedicated to the co-construction, capitalization and transfer of knowledge and practices to managers and decision-makers.

In this context, support for the development of integrated natural risk management actions, public awareness raising and enterprises is essential. Integrated multi-hazard approaches, nature-based solutions and research-action are crucial levers for the quality of life, resilience and development of Alpine territories.

The main objective of integrated natural risk management in France is to optimize risk governance at the catchment level. It targets all risk prevention levers:

- Knowledge of hazards and risks
- Recognition and optimization of nature-based solutions, particularly forestry
- Monitoring in order to anticipate an event
- Information for citizens and risk culture
- Control of urbanization by integrating local and systemic risk management into planning documents
- Reducing vulnerability
- Emergency preparedness
- Experience feedback

In 2015, the Baronnies Provençales Regional Nature Park (BPRNP) initiated a process to develop an Alpine Territory of Integrated Natural Risk Management (ATINRM, TAGIRN in French). The challenge for a TAGIRN lies in the definition and implementation of innovative projects that make it possible to initiate synergies with respect to natural risks while seeking to increase resilience through the new and different involvement of the actors in the territories in question.

One of the park's objectives is to complement the regulatory prevention of natural hazards with a more integrated and efficient approach capable of limiting the consequences of disasters from an economic, social and environmental point of view. Through this multi-risk project, the park's aim is to develop a risk culture among the population and elected representatives by implementing targeted activities according to the actions and the public. The emergence of this risk culture

begins with the provision of information and knowledge of natural risks to local authorities, the local population and local associations in order to raise awareness. Indeed, the memory of risk is fading in Baronnies Provençales; therefore, the main objectives of this TAGIRN project are as follows:

- to raise awareness among the population of natural risks, in particular the risks of forest fires, falling rocks and landslides;
- to develop coordination and synergy between the actors;
- to qualitatively and quantitatively develop an integrated management of natural risks in the territory with consideration of solutions based on the forest;
- to improve knowledge and awareness of natural hazards.

This TAGIRN project also has an interregional dimension with the opportunity to network actors and state services of the Drôme and Hautes-Alpes departments and to organize meetings and exchanges on working methods concerning natural risk management. Indeed, at the beginning of the demarche, differences in the approach to risk were identified between the services, resulting in significant differences in the understanding of risk management.

The desire of the park to develop an integrated management of natural risks, based among others on nature-based solutions, and the motivation of the actors of this territory, led us to select it as the French Pilot Area Region (PAR) of the GreenRisk4Alps Interreg Alpine Space project.

As an example of good practice related to forest-based solutions (FBS) for rockfall risk mitigation, the benefit of large-scale rockfall risk modeling, the analysis of potential cascading effects and the added value of a territorial diagnosis for better wellbeing in an Alpine territory, we present in this chapter the main conclusions of our analysis.

2. Description of the baronnies provençales regional nature park PAR

2.1 General data

Crossed by the northern limit of the presence of the olive tree, which has been cultivated here since antiquity, the Baronnies are authentically Provencal. However, it is a mountainous Provence, a mosaic Provence, constantly attenuated or affirmed according to altitude and latitude.

The Baronnies Provençales are located on the borders of two large regions, two thirds in the Rhône-Alpes, in the department of Drôme, and one third in Provence-Alpes-Côte d'Azur, in the department of Hautes-Alpes (**Figure 1**). This off-center mountainous territory remains far away from the main transport routes and urban areas.

The remoteness and geographical compartmentalization of the Baronnies Provençales have left it on the fringes of the industrial development dynamics that prevailed in the last century. A territory forgotten by the industrialization of the 19th century, devoted to mixed farming and stockbreeding, the Provençal Baronnies have long preserved the traditional forms of rural society, punctuated, until the middle of the 20th century, by agricultural work, markets and the life of the villages. This restrictive geographical context has enabled the Baronnies Provençales to preserve particularly unspoilt biological wealth and original landscape structures associated

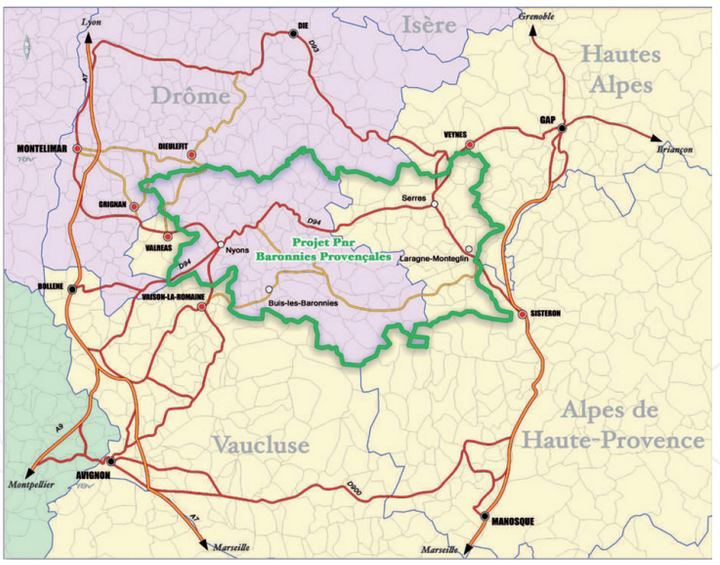

Figure 1.
Geographical scope (green contour) of the BPRNP [1].

with a great diversity of traditional production, which make this territory so distinctive and justify its recognition as a regional nature park.

The recent but marked changes in agriculture have considerably modified the landscapes and terroirs over the last few decades. Mechanization has caused many hedges to disappear. The old canals have been abandoned or replaced by sprinklers. The dry stone terraces on the well-exposed hillsides, which were used for vineyards or olive groves, have been abandoned. The forest is advancing on land covered by too few herds, and the life of men has retreated to the bottom of the valley. The land, which was once domesticated, including at high altitude, is now becoming more and more fertile, giving the region the picturesque character of a wilderness as soon as one leaves the cultivated valley bottoms.

The BPRNP is a tool at the service of the inhabitants, a responsible rural development project for an exceptional territory that we wish to preserve and also develop. It serves to find a balance between development that allows us to live better on a daily basis and the preservation of natural and cultural heritage.

Here, the fauna, flora and landscapes are protected, the built heritage is enhanced, cultural and tourist projects as well as economic development are encouraged, people meet, act together and bring their territory to life with passion.

This exceptional place of preserved nature is recognized at the national level for its rich terroir (Protected Designations of Origin, Protected Geographical Indications, red labels), its unique landscapes, built heritage (dry stone terraces, perched villages) and emblematic agricultural heritage (orchards, olive groves, lime trees, lavender, thyme, rosemary, etc.), as well as for its remarkable geology and biodiversity. There is not a single piece of land in this dry medium-sized mountain area that has not been used, valued or named by the inhabitants, from the valley bottoms to the mountain peaks. The search for land for cultivation led to the use of very steep slopes, with constructions and facilities essential to agricultural activity: terraces, sheds or shelters; water distribution networks; reservoirs; drainage galleries; etc. This medieval and agricultural heritage was gradually abandoned from the 1850s onwards, in favor of sites or land that were easier to occupy or exploit. The ways of living, occupying space and moving around transcend major administrative, historical or political boundaries, and bear witness to social and spatial similarities on which a project community can rely. In the Baronnies Provençales, Man and nature have lived together everywhere. The inherited

cultivated landscapes express the skilful use of the land, a harmony of the senses. The alternating atmospheres of the interior valleys reveal this feeling, the visual richness, in mosaic, of the lavender fields, the vineyards and the orchards accompanied by their colorful and olfactory notes. If the quality of the territory is partly linked to its intrinsic characteristics, it depends for the most part on the complicity that Man has established here with nature. However, the continuity of the long process of adaptation to a rural mountain life, which has produced the rich heritage of the Baronnies Provençales, is now threatened by the devitalization of the heart of the territory. The significant aging of the population is the first worrying sign of imbalance. It calls for a proactive policy to win back the population by attracting new workers.

Uncertainties about the future of agricultural policy make the transfer of farms more fragile, especially as the current economic valuation hardly remunerates the requirements of production methods that respect the environment, biodiversity and the landscape. The construction of an economic alternative based on the recognition and enhancement of the specificities of local production is another challenge for a collective approach.

The future of agriculture in this dry mountain region cannot be conceived independently of water resource management. Under the effect of climate change, tensions may arise, particularly during summer low water periods. The search for a better balance between water abstraction and the availability of the resource is therefore an essential challenge for the organization of life in the area. An important network of rivers, which have structured the settlements and trade areas, irrigates the Baronnies Provençales. However, the regime of these rivers, which are torrential in nature, is very irregular and strongly marked by the seasons. They play a major ecological and tourist role and shape the landscape.

If the highly preserved character of the Baronnies Provençales is now becoming a factor of attractiveness, it is first for the benefit of the development of second homes. The resulting pressure on the land entails risks of imbalance in access to housing. The control of land, the development of the built heritage, the emergence of eco-construction, the development of communication technologies for the benefit of young people and the reception of new residents represent a real challenge for the territory.

The attractiveness of the area is also reflected in the development of seasonal tourism based on outdoor activities. The organization of these activities in order to optimize the economic spin-offs is a development issue, just as the control of visitor numbers in the most vulnerable natural sites is necessary to preserve the value of the natural heritage. The industrial past has had little impact on the area. Peri-urbanization remains a one-off phenomenon for the time being. The landscape of the Baronnies Provençales is therefore not polluted by heterogeneous buildings or by the proliferation of unmarked business areas.

In this geographical and socio-economic context, forest areas occupy a large part of the park. These are alternating green or white oak forests, beech forests and pine forests that can be seen as you drive through the Baronnies Provençales.

The BPRNP in a nutshell:

- Administrative headquarters: Sahune, in the Drôme department.
- Surface area: 1,818 km2.
- 152,759 ha of woodland and moorland (84.02% of the territory).
- 24 historical monuments, including 10 “listed” and 14 “remarkable” sites.

- Around 2,000 plant species.
- Over 200 animal species protected at the national or regional level.
- 10 "Natura 2000" sites.
- 33,250 inhabitants [2].
- 97 communes classified as a Park +1 associated commune.
- 2 main communities of communes and 7 gateway towns: Dieulefit, Grignan, Montélimar, Sisteron, Valréas, Vaison-la-Romaine, Veynes.
- Baronnies Provençales Regional Nature Park is a member of the network of 54 French regional nature parks. It has been classified as a regional nature park for 15 years.

2.2 The main issues and activities in dealing with natural risks

A natural risk only exists if a natural hazard threatens one or more socio-economic elements. Given this definition, for a territory, the implementation of a real integrated management of natural risks requires the establishment beforehand of a territorial analysis allowing an understanding of the main components characterizing the economic stakes and the main trends of territorial development. The LESSEM research unit (Laboratory of Ecosystems and Societies in Mountains) of the National Research Institute for Agriculture, Food and the Environment (INRAE) has developed an information system dedicated to territories (SIDDT). This information system provides users with the LESSEM "territory" database:

- Large national statistical files, "BD Communale" section.
- GIS data, "Geographic Information" section.

The functionalities and databases of this information system are constantly evolving, allowing the characterization of evolutionary trends.

The SIDDT query and consultation portal was used to carry out the first stage of the territorial analysis relating to understanding the demographic and socio-economic components of the BPRNP.

The BPRNP has a population of approximately 33,000 inhabitants. The most densely populated areas of the territory are on its eastern and western margins in the lower valleys of the Eygues, Ouvèze and Buëch rivers, with 60 inhabitants per km^2. On the other hand, the heart of the territory, which is very enclosed, is one of the least densely populated areas in France with less than 10 inhabitants per km^2 (**Figure 2**). Thus, the specific geographical context of the territory has led to urbanization that is essentially limited to the valley bottoms or the plains, with a relatively weak intra- and inter-basin road network.

In 2017, the unemployment rate in the BPRNP (**Figure 3**) was higher than the national unemployment rate (France: 9.4%). This trend continued between 2018 and 2020.

If the quality of the territory is partly linked to its intrinsic characteristics, it depends for the most part on the complicity that Man has established here with

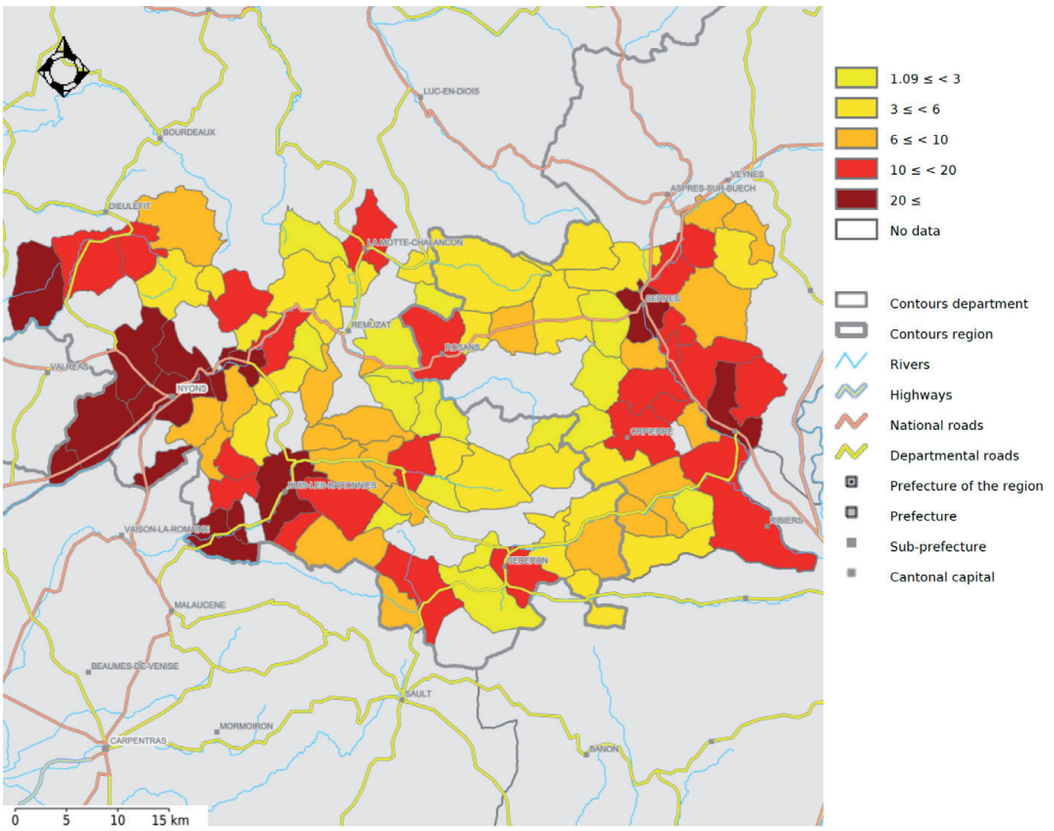

Figure 2.
Population density in 2017, inhabitants/km² [2].

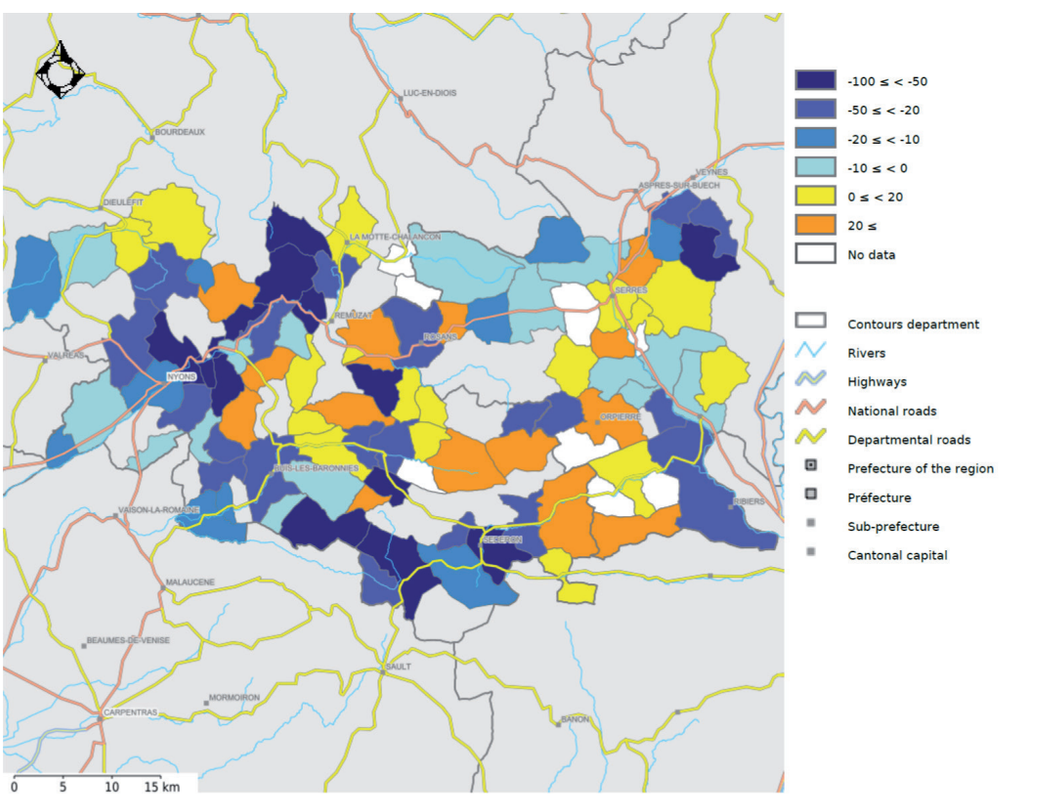

Figure 3.
Evolution of utilized agricultural land from 2000 to 2010 (%) [3].

nature. However, the continuity of the long process of adaptation to a rural mountain life, which has produced the rich heritage of the Baronnies Provençales, is now threatened by the devitalization of the heart of the territory. The significant aging of the population and high unemployment rate are the first worrying signs of imbalance. It calls for a proactive policy to win back the population by developing new economic activities and welcoming new workers.

From 2012 to 2017, the population increased by 1.93%, of which 1.03% was due to natural population growth and 0.90% to immigration. In association and since 1968, there has been a very strong upward trend in the aging of the population. The aging index (ratio of the population aged over 75 to that aged 20, expressed as a percentage) has been rising steadily since 1968. It went from 28.87% in 1968 to 84.36% in 2017 (more than tripling in 50 years!).

In parallel and in line with these trends, the share of personal services equipment is clustered around the main local areas of activity and population.

These demographic and employment trends generate the strong use of the road networks in favor of outgoing flows from the park territory compared to incoming flows: for the active population, the outgoing flow is on average twice as high as the incoming flow.

In addition, during the touristic season, these flows increase due to the occupancy capacity of tourist accommodation and the outdoor activities on offer (canoeing, climbing, hiking trails, etc.). The organization of these activities to optimize economic spin-offs is a development issue, just as the control of visitor numbers in the most vulnerable natural sites is necessary to preserve the value of the natural heritage.

The evolution of agricultural activities is one of the main indicators of the evolution of the physiognomy of this territory over time (**Table 1**, **Figure 3**). Since 1979, this evolution has been negative and reflects a very strong agricultural decline. The agricultural area decreased from 50,910 ha in 1979 to 39,919 ha in 2010, a loss of 21.59% of the agricultural surface. In parallel, the forest area has increased by 1.73%.

Given the geographical, economic and social characteristics of the park, natural risks must be anticipated and managed as closely as possible to the realities of this territory. Thus, the Baronnies Provençales Regional Nature Park includes the management of natural risks in a territorial and multi-actor approach, integrating all the active forces of the territory (elected officials, technicians, local populations, economic circles and decentralized institutions).

The territory of the park is affected by the following natural risks:

- Water-related risks: flooding, torrential floods, debris flows. In particular, the development of urbanization at the bottom of valleys raises the issue of flood management linked to run-off water.

	1979–2000 (%) (reference year: 1979)	**2000–2010 (%) (reference year: 2000)**
Number of farms	−25.4	−22.4
Utilized agricultural land	−14.1	−8.2
Permanent grassland	−25.7	−15.7
Cropland	−11.1	−9.8

Table 1.
Evolution from 1979 to 2000 and from 2000 to 2010 of the main agricultural indicators [3].

- The risks of ground/terrain movements: landslides, rockfalls (**Figures 5** and **6**), consequences of clay shrinkage and swelling on housing.

- The risk of forest fires: Almost 70% of the park area is wooded. This characteristic, combined with the Mediterranean climate, the dry stations and a diffuse habitat, makes the risk of forest fires present. This is why all of the park's communes are classified by prefectural decree in the list of communes at risk, subject to legal obligations to clear brushwood.

- Seismic risks: since the new zoning of 22 October 2010, the communes of the park are in a low to moderate seismic zone. The damage from past tremors has been non-existent or minimal.

In terms of the consequences of these phenomena, 5% of the communes of the park have been affected by natural disaster decrees, which mainly concern floods, mudslides and land movements. In France, it is possible to be compensated for a disaster due to a natural or technological catastrophe if insurance against these risks has been taken out. However, an interministerial order (so-called natural disaster decree) must recognize the state of natural or technological catastrophe (**Figure 4**).

2.3 Forests and forestry in the Baronnies Provençales regional Nature Park PAR

In France, the July 2001 Forestry Orientation Law gives an important role to the development of a sustainable and multifunctional forest management policy, introducing the notion of territorial integration through the implementation of Territorial Forest Charters (TFC). The purpose of TFCs is "to structure a project for the sustainable development of rural areas, integrating forests more closely into their economic, ecological, social or cultural environment". In 2012, the Park drafted is first TFC for its entire territory.

Figure 4.
Example of rockfall risks in the park (photos F. Berger INRAE).

The park's forestry heritage represents an important potential lever for local development and a major challenge for sustainable development. The Forestry Charter approach is an opportunity to carry out a shared reflection with all the local stakeholders for developing a real forestry dynamic in this area.

Forest cover is substantial in the Baronnies Provençales compared to the rest of the country: the degree of afforestation is almost of 84%, i.e. around 152,000 hectares (BD forêt v2 data), which is evenly distributed. In France, the national degree of afforestation is 31%. This land use makes the forest a considerable lever for local development. However, it currently generates very little economic benefit in relation to the space it occupies.

With respect to the forest sites, according to ecological and vegetation conditions, oak forest types predominate in terms of area. The percentage share of area for the most important forest types is as follows:

- Coppice with a majority of oak sp. (43%) present on sunny slopes and/or on poor and superficial soils.
- Beech coppice (5%) on the higher northern slopes.
- Scots pine forests (19%) abound throughout the area.
- Other coniferous forests (5%), generally of Aleppo pine, are located in the most Mediterranean part of the area.
- Austrian black pine stands (5%) are widely scattered throughout the area. They constitute important massifs, mainly in communal and state-owned forests and locally in private forests. They reflect the artificial afforestation effort using Austrian black pine, generally carried out on former agricultural land colonized by Scots pine.
- Heaths and wooded moors (22%) are present on most of the slopes.
- According to the European forest types [5], the percentage share of area of the two most important forest types is as follows:
- 3.3 Alpine Scots pine and black pine forest: 22.4%
- 8.8 Other thermophilous deciduous forests: 60.7%
- The percentage share of area of the main tree species is presented in the map in **Figure 5**.

The characteristics of the Baronnies Provençales forest reflect the forestry context of the area: a young forest with low volumes, often resulting from the natural reclamation of former pastoral or agricultural areas whose soils are generally chalky and superficial. These low-value stands are composed of an abundance of pubescent oak coppice, Scots pine forests and, to a lesser extent, black pine forests. Beech forests are rarer and fir forests are almost anecdotal (**Figures 5** and **6**).

The forest of the park is essentially private: it represents 82% of the woodland and slightly more than 10,000 owners. Seventy-five percent of the forest properties are smaller than 5 hectares. Ninety percent of the private forest territory concerns properties of less than 100 ha, but 46% is occupied by properties of more than 25 ha and therefore requires a simple management plan approved by the state.

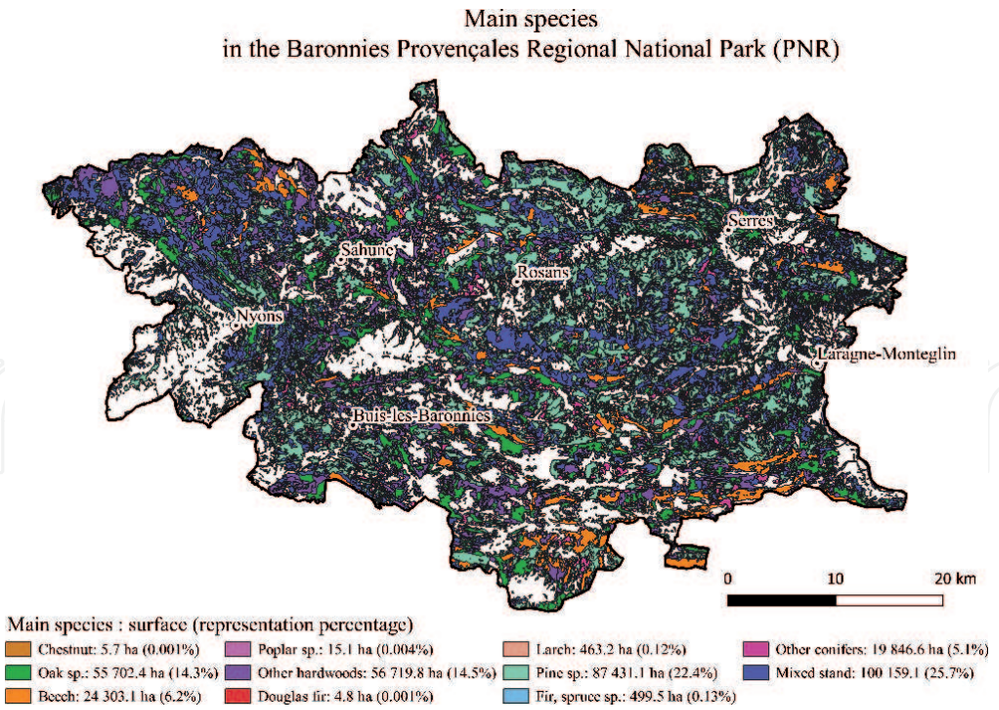

Figure 5.
Map presenting the spatial distribution of the main tree species [4].

Figure 6.
Example of residual rockfall risks below an Austrian black pine stand in the park (photos F. Berger INRAE).

Private forests are therefore relatively fragmented, which hinders the mobilization of the resource.

Public forests represent 18% of the wooded area: 56% communal and 44% state-owned. They are evenly distributed over the area.

The analysis of the national forest inventory data on the territory makes it possible to estimate the main values of wood capital. Taking all types of stands together, there are approximately 7 million cubic meters of wood. The estimation of the annual production is 240,000 m^3, but this volume should be put into perspective because more than 60% of the areas are difficult or very difficult to exploit (problems of

access, quality of the stands, etc.). Most of the wood in the Baronnies Provençales is harvested in public forests, due to the quality of the roads and the stands. In private forests, the problems of access, fragmentation and the low value of the stands explain the low mobilization of timber, which is more complex to manage. Taking private and public forests together, the annual volume exploited is estimated at between 10,000 and 15,000 m^3 per year, i.e. around 5% of the annual productivity of the forests.

There are only two logging companies in the area. Twelve to fifteen companies from outside the area are involved in the process of forest resource mobilization. Some local construction and public works companies carry out part of the transport. Several factors explain this situation:

- a lack of trained workers (loggers, skidders, etc.) linked to the arduous nature of the work relative to remuneration.
- a tense economic situation in which the value of wood remains low.
- the cumbersome nature of the investment involved.
- the increasing complexity of the regulations and the handicaps of the territory (land, access, slopes), including access to cuttings (inadequate access, tonnage limitations, etc.).

Primary processing is the most worrying link in the Baronnies Provençales. In ten years, nearly ten sawmills of various sizes, located in the area or nearby, have closed. The disappearance of sawmilling condemns any possibility of local valorisation of the production in transformed products. A reflection on the installation of the first transformation units is therefore necessary to meet the needs of the second transformation. Black pine in particular is a species with very good mechanical properties suitable for construction. Traditionally, secondary processing companies used to source very unprocessed products directly from local sawmills. Today, they are turning to the use of semi-finished and technologically advanced products. At the same time, wood construction has undergone a technological leap: regulations have been refined and the quality requirements of companies are increasingly stringent. In addition, secondary processing companies (carpentry and joinery) prefer industrial products that meet precise criteria (grading, drying, etc.), which are not available locally due to the absence of modern sawing units. Finally, in the face of the craze for wood construction, the territory is faced with a deficit of carpentry companies, whereas secondary processing is a real link in the local economic development.

The main outlet for hardwoods (beech and oak) is energy wood (mainly logs). There is a significant amount of estovers. The forest communities therefore derive little benefit from their forests, preferring to focus on the social and community aspects. The almost exclusive outlet for softwoods is pulping, except for black pine for which outlets are more diversified. Wood energy in the form of forestry chips represents a promising outlet, especially since, unlike industrial wood, it can be used in short marketing channels.

3. An example of best practice: the benefit of large-scale rockfall modeling for developing efficient forest-based integrative management of an alpine territory

The preservation and enhancement of the role of forests in mitigating natural hazards is essential in strategies to protect inhabitants and economic activities in

mountain areas. In order to avoid the catastrophic consequences generated by the alteration or even disappearance of forest cover, it is first necessary to locate the forests that play a role in protection against hazards.

With the exception of the risk of forest fires, the Baronnies Provençales Regional Nature Park had not carried out any assessment of the ecosystem service of protection against natural risks provided by the forest ecosystems present on its territory. Due to the masking effect of the forest cover and the lack of exhaustive mapping of the potential of phenomena in the absence of any forest vegetation, this protective service was either unknown or considered to be present throughout the territory.

In view of this observation, and the models developed by INRAE and its Alpine Territory for Integrated Natural Risk Management approach, the park asked the COMPET research team from the INRAE Centre in Grenoble to deploy its tools to carry out the first territorial assessment of the ecosystem service of rockfall risk protection in BPRNP forests.

The main aspects of the methodology, associated tools and results are presented in the following chapters.

3.1 The ROCK-EU-mapping model

Spatial models are effective tools for determining rockfall source, transit and deposit areas, and can be used for recognizing areas at risk due to rockfalls. Based on such models, a harmonized method for mapping rockfall protective forests for the entire Alpine Space (AS) has been developed by the consortium of the Interreg Alpine Space project RockTheAlps (#462). The innovative model Rock-EU-Mapping has been so developed.

Rock-EU-Mapping enables the large-scale identification of forests that could potentially play a role in protection against rockfall hazards. This model is relevant for providing studies on a regional scale or for a mountain massif. The calibration and validation of the methodology [5] was carried out using a database gathering information on past rockfall events. This database (2,812 events at the date of the model calibration) was initiated in the framework of the Interreg Alpine Space project RockTheAlps and is updated regularly. On 1 January 2021, 6,116 past events were registered in this database, and a new calibration of the model is scheduled for December 2021.

Spatial input data were chosen to be homogeneous over the whole Alpine Space and in open access. They were taken from two main sources: The European Union's Copernicus Earth Observation Program and OpenStreetMap. Relief and topography were obtained from EUDEM v1.1, which is a digital elevation model (DEM) available in raster format for Europe at a 25 m spatial resolution. Land and forest cover were extracted from Corine Land Cover (CLC) 2018. CLC is produced by visual interpretation of high-resolution satellite imagery. It is available in shapefile (vector layer of polygons) format with a minimum mapping unit of 25 ha. Water surfaces and rivers were obtained from OpenStreetMap contributors in shapefile format and used also to develop the classification of soil types (needed for defining soil rebound coefficients). Human assets (buildings, roads and railways) were extracted in shapefile format from OpenStreetMap contributors locating different topographical information over the world. Using all these input data, the model simulates the propagation of rocks along the slope on a rasterized digital terrain model by successive sequences of free flights in the air and rebounds on the slope surface. Rebounds are directly calculated using a classical rebound model [6].

The detection of block release areas is based on the use of slope thresholds. The parameters required to compute the rebound are derived from 7 soil classes which are defined from the land use map and specified according to elevation, slope and information on human assets, water surfaces and rivers.

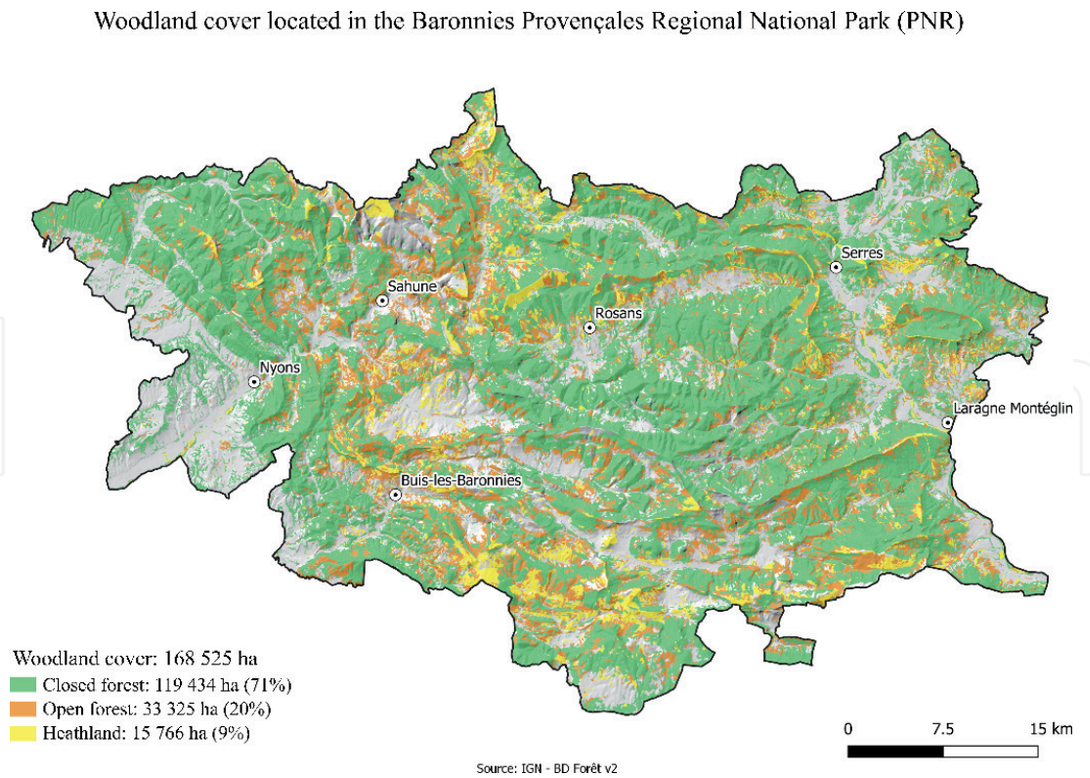

Figure 7.
Woodland cover of the Baronnies Provençales regional Nature Park [7].

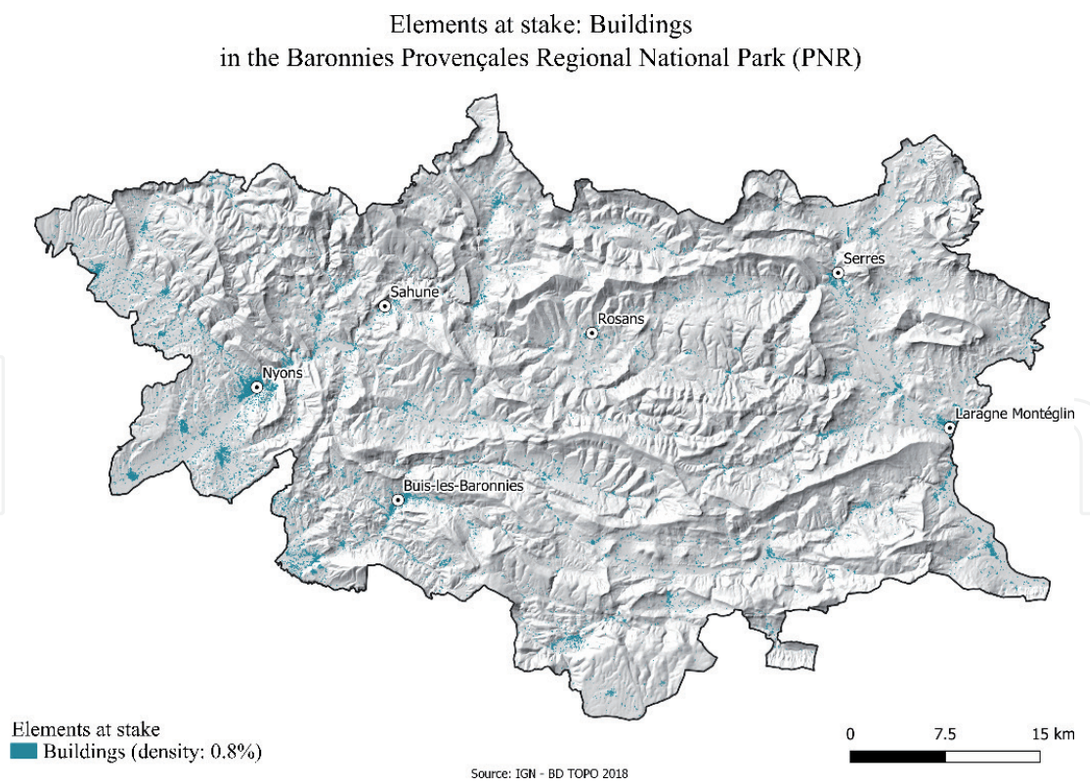

Figure 8.
DEM and building locations in the Baronnies Provençales regional Nature Park [8].

Since these first works, the model has been calibrated for the French territory to use a French DEM and OSO data, both with a resolution of 10*10 m. OSO is the national scale map (Metropolitan France) of land cover in 30 classes, with a resolution of 10*10 m and an annual update frequency. The data used are a series of

multi-temporal optical images at high spatial resolution (Sentinel-2 type, but also in the future SPOT-6/7, or even Pleiades).

Figures 7–10 present the main input parameters of the model.

In addition to these three main categories of elements, the park also requested the consideration of orchards and vineyards as important elements of the economic activities within its territory.

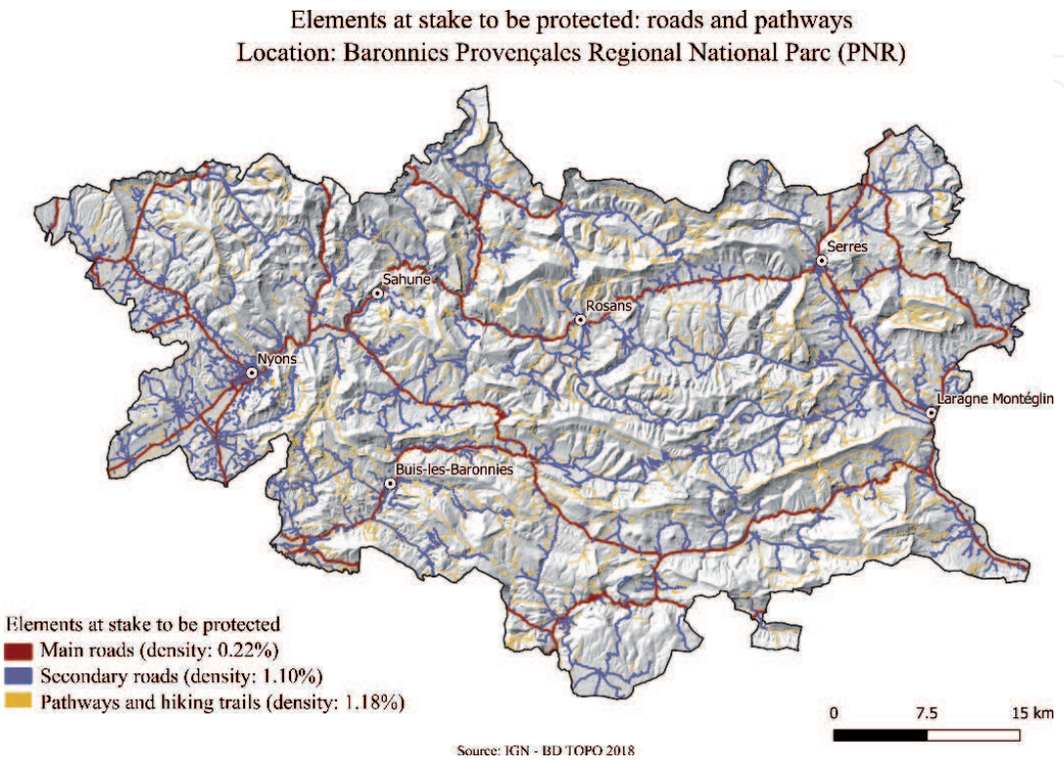

Figure 9.
Road network in the Baronnies Provençales regional Nature Park [9].

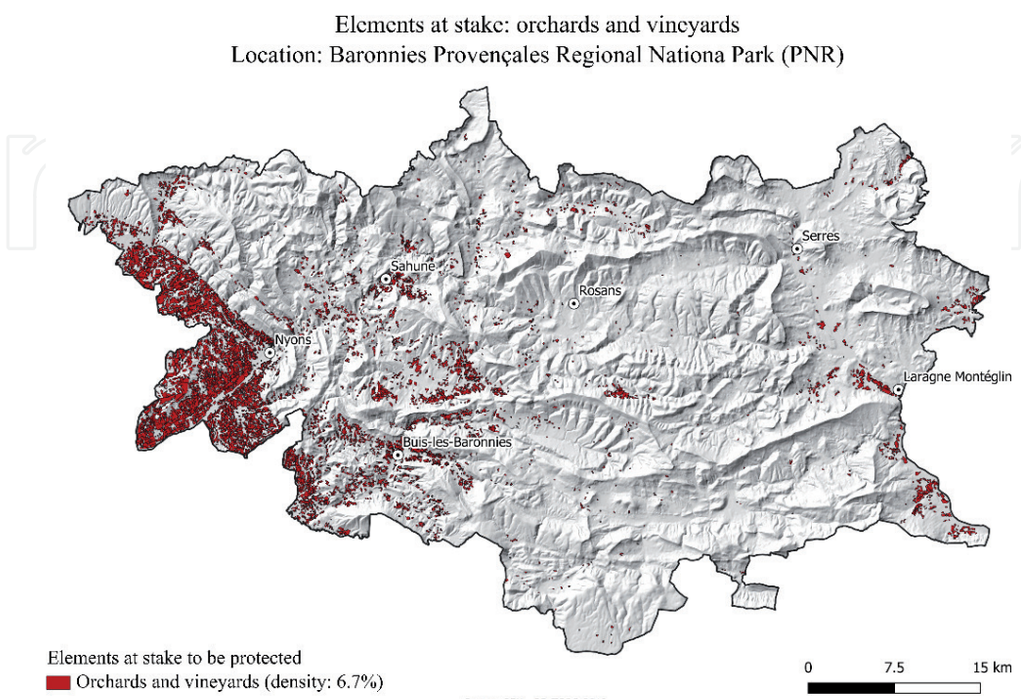

Figure 10.
Orchards and vineyards in the Baronnies Provençales regional Nature Park [10].

All these input data are automatically processed by the ROCK-EU-Mapping model in order to provide a map of the forest areas offering a potential protection role against rockfall risks. Two classes of slope values are used for defining potential release areas: 28° to 42°, corresponding to foothill conditions, and greater than 42°,

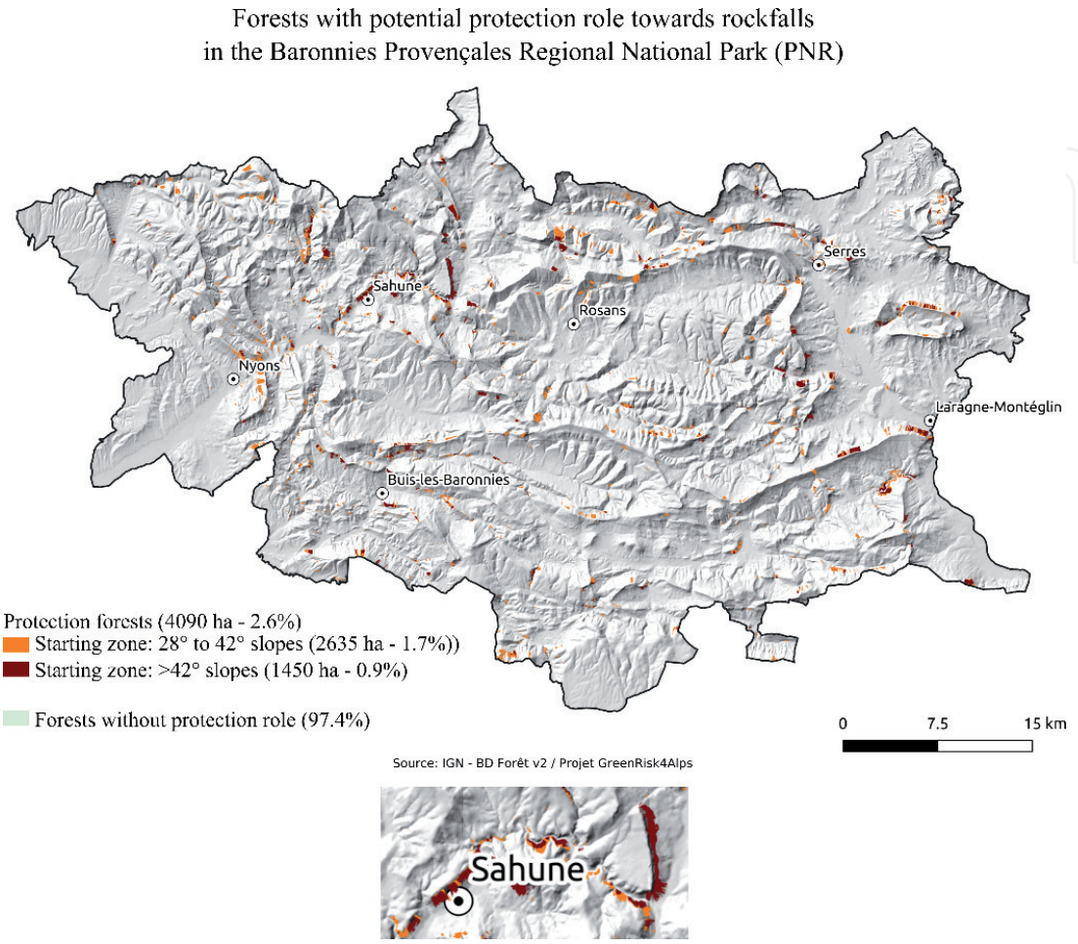

Figure 11.
*Forests protecting against rockfall risks in the Baronnies Provençales regional Nature Park with a blow-up of the Sahune area (***Figure 12***) [11].*

Figure 12.
Example of the protective effect of thermophilous deciduous forests in the Baronnies Provençales regional Nature Park (photos J. Jarjaye).

corresponding to mountain and cliff conditions. According to the geographical and topographical conditions of the park, all the results obtained for slopes greater 28° have to be considered.

Therefore, forests protecting against rockfall risks represent only 2.6% of the park's woodlands. The main element endangered by rockfall risks is the road network. As such, these forests are one of the actors, but not the main ones, of the policy of securing the transport routes in this territory. This analysis allows this ecosystem service, which had been largely overestimated by forest managers, to be put in its proper place (**Figures 11** and **12**).

3.2 Assessment of accessibility to logging machines in protective forests

Identifying and characterizing the conditions of access to forest resources are strategic points for their sustainable and multifunctional management. This issue of accessibility is all the more important for protective forests as it determines their maintenance and management strategies.

In order to fulfill these two objectives, INRAE developed the Sylvaccess model in 2015. This model is designed to automatically map the accessibility of forests with the three main logging techniques currently used in France: skidder, forwarder and cable yarder. The model is based on spatial information and specific parameters of each logging technique. It can also integrate physical or environmental obstacles in the analysis. The outputs of the model can be used for many applications ranging from forest management and planning of logging operations to the comparison and selection of new forest road projects.

The Sylvaccess model requires different layers of geographical information. The three layers necessary for its operation are as follows:

- A digital terrain model (DTM) in raster format. The resolution of the DTM determines the resolution that the model uses for all processing.

- The forestry access network. This data is a vector of polylines. It lists all the public roads in the network, forest roads (accessible to timber trucks) and forest tracks (only accessible to logging machines). A specific field in the attribute table, previously filled in by the user, allows the model to automatically distinguish between these three types of service. The quality of processing depends on the completeness of this layer. Careful preparation of this information is therefore important. Before processing, the model checks the connection between the forest service and the public network. If errors are detected, it returns a warning message and a GIS layer for locating possible problems.

- The forest area. This data is a vector of polygons. It allows the model to identify forest areas. In France, BD Forêt v2 provided by the IGN is a source of information adapted to the analysis scale.

The Sylvaccess model is a useful diagnostic and decision-making tool for forest managers and public decision-makers. It allows the identification of accessible forests with the main logging methods and the comparison of different alternatives during service projects. The results are summarized in the form of a map of logging methods. This map can be used as a basis for the planner and manager to plan the felling and silviculture to be carried out, which is of a different nature depending on the chosen exploitation mode [12]. The Sylvaccess model can be downloaded at https://sourcesup.renater.fr/projects/sylvaccess/.

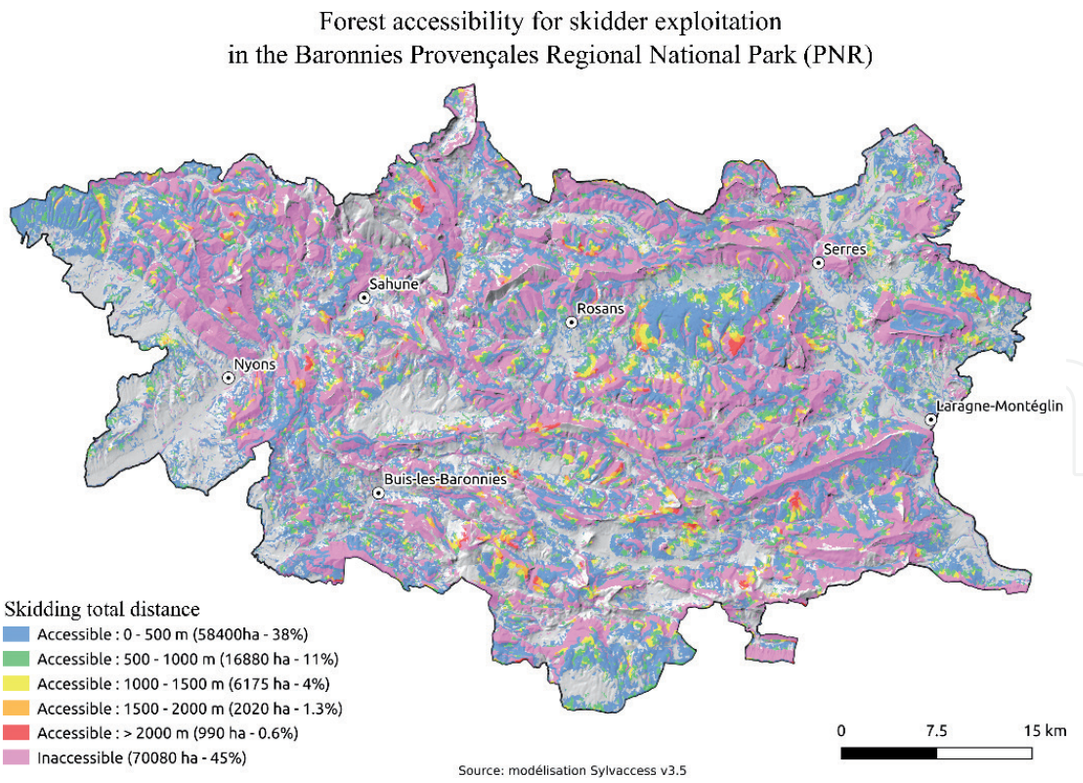

Figure 13.
Forest accessibility for skidder exploitation in the Baronnies Provençales regional Nature Park [13].

It is governed by the CeCILL license, which is subject to French law and respects the principles of free software distribution. Any forest manager, private or public, is able to use it free of charge for his own needs.

This model has been applied to the entire territory of the park. The first result confirms the difficulties in accessing forest areas. Sixty-two percent has a skidding distance longer than 500 m. This result confirms the impression of the local managers who considered in the first approach that more than 60% of the forest is difficult to access.

The second result is that 73% of the forest protecting against rockfall risks is not accessible to forestry equipment. This highlights the fact that protective forests are located in extreme topographical conditions, which makes them inaccessible to foresters even on foot (**Figures 13** and **14**).

3.3 Assessment of accessibility to fire fighting and rescue vehicles in protective forests

The dryness of the climate, the aerology and the type of forest species make the Baronnies Provençales an area that is highly exposed to the risk of forest fires. All the communes are classified by prefectural decree in the list of communes at risk, subject to the obligation to clear brushwood. As a result, the territory has several management documents such as the Departmental Plans for Forest Fire Defense (FFD). With regard to these documents, the fire risk hazard and the level of FFD equipment are precisely known. However, none of these documents spatializes the areas that are actually accessible from the forest road network. This question of the accessibility of protective forests is crucial for assessing the sustainability of this function in a territory where the risk of forest fires is high. A forest fire can effectively nullify this function and force managers to implement civil engineering techniques as a replacement. Knowing the location and accessibility of protective forests, firefighters can then build an adapted intervention strategy for these forests.

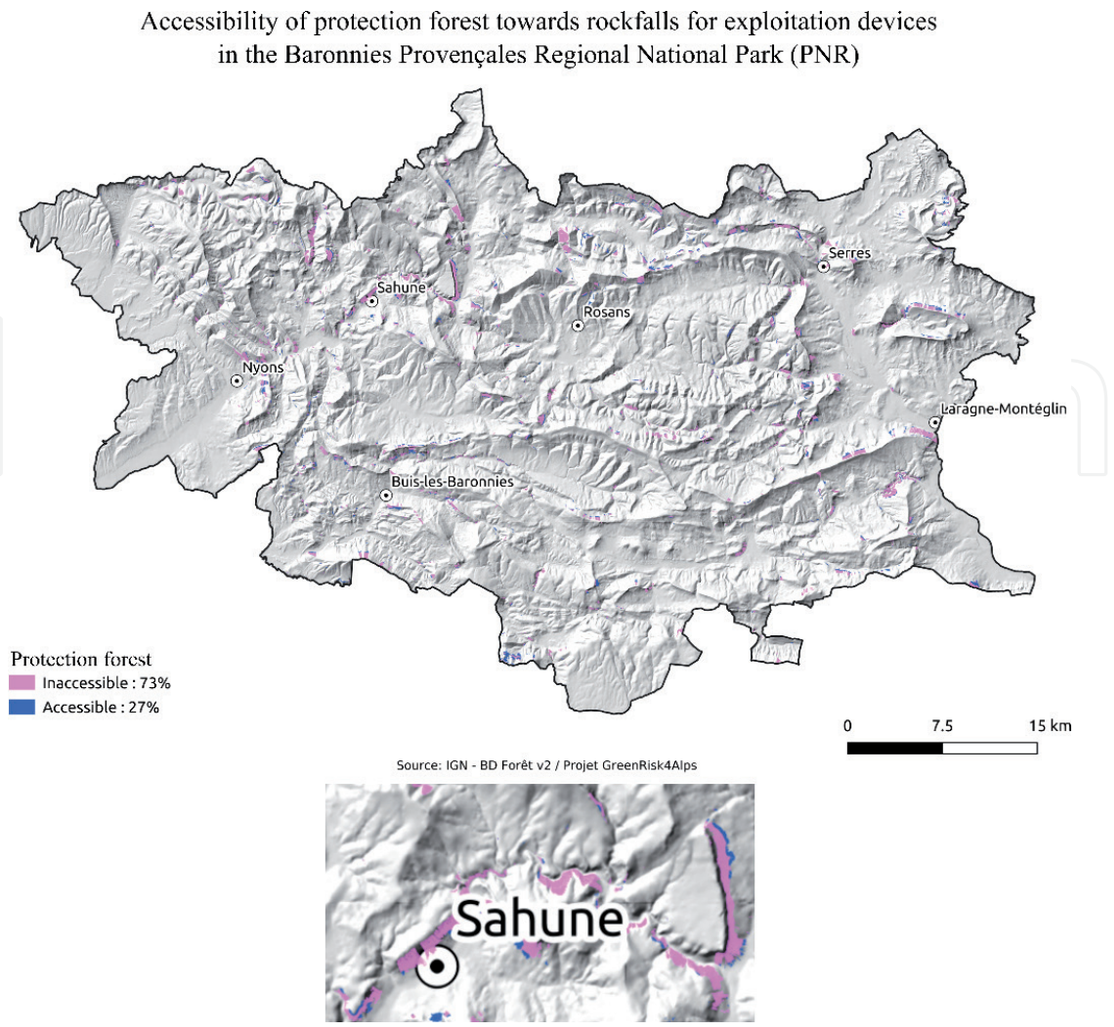

Figure 14.
Accessibility of forest protecting against rockfall to exploitation devices in the Baronnies Provençales regional Nature Park with a blow-up of the Sahune area [14].

Within the framework of the Interreg Alpine Space project GreenRisks4Alps, Sylvaccess has been adapted to the context of the accessibility of forest areas to fire fighting and rescue vehicles. The first prototype of the Fireaccess model was developed and tested on the territory of the Baronnies Provençales Regional Nature Park.

This new model makes it possible to identify and map forest areas that are accessible to land-based firefighting equipment (**Figures 15–17**).

The key result is that, based on a distance threshold of 100 m from both sides of a forest road or track, 74.8% of the forest is mainly inaccessible to classical land-based fire fighting vehicles (**Figure 18**). Another way of calculation is to evaluate the density of the forest surface accessible from a road or track. This density is calculated using a base of 100 ha. With this indicator, 71.4% of the forest has an accessibility density of less than 50% (for a forest area of 100 ha, less than 50 ha is accessible). These two results converge, underscoring the potential consequences of a forest fire in this territory if air-based equipment cannot be used.

Combining the map of the rockfall protective forests with the map of the accessible forest density to terrestrial based firefighting devices reveals that 59% of these forests have an accessible density of less than 50%. The difference with the previous result presented is due to the location of these protective forests close to the road networks that they are protecting.

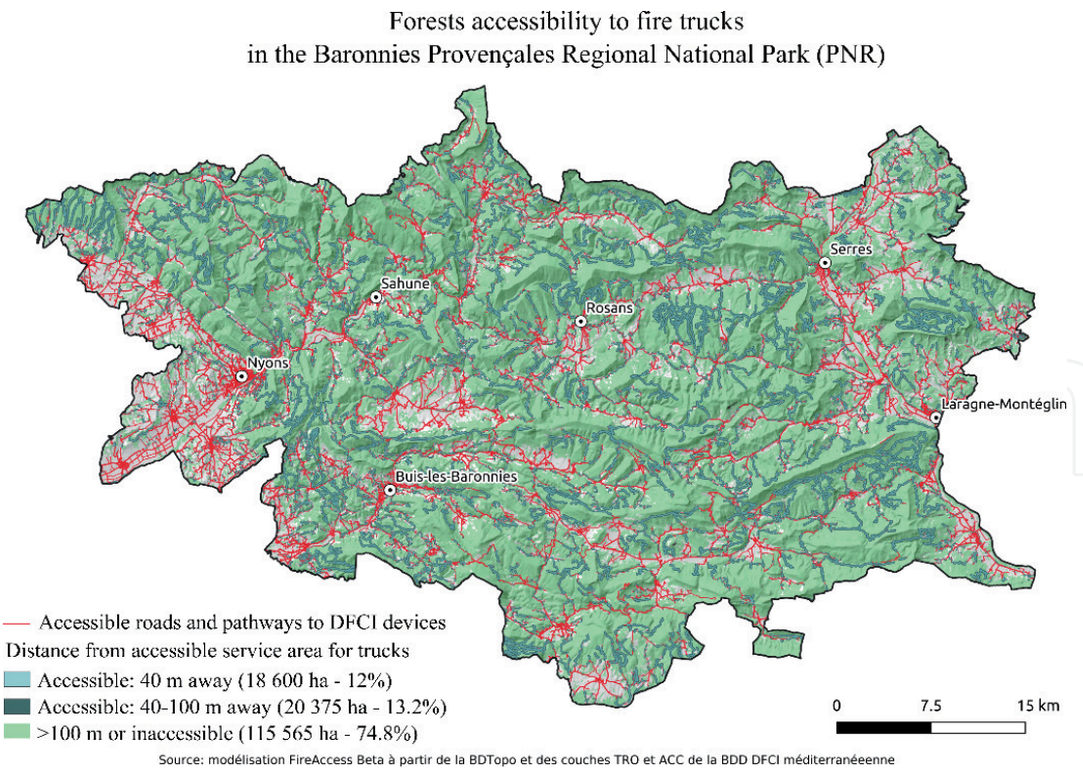

Figure 15.
Forest accessibility to terrestrial based firefighting devices in the Baronnies Provençales regional Nature Park [15].

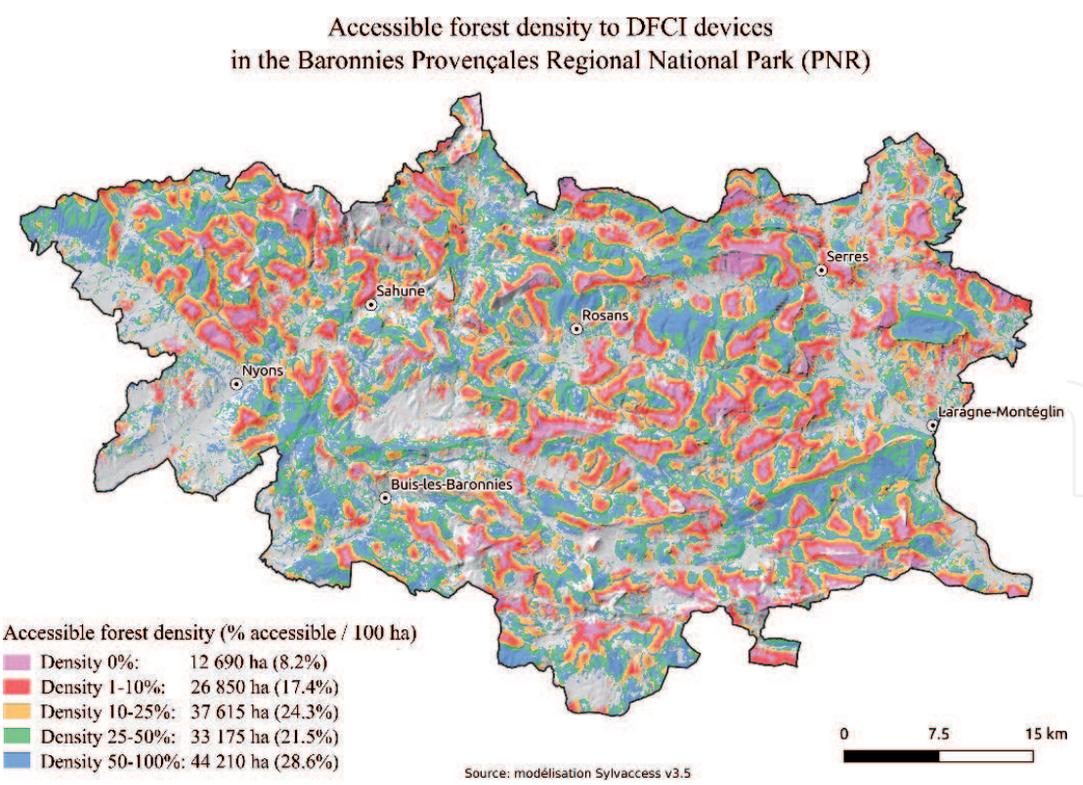

Figure 16.
Accessible forest density to terrestrial based firefighting devices in the Baronnies Provençales regional Nature Park [16].

DOI: http://dx.doi.org/10.5772/intechopen.99010

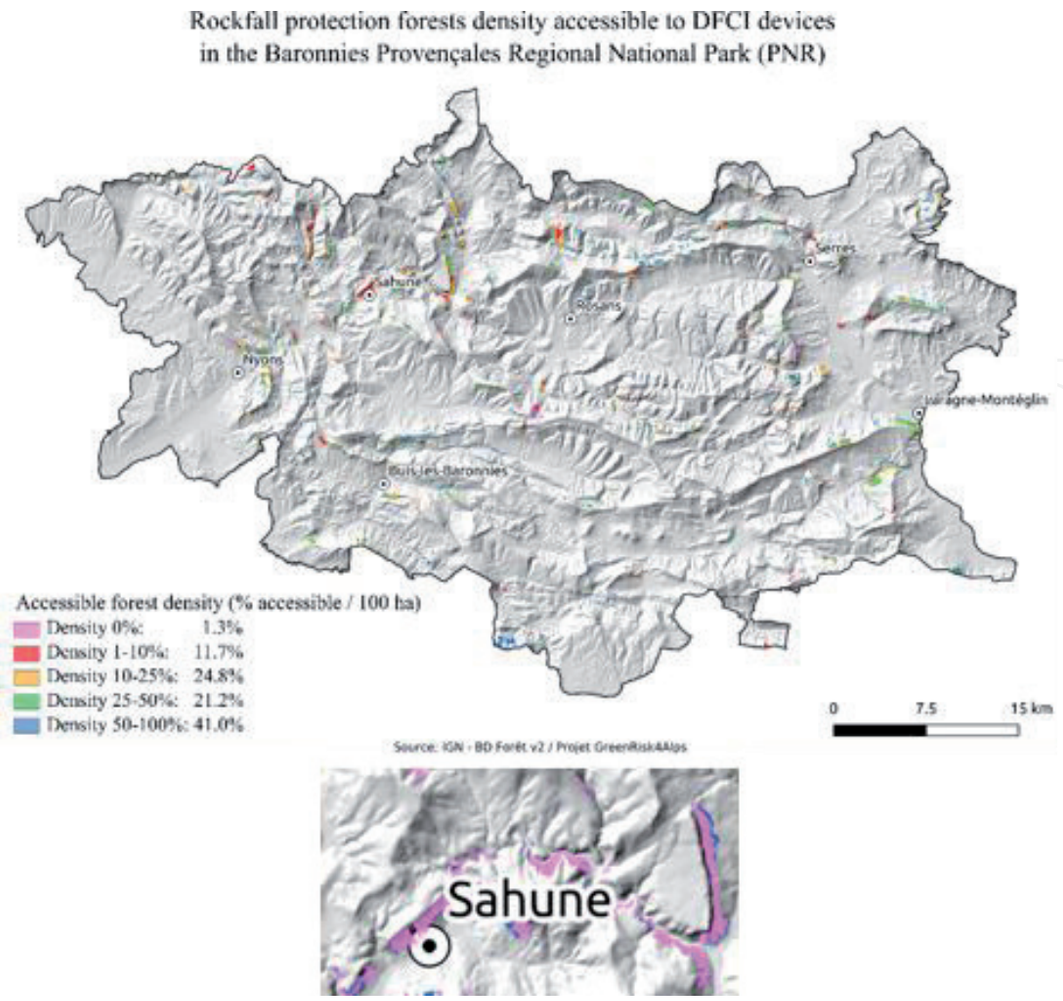

Figure 17.
Rockfall protection forest density accessible to terrestrial based firefighting devices in the Baronnies Provençales regional Nature Park with a blow-up of the Sahune area [17].

Figure 18.
Example of trees left across the slope. Debarking may be necessary to avoid phytosanitary problems (photos F. BERGER INRAE).

4. Conclusion

The main objective of this work was to produce and transfer the necessary and sufficient cartographic data to enhance the rockfall risk protection service of the forest heritage in the integrated natural risk management approach of the Baronnies Provençales Regional Natural Park. This objective answered the desire to develop a territorial intelligence as a response to the societal demand for the improvement of the prevention of natural risks by better taking into account the functions offered and the services rendered by the forest ecosystems. The general objective was to carry out the first territorial assessment concerning all the parameters for qualifying the forest ecosystem service of rockfall risk protection.

The first stage of the territorial assessment was to identify and understand the socio-economic factors explaining the development of this territory. From this first analysis, it emerged that the road network and the maintenance of its practicability are the two most important issues. Not only does this network ensure the proper economic functioning of the territory, it also represents access routes for intervention and rescue vehicles to fight forest fires.

The second step allowed the identification and display of the forest sectors protecting against rockfalls. The use of a trajectographic simulation model greatly facilitated this mapping work. Thanks to this approach, it was possible to carry out a concerted and harmonized action for the whole of this territory, freeing it from communal boundaries. In the end, it was found that only 2.6% of the park's forest area is capable of performing this protective function. Given the importance of the risk of forest fires, which affect the entire territory (remember that 84% of the territory is forested!), the management of this ecosystem service is not a priority action due to its low representativeness in the park's territory and is secondary to forest fire protection. This is especially true since only 25% of the forests protecting against rocky hazards are accessible to fire service vehicles. For the first time in France, the information produced by large-scale simulations makes it possible to prioritize the forest fire defense intervention sectors according to the presence or absence of the ecosystem service of rockfall risk protection.

All of the park's communes are classified by prefectural decree in the list of communes at risk, subject to legal obligations to clear brushwood. As such, there is a potential conflict of objectives between fire and rock protection forestry. Given the very low rate of forests with a rockfall risk protection function and their accessibility to land-based DFCI equipment, this management conflict does not really exist. For these forests, the management compromise is very simple:

The obligation to clear brushwood is imposed according to the distance of the forest stands from the objects.

It is possible to cut down trees and leave them in place provided that:

- The trunks on the ground are lopped off and the branches are removed from the site.
- The trunks on the ground must be positioned at an angle of 30° to the contour lines.
- The height of the obstacles thus created must be at least equal to the largest dimension (a projectile is characterized by its shape and its three dimensions: width, height, length) of the largest rock projectile present on the site.

If necessary, it is possible to use the trees present as supports for a rockfall protection net. If this solution is chosen, it is necessary to carry out a 3-dimensional trajectographic study to define the mechanical characteristics of this structure.

The main conclusions of this forestry territory analysis have been integrated into the integrated natural risk management approach of the Baronnies Provençales Regional Nature Park (a first in France) and will be included in its forestry territory charter when it is revised. More specifically, they will feed into two main objectives:

- Enhancing natural and human assets.
- Designing sustainable forestry development based on solidarity.

In this respect, they demonstrate the contribution of large-scale modeling work to decision-making and to the development of a genuine territorial intelligence based on the display of the ecosystem service of protection against natural hazards. Very often and unfortunately, awareness of this service is only raised when the forest cover disappears. These tools therefore offer the possibility of anticipating the consequences of forest cover change.

The issue for decision-makers now is the recognition of forest-based solutions in natural hazard prevention policies, but that is another story to follow.

Acknowledgements

Finally, we would like to thank everyone who contributed to the production of the materials used for the drafting of this text.

Author details

Frédéric Berger[1*], Benjamin Einhorn[2], Jessica Jarjaye[3], David Toe[4], Jean-Baptiste Barré[5] and Sylvain Dupire[6]

1 INRAE, Saint Martin d'Hères, France

2 PARN, Saint Martin d'Hères, France

3 SMBP, Sahune, France

4 SNCF, Chambéry, France

5 IGE, Saint Martin d'Hères, France

6 Sylvalab, Barraux, France

*Address all correspondence to: frederic.berger@inrae.fr

References

[1] Syndicat Mixte des Baronnies Provençales, 2012 : []. Charte Forestière de Territoire des Baronnies Provençales. https://www.ofme.org/documents/actualite/201207/CFTBaronniesProvencales-DocumentFinal.pdf

[2] INRAE- research unit LESSEM -Computer development and database: F. Bray & A. Torre. Geographic data source: INSEE, démographie – la population 2017. Completion date: March 2021

[3] INRAE- research unit LESSEM -Computer development and database: F. Bray & A. Torre. Geographic data source: AGRESTE, SCEES, RGA 2010 Communal. Completion date: March 2021

[4] INRAE- research unit LESSEM -Computer development and database: P. Favier. Geographic data source: IGN BDforêtV2. Completion date: March 2021

[5] European forest types, Categories and types for sustainable forest management reporting and policy, European Environment Agency EEA Technical report No 9/2006

[6] Dupire, S., Toe D., Barré J.-B., Bourrier F., Berger F., 2020. Harmonized mapping of forests with a protection function against rockfalls over European alpine countries. Applied geography, Elsevier, 2020, 120, pp.102221. ff10.1016/j.apgeog.2020.102221ff. ffhal-02519495v2f

[7] Bourrier, F., Berger, F., Tardif, P., Dorren, L., Hungr, O., 2012. Rockfall rebound: Comparison of detailed field experiments and alternative modelling approaches. Earth Surface Processes and Landforms 37 (6), 656-665.

[8] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD forêt V2. Completion date: March 2021

[9] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021

[10] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021

[11] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021

[12] Dupire, S., Bourrier, F., Monnet, J.M., Berger F., 2015. Sylvaccess : un modèle pour cartographier automatiquement l'accessibilité des forêts. Revue forestière française, AgroParisTech, 2015, 70 (2), pp.111-126. ff10.4267/2042/57902ff. Ffhal-01255892

[13] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021

[14] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021

[15] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021

[16] INRAE- research unit LESSEM - Computer development and database:

S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: **March 2021**

[17] INRAE- research unit LESSEM -Computer development and database: S. Dupire and P. Favier. Geographic data source: IGN BD topo 2018. Completion date: March 2021