A GIS PROCEDURE TO MAP FORESTS WITH A PARTICULAR PROTECTIVE FUNCTION

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Abstract

The aim of this work is on one side to implement a GIS methodology to create maps of forests with particular protective function and on the other side to furnish new information to define the risk type from the point of view of the forest planning and management with the greatest possible detail. To locate the real forests with particular protective function (bpfp) that is those forests with particular protective function that directly protect human life or important objects, a classification of the objects in order of importance has been carried out. The comparison between bpfp and forests classified with protective function in the traditional management plans has highlighted the need to reconsider the concept of forest protection. The method has permitted to obtain a quick delimitation of bpfp, with a procedure that can be exported and adapted to other different situations. In particular, with the aid of GRASS detailed maps that distinguish bpfp depending on different criteria have been obtained and these maps can be really effective to make easier the phase of the planning of sylviculture.

1. Preamble

This research has been carried out in a very particular time for the Italian forest planning. The Forestry Commission is evaluating the possibility to introduce, also in our Country, a superior level of planning, which can be identified as a planning at a regional scale. The traditional way of operating of the forest management plan is very efficient at the level of an individual farm; instead it has been realized that at the level of a whole region this instrument can present some lacks or anyway, it doesn't allow to have a whole vision of the situation. Actually, at the regional level it's easier to identify and analyse all the forest functions and roles that can be useful to society so to lay the foundations of a sylviculture which can improve all the different functions of woodlands.

In particular, the right sylvicultural management of woodlands can contribute to improve the protection role carried out by the forestry towards the land.

The management has to be peculiar and special on those slopes where there are direct natural risks, such as falling rocks or starting of avalanches, for the human life or for important targets. In this

case we talk about a function of *direct protection* and the woodlands which have this role are named forest with a particular protective function – bpfp.
Mapping and differentiating bpfp according to the different dangers towards they offer protection is very important, because the kind of sylvicultural treatment is function not only of the type and of the characteristics of woodland but also of the different type of protection that the forest has to exercise. Once bpfp are identified, the right sylvicultural treatment can play a very important role in the risk prevention.

2. Introduction

The concept of forest with a particular protective function comes from the Swiss forestal legislation; in this Country a high sensibility for the sylvicultural problems and for the conservation and management of the forestal patrimony led time ago to set aside a fund to carry on the interventions on woodlands, in order to preserve the integrity of those forests which protect towns, infrastructures, facilities and communication routes from natural risks. In Switzerland the methodology to map forests with a particular protective function is codified by law and it leads to the use of special funds for the sylvicultural interventions directed to preserve and improve the protective function. According to the Swiss regulations the treatment of bpfp can be equalized to the building of protective fortifications, with the advantage that the treatment of woodlands is usually cheaper. For instance, according to a recent research [1], Switzerland should face in the next 30 years expenses of more than 72 billions of euro just for the damages provoked by avalanches; if woodlands deteriorated to the point that a total restoration should be necessary, the works to put new fortifications against avalanches would cost around 153 billions of euro. On the whole, the protective function of woodlands can be translated into a material value of 2.4 – 2.8 billions of euro.

2.1 Forest with a particular protective function: what it is

The definition of forest with a particular protective function comes from the "article 42 cpv. 2 Ofo" [2], which says "*a forest with a particular protective function is located on a slope where there is a direct risk for human life or for material goods of high value, due to avalanches, landslides, erosion, debris flow or falling rocks*".
The woodlands which offer an indirect protection, such as the regulation of the water flow, and those woodland located downhill the risk – for instance downhill the starting zone of avalanches - are not to be considered bpfp.
Along this work, those forest located on slopes where there are natural risks due to the morphological conformation are named potential bpfp while those forests which offer a direct protection to objects of primary importance are referred to as effective bpfp.

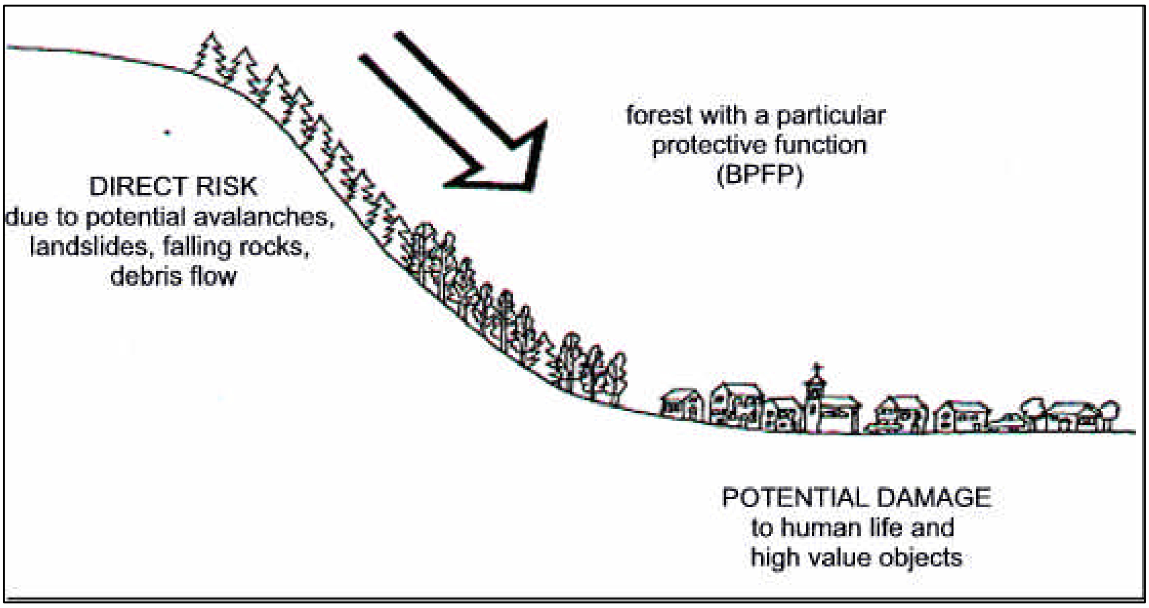

Figure 1 Scheme of a forest with a particular protective function. a forest with a particular protective function is located on a slope where there is a direct risk for human life or for material goods of high value, due to avalanches, landslides, erosion, debris flow or falling rocks [2].

3. Objectives

The first aim of this research is to identify, define and implement a GIS procedure of general applicability, to map forests with a particular protective function, standardizing and accelerating that part of procedure that in Swiss is carried out manually.
Moreover, with this study, there is an attempt to provide new elements and to add new information to the maps created, in order to define in details the types of risk, useful to planning and to forest management. So all the maps created have been refined with new analysis according to typology and availability of additional data.
The implemented procedure has been applied to an actual case, in order to verify the results with on–site investigations. This phase was really very important, since it allowed to understand the results obtained by the model and to adjust the procedure properly.

4. GIS

The GIS chosen to carry out the research is GRASS, in the latest available version when the research was carried out, that is 5.0.0 pre3. GRASS is an open source software, and it can be used and distributed freely. GRASS has been installed under LINUX operative system. An additional help was also obtained by the commercial GIS MapInfo, in Windows environment, to convert some of the data format and to correct some errors generated during the data importation. It is important to stress that now the latest updates of GRASS allow to import the data without generating errors.

5. Data origin

To carry out this work many input data coming from different sources have been used.

The elevation data are stored in vector contours mapped every 10 meters, and are available in the cd "Base 1.1/96 – Cartografia Tematica 1:10000" provided by the Council of Trento. The Pejo Valley council boundaries were stored in the same cd. The land use map, provided by the bureau "Azienda Speciale di Sistemazione Montana" of Trento Council represents the subdivision of the investigation area according to the different land use; this use can be roughly classified in 15 different categories.

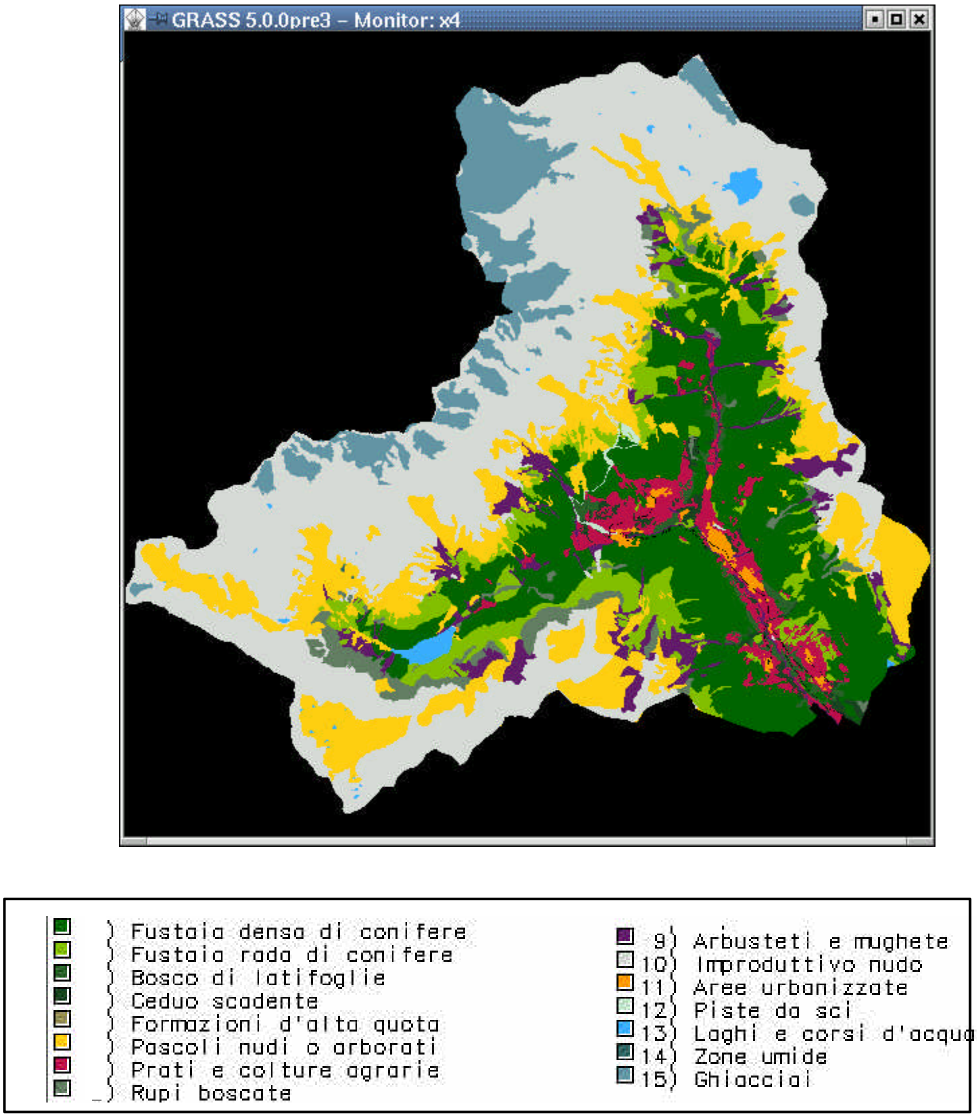

Figure 2. Land use of Pejo Valley. The map has a complex classification, as it identifies 15 different categories.

The road network data of the investigation site can be divided in two different categories: main road network and forest road network and are available in the cd "I dati della viabilità forestale 2000 – Edizione 2001 –".

As to geological data, they have been provided by the bureau "Azienda Speciale di Sistemazione Montana" of Trento Council. The geological map contains not only information about the geological subdivision of the land, but also data about permeability, erosion and thickness of each layer. This is the result of an investigation carried on by geological technicians in Pejo Valley, for the National Geological Service.

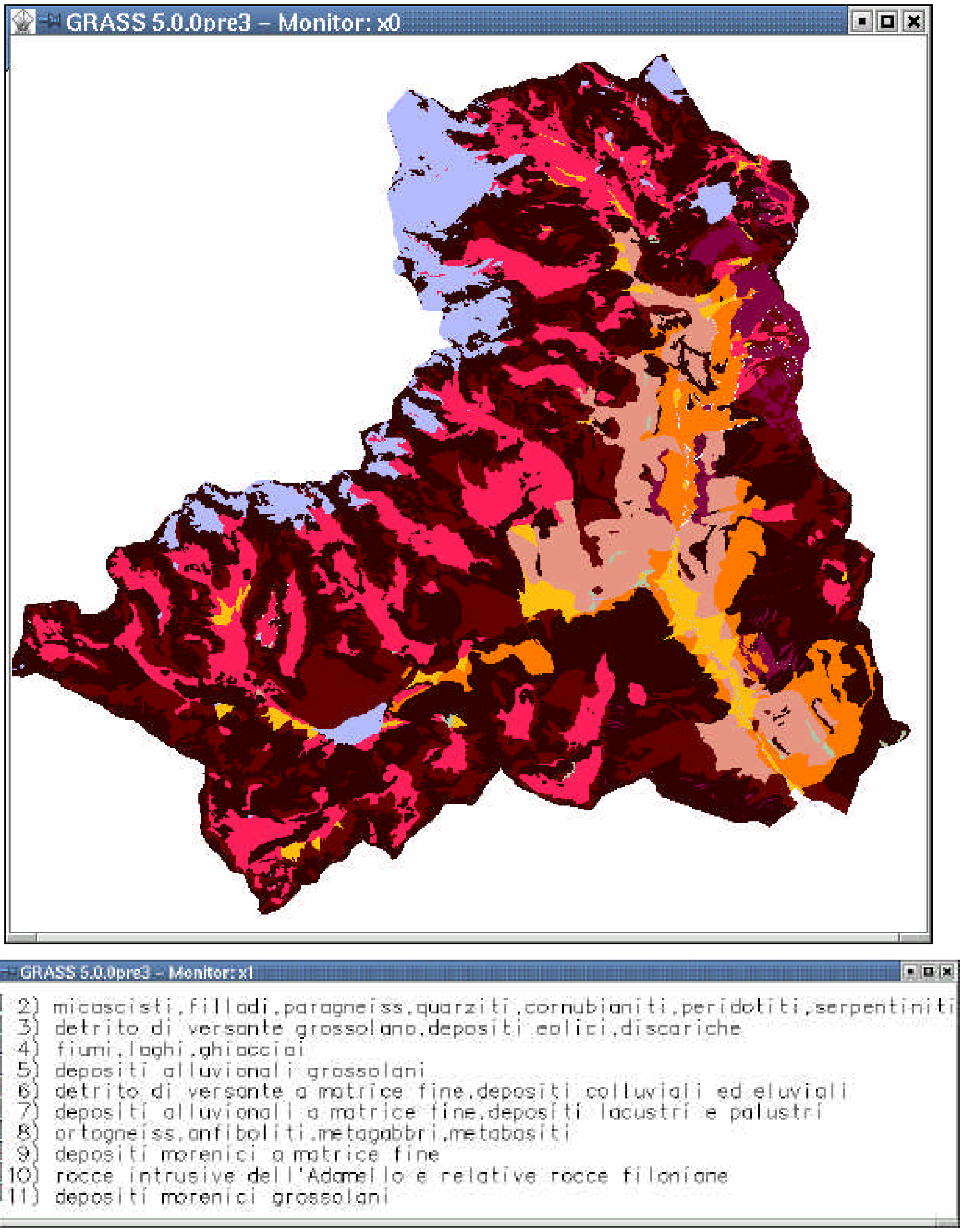

Figure 3. Geological Map of Pejo Valley.

The Landslides and Geological instability map, obtained from the bureau "Azienda Speciale di Sistemazione Montana" of Trento Council, includes information about the localization of landslides and the position of geological instability, identifying also quiescent and active landslides.

The geological risk map, available by the bureau "Servizio Geologico" of Trento Council classifies the whole land into high risk, medium risk, low risk areas. This classification was carried out using the synthesis geological map and the CLPV (probable avalanches localization map).

The geological risk map identifies three different categories:

- class 1, high geological risk;
- class 2, medium geological risk;
- class 3, low geological risk.

This is the result of the refining of the synthesis geological map with inspections and survey on – site. The synthesis geological map, which proposes the geological classification of the land for town planning purposes, is created overlaying and crossing different thematic maps: the geolithological map, the clivometric map, the hydrogeologic map, the morphologic map, the CLPV and the land use.

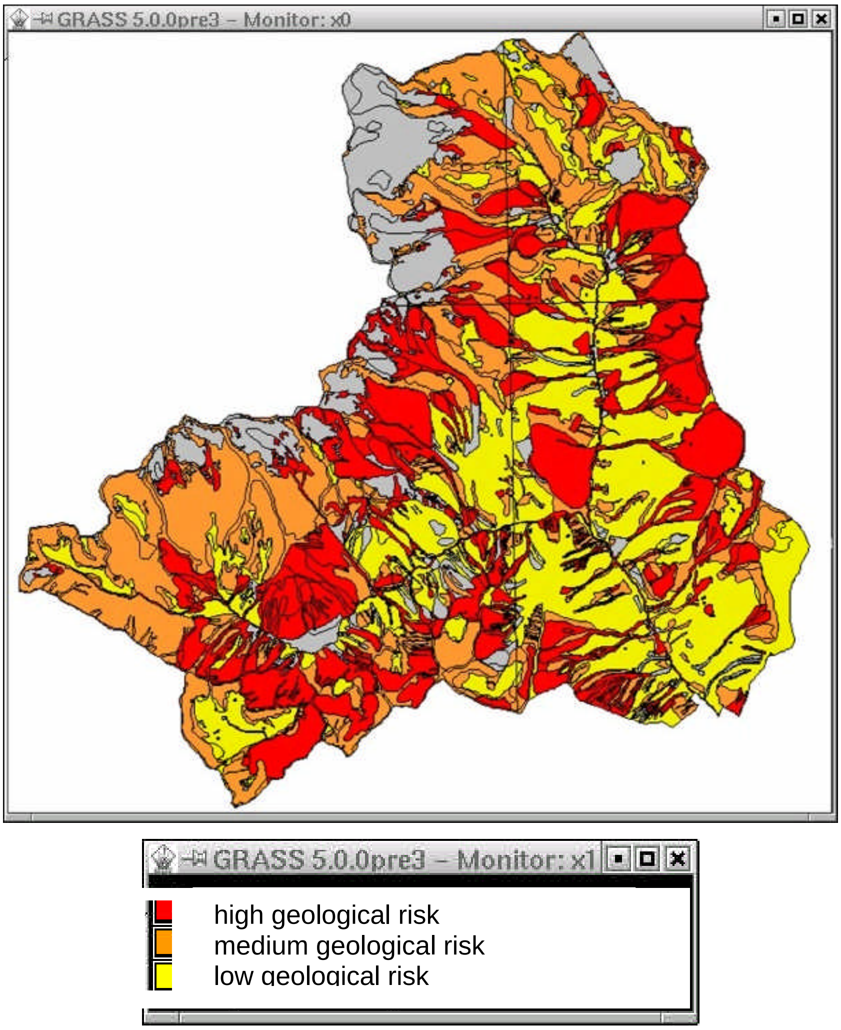

Figure 4 Geological risk map: the land is divided into three different classes: class 1 in red high geological risk; class 2 in orange: medium geological risk; class3: low geological risk.

The Probable Avalanches Localization map (CLPV) supplied by the bureau “Ufficio neve e Valanghe” of Trento Council identifies the boundaries of the areas where avalanches passed in the past. The clpv data used have been created in 1999.

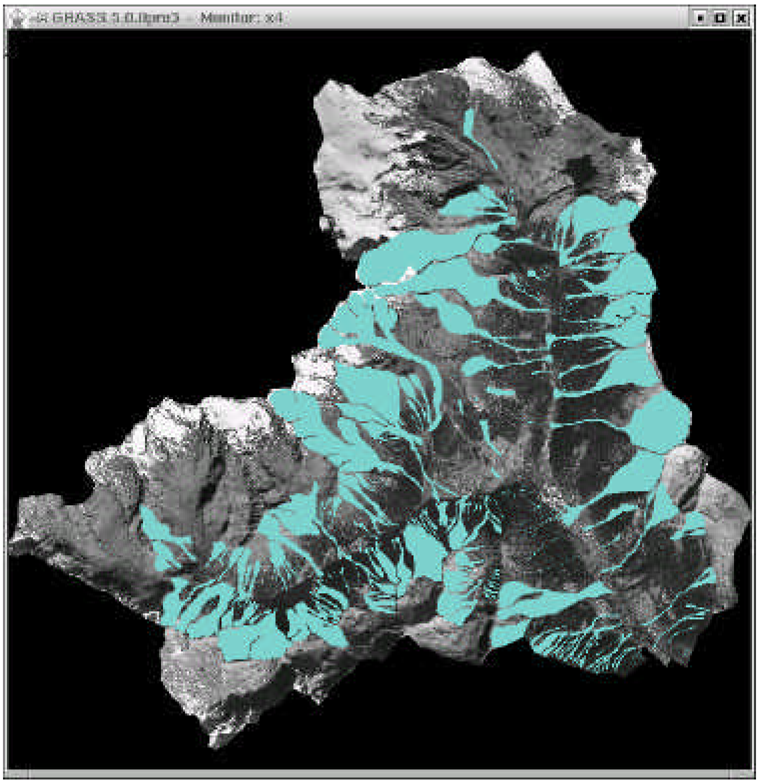

Figure 5 Probable Avalanches Localization map of Pejo Valley.

The most recent data about CLPV, updated in 2000, contain also the information about the photointerpretation of avalanches risk areas. This means that in this map are individuated not only the areas where avalanches certainly passed in the past, but also those areas which are potentially subjected to the risk of avalanches.

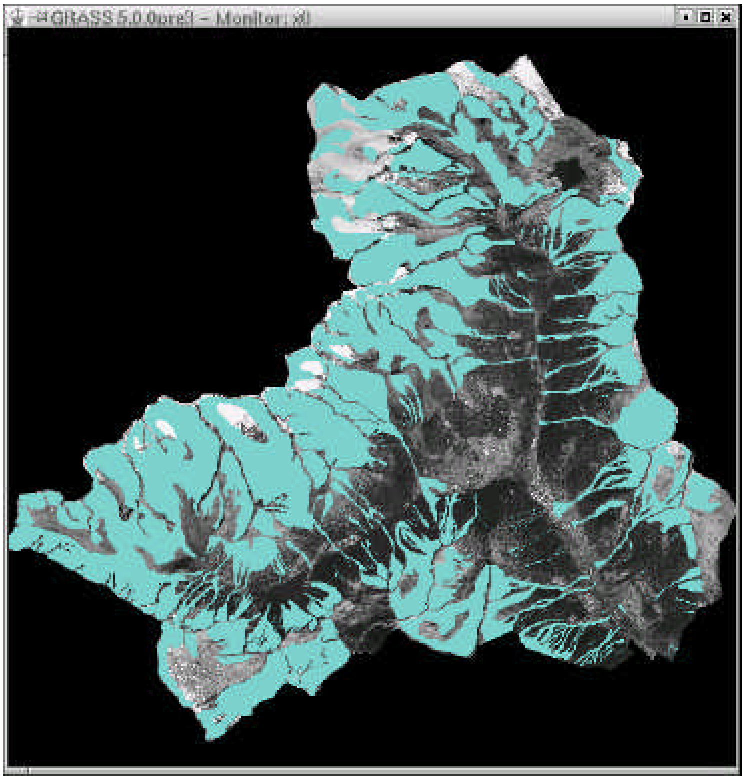

Figure 6 Map of the risk of avalanches, integrated with the information given by the photointerpretation. Data of 2002.

The map of woodlands with a protective function according to the forest management plans, available in the cd “I dati della pianificazione forestale aggiornati al 31/12/2000”, identifies all the areas covered by coppice which have a protective function. In this case the term protection has another meaning, which is very different from before: the term protection is an indication of the type of management of that area; this means that all those areas classified as protective are just areas usually inaccessible, and therefore it is impossible to carry on any kind of treatment, or areas particularly steep, and so the woodland has a function of indirect protection.

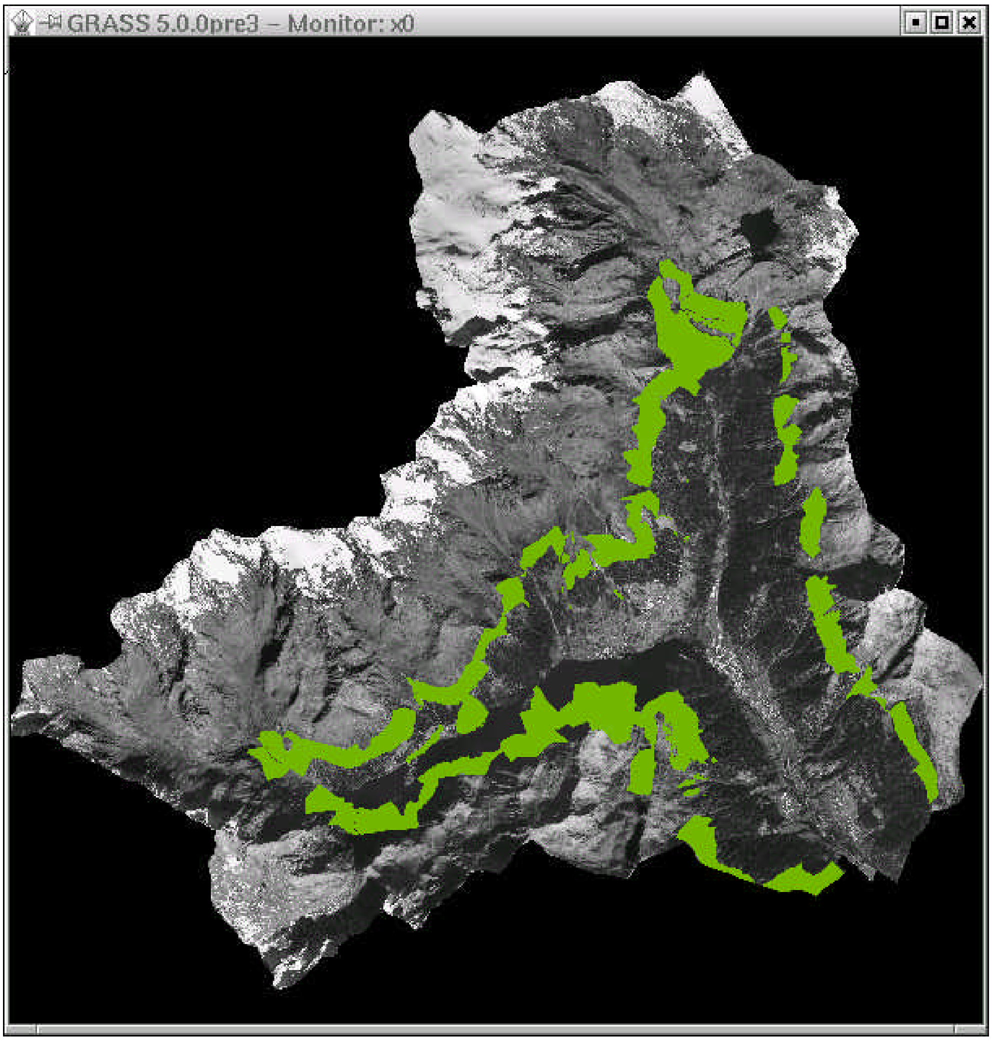

Figure 7 Map of woodlands with a protective function according to the forest management plans.

6. Swiss procedure to identify the bpfp

The necessary condition to have a bpfp is the existence of a natural risk; so the identification and mapping of these particular forests is first possible by consulting risk maps and cadastre. If this documentation doesn’t exist, and the presence on the land of a potential natural risk is certain, such as starting of avalanches, falling rocks, debris flow or landslides, in this case is necessary that technicians and experts carry out surveys on the land.

The next phase is to verify the existence of a direct risk for the human life of for objects of high value onsite, with the methodology of the global slope [3] defined as the slope between the starting area and the lowest point of the deposition area.

a) Avalanches risk

There is a potential avalanches risk if the slope is steeper than 50% and the slope length is more than 60 meters. The threatened objects have to lie under the global slope of 40%.

b) Falling rocks risk

There is a potential falling rocks risk if the slope is steeper than 50%. The threatened objects have to lie under the global slope of 40%. In that case all the woodlands to the lower limit of the deposition area are to be considered bpfp.

c) Landslide and debris flow risk

There is a potential landslide or debris flow risk if the slope is steeper than 40%. The landslides considered are the superficial ones, with a 0 – 10 meters deep sliding plan. The threatened objects have to lie under the global slope of 20%. If there is the evidence of a landslide danger, also the ones lying till 4 – 5 meters above the boundaries of the woodland can be considered threatened objects.

The bpfp have to protect the following objects:

- Houses inhabited all the year long;
- Commercial, industrial and craft facilities and infrastructures working all the year long;
- Public infrastructures, working all the year long, as schools, hospitals, barracks, churches, hydroelectric plants;
- National roads;
- Cantonal roads.

In particular situations also the following objects have to be considered:

- Important water supply and waste water disposal infrastructures;
- Council roads classified as evacuation roads in the council evacuation plan.

The Swiss procedure to map forests with a particular protective function can be divided into two steps. The first phase is the production of the preliminary maps; this part is referred to *as generic potential bpfp mapping.* The second step consists in going onsite in the investigation area with all the documentation and the maps previously created and carrying on a survey to identify the bpfp which have a function of direct protection. The procedures used is the global slope method, which requires a high familiarity with the survey area and the knowledge of the probable falling rocks areas. For all these reasons it's evident that these kind of analysis can be carried out only by local technicians and experts of the investigation site, and that the results are based more on the experience and on the knowledge of the area by the experts, than on cartographic information.

7. Procedures applied in this project to identify bpfp

In order to produce a GIS automatic procedure, interactions and consultations with Swiss and Italian forestry experts has been carried out, in order to sketch all the concepts that define a bpfp.

The preliminary maps produced by the Swiss during the definition of *potential bpfp* are extremely generic, they only contain a few information and cannot identify the different types of risk (this should be a basic information to differentiate the sylvicultural management of woodlands). The identification of the risk can be done with on-site surveys, but some aspects can always pass unnoticed (like possible avalanches start areas), if not well highlighted on preliminary maps.

In this work the Swiss methodology has been deeply analysed and then used just as a basis to start to realize a new and more automatic procedure to define bpfp. Therefore, the whole phase of *potential bpfp* mapping was taken from the Swiss methodology, while the on-site survey phase was not at all developed.

A new and totally indipendent approach was then developed. The new procedure identifies the *effective bpfp*, that is all those woodlands among *potential bpfp* which protect primary importance objects. This step was carried out using a new methodology, innovative for the use of a GIS and of different analysis techniques. Finally, the *effective bpfp* have been classified in order to make the sylvicultural planning easier. This bpfp classification takes into account two elements: the importance of the objects to be protected by the woodland and the geomorphology of the land where the forest is located. In the first case houses were considered more important than communication routes; in the second case a complex methodology was implemented in order to produce a classification that takes into account the tendency to geological instability of the areas where bpfp are located. This procedure involves the use of geological maps, CLPV maps, maps of probable avalanches start areas, photointerpretation of avalanches risk areas, comparison with geological risk maps of the Geological Service, on-site inspections and consultations with forestry technicians and experts.

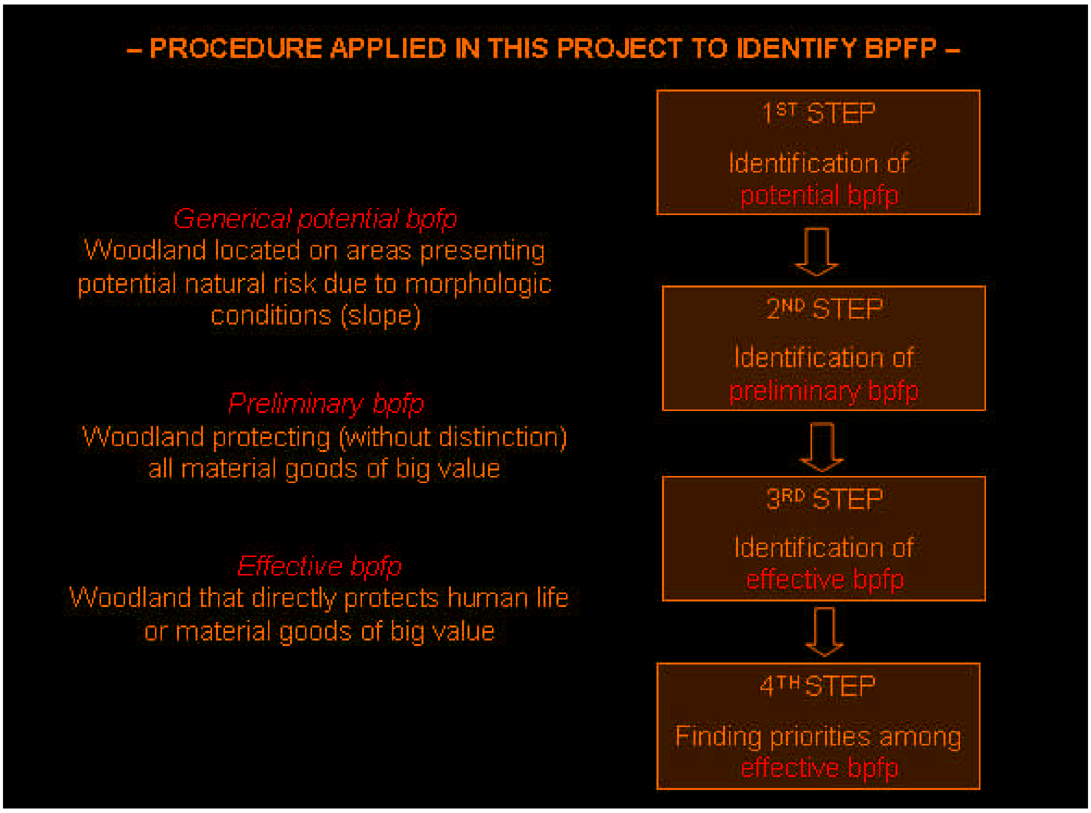

Figure 8 Resume of the procedure used in this work to identify bpfp.

The site of investigation is the administrative council of Pejo Valley, an area where a peculiar geomorphology represents a factor of high natural risk, and the availability of several digital thematic maps allows to easily apply GIS procedures.

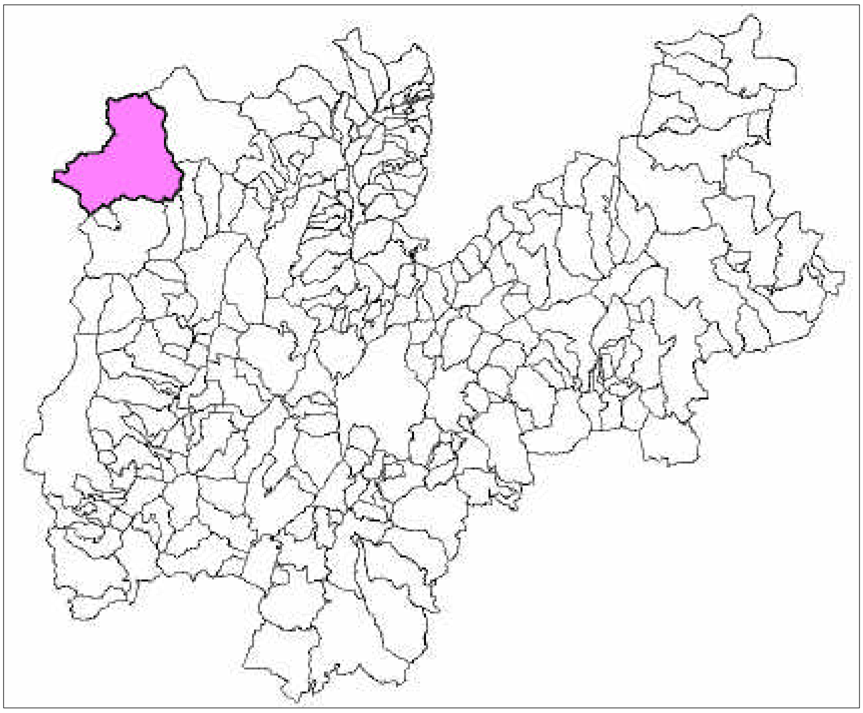

Figure 9 District of Trento and its councils. The Pejo Valley administrative region is highlighted in pink.


Figure 10 View of Pejo Fonti village. This photograph was shot from the road leading to Pejo Paese village.

7.1 Identification of *generical potential bpfp*

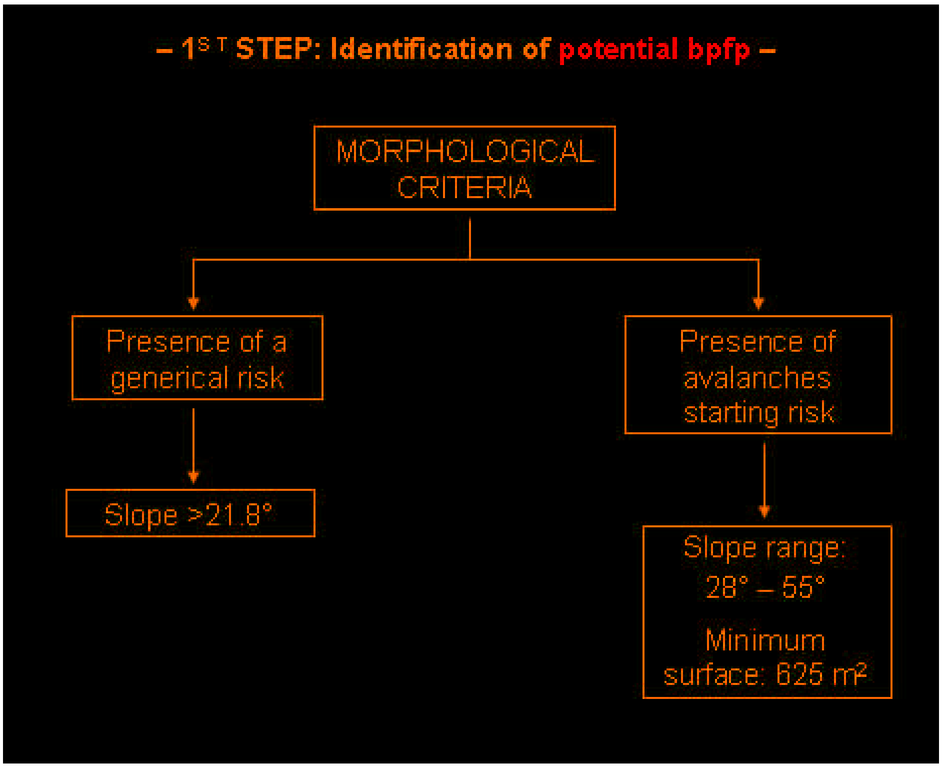

Figure 11 Scheme of the procedure to map "generical potential bpfp".

First of all a slope map of Pejo Valley was generated: at this aim a 5 meters resolution DTM was previously realized using the rasterized vector contours.

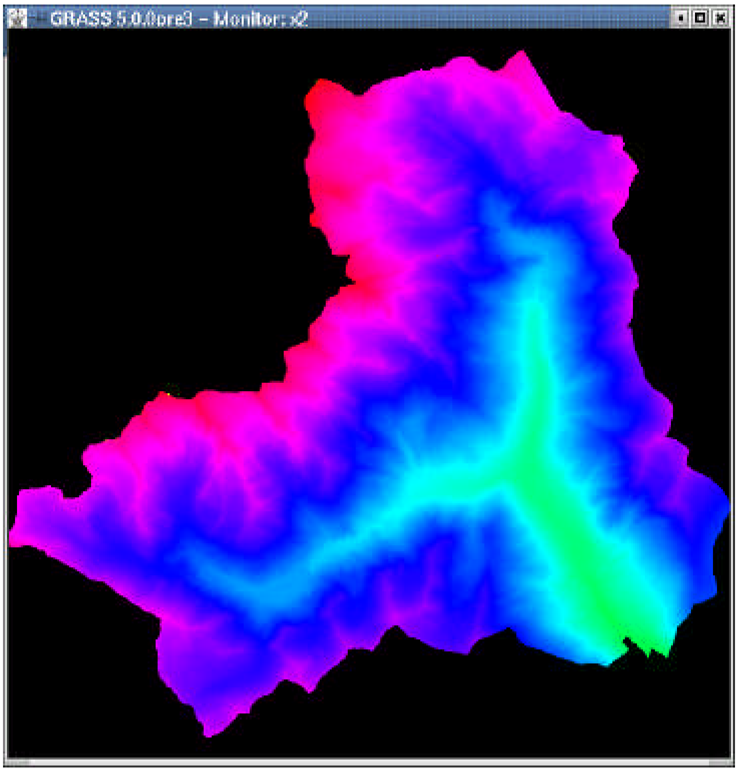

Figure 12 DTM, Digital Terrain Model of the area of investigation. The DTM was created with r.surf.contour GRASS command using the rasterized vector contours. Colour depends on cells elevation value.

All cells with a slope steeper than 40% have been extracted from the slope map: these areas are subject to potential natural risks due to the land morphological conformation (according to the Swiss methodology). Obviously only areas covered by woodland have been considered.

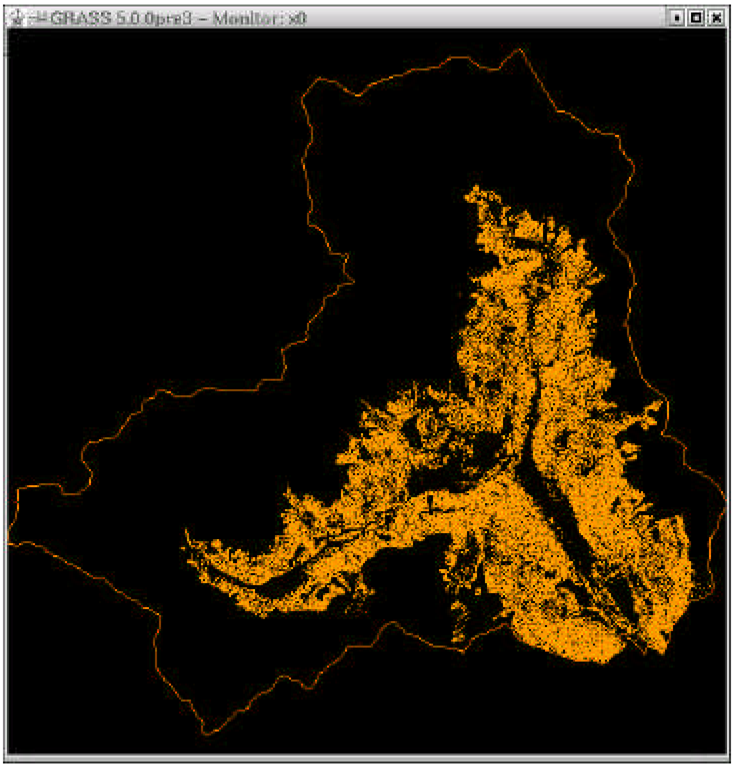

Figure 13 Map of "generical potential bpfp", that is all the areas where generical natural risks can be prevented by the presence of stable woodland.

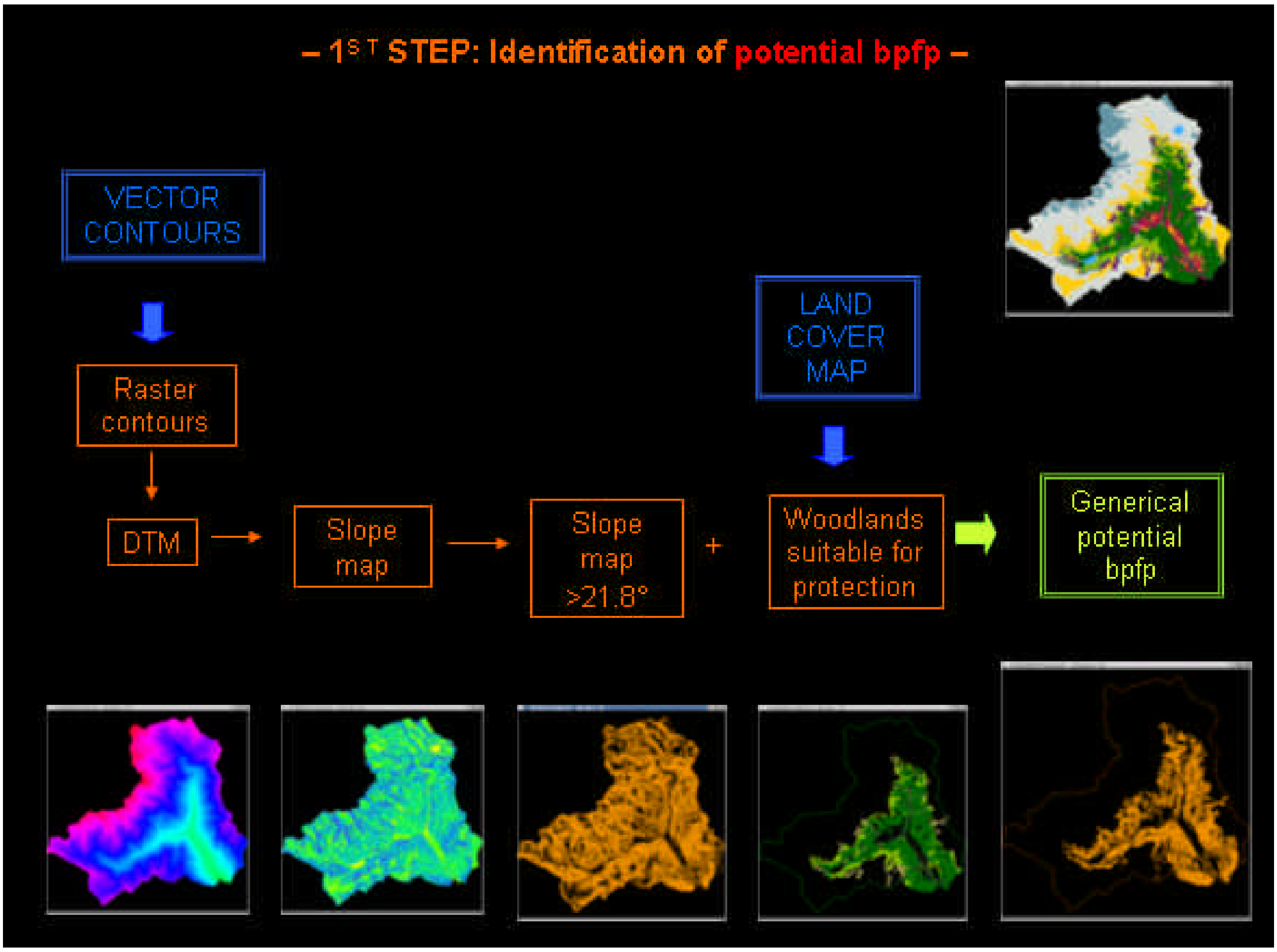

Figure 14 Scheme that summarizes the procedure to map "generical potential bpfp" and of the maps obtained after each step.

7.2 Identification of *generical potential bpfp with avalanche starting protection function*

In order to produce a more detailed map and to refine the results of step 1, among *generical potential bpf generical* have been identified the *potential bpfp with avalanche starting protection function.* This distinction is particularly important, because it determines the kind of sylvicultural treatment to apply to the woodland to preserve and improve its protective function.

At this purpose the well tested criteria of the Ecology Laboratory of the DICA (Dipartimento di Ingegneria Civile e Ambientale) – University of Trento – have been applied. According to these criteria slope is one of the main topographic components causing detaching and sequentially propagation of avalanches: critical slope range is 28° - 55° [4]. Another element that has to be considered when studying the probable avalanches starting areas is the detaching minimum surface; the extension of this surface is function of many different factors, like local slope, aspect or snow properties: in this case a fixed value of 625 m^2, corresponding to a square of 25 meters of width and height, has been adopted as indicated in literature [5].

By means of GIS all the areas presenting a slope between 28° and 55° with a detaching minimum surface of 625 m^2 have been identified; then woodland areas have been overlaid: in this way *generical potential bpfp with avalanche starting protection function* have been identified.

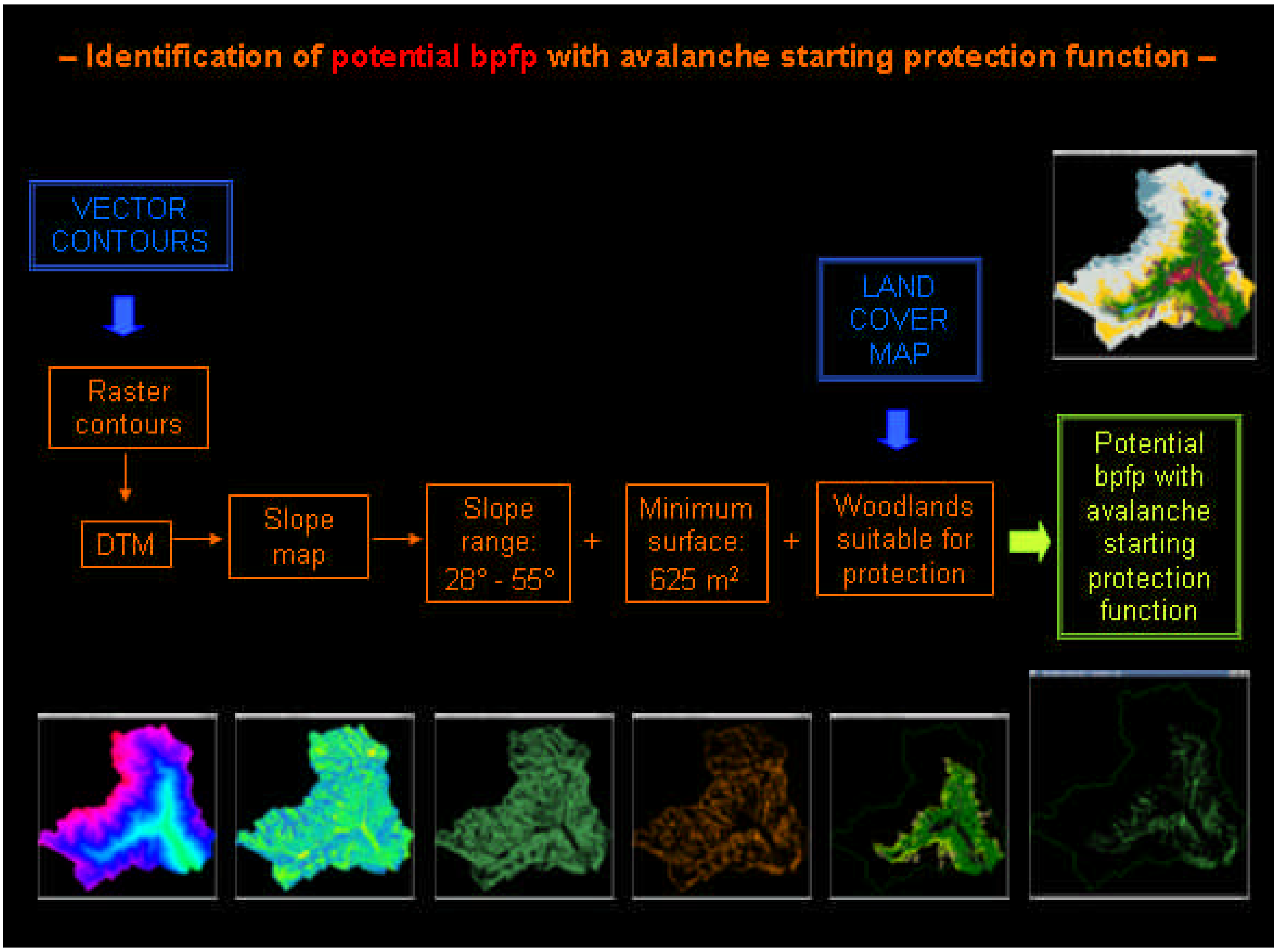

Figure 15 Scheme of the procedure to map "potential bpfp with avalanche starting protection function" and maps obtained after each step.

7.3 Identification of *preliminary bpfp*

The third phase is the identification of *preliminary bpfp:* woodlands that protect (without distinction) all important material objects. To identify these areas, buildings and communication routes layers have been overlaid to the previously identified *generical potential bpfp* (step 1). Then all areas with the following features are manually removed from the map of *generical potential bpfp*:

- woodland located where no material objects of high value exist;
- woodland located downhill material objects of high value;
- woodland placed on the opposite mountainside than the one of the material objects of high value.

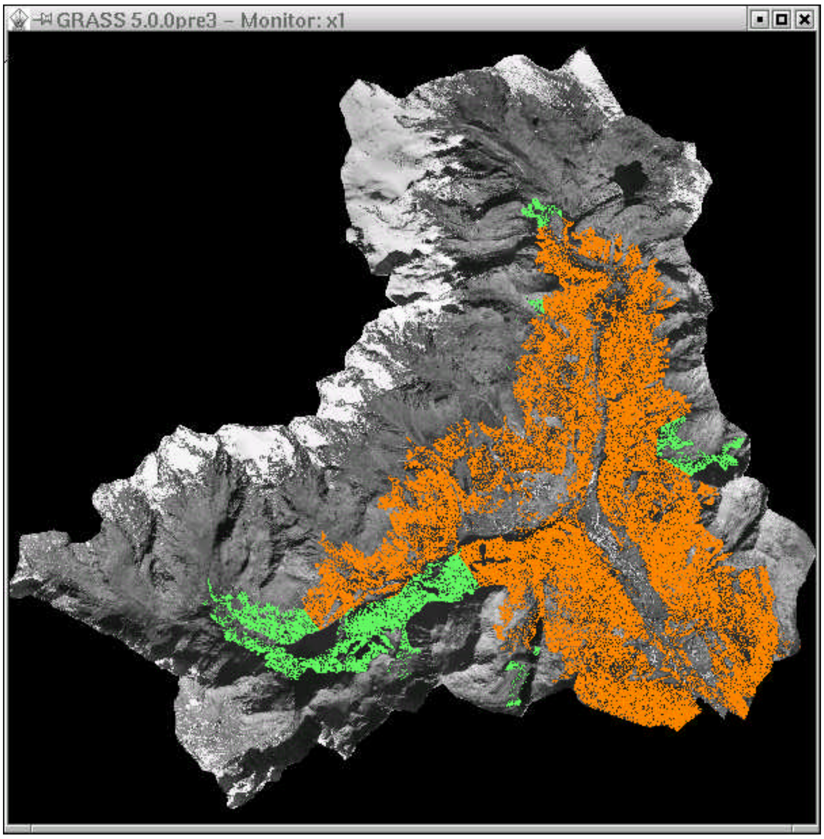

Figure 16 Comparison between" preliminary and generical potential bpfp": the first ones are represented in orange; the green areas represent the" preliminary bpfp" areas not included in the "generical potential bpfp".

Excluded zones are quite a minority: that's because of the morphological conformation of the valley. Urban agglomerations and roads are not exclusively located on the valley floor: some communication routes wind along the mountainside, and this fact highly reduces the amount of areas to be excluded from the *generical potential bpfp*. Furthermore no lateral valleys are present in the area of investigation, and only a few woodland are placed on the opposite mountainside than the ones of the material objects of high value.

7.4 Identification of *effective bpfp*

Effective bpfp are woodlands that directly protect human life or material objects of high value. After a deep analysis of urban agglomerations and infrastructures, a classification has been made of the importance of the protected objects, splitting the related *effective bpfp* in different categories. Three priority classes have been defined: class 1 for urban agglomerations, class 2 for communication routes leading to civil habitations, class 3 for secondary or forest roads: a high priority corresponds to a low class number. According to this classification only woodlands that directly protect the first two classes can be considered as *effective bpfp*. This discrimination among bpfp has a particular value, both from an urbanistic and a forestal points of view.

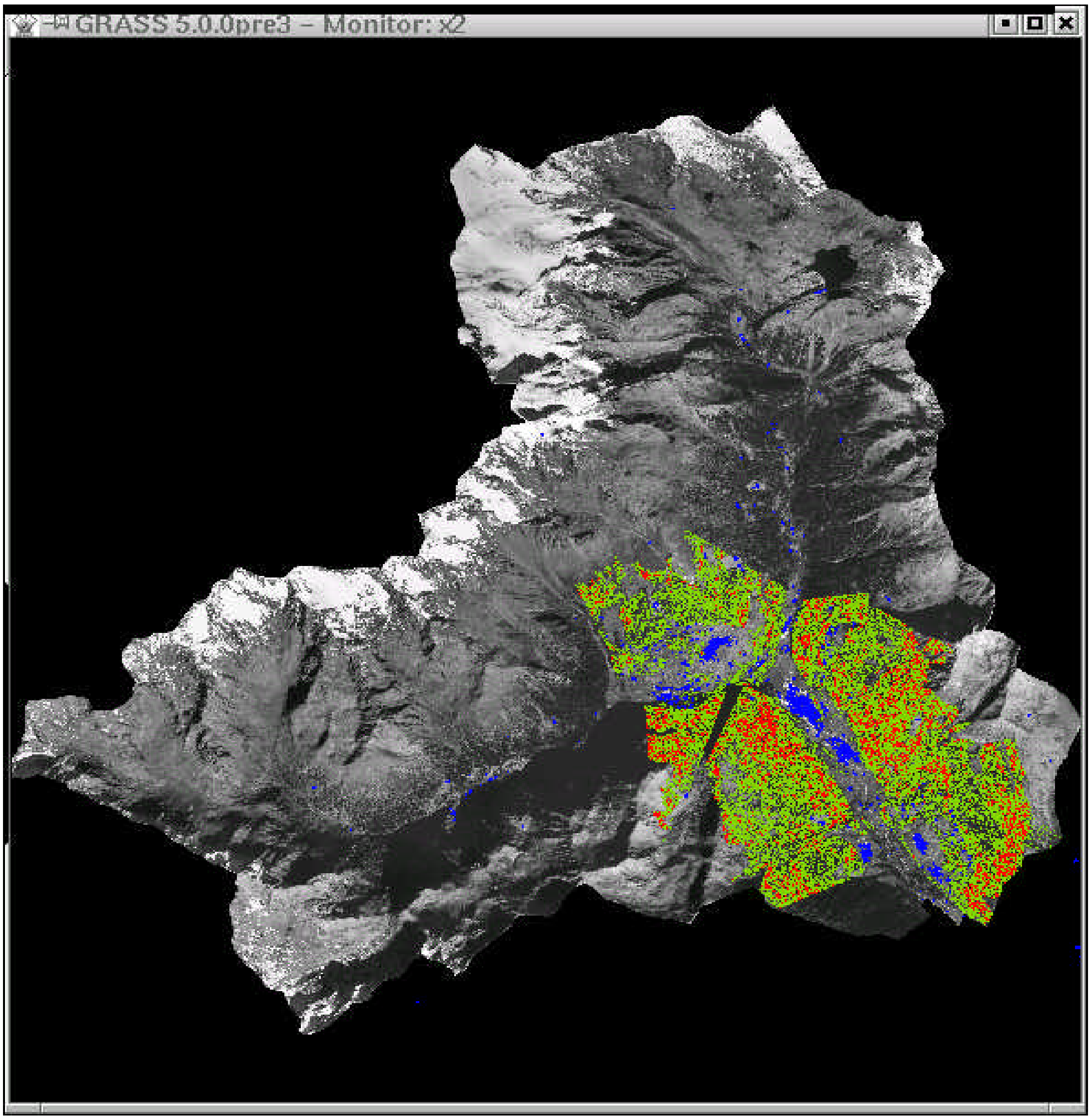

Figure 17 Map of "effective bpfp" that directly protect civil habitations and urban agglomerations (represented in green); "effective bpfp with avalanche starting protection function" are represented in red. Buildings are represented in blue: those that are not protected are refuges, cattlesheds or houses not inhabited all year long.

***PRELIMINARY GENERICAL BPFP* SURFACE (hectares)**	***EFFECTIVE BPFP* PROTECTING CLASS 1 SURFACE (hectares)**	***EFFECTIVE BPFP WITH AVALANCHE STARTING PROTECTION FUNCTION* PROTECTING CLASS 1 SURFACE (hectares)**
3301.34	1 727.14	351.49

Table 1 Comparison between surfaces of "preliminary generical bpfp", "effective bpfp" protecting class 1, and "effective bpfp with avalanche starting protection function" protecting class 1. These areas have been calculated using GRASS r.report command.

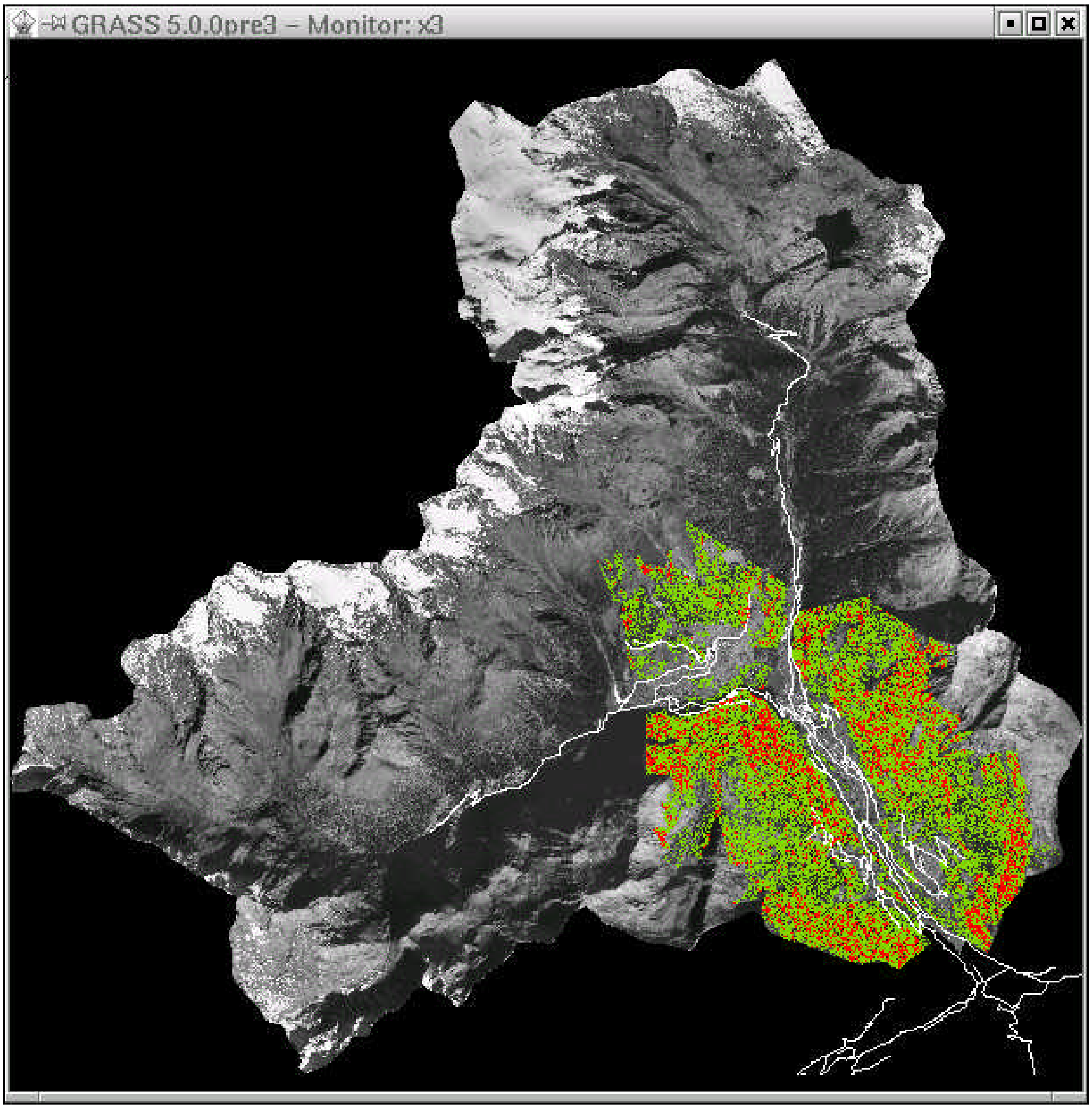

Figure 18 Map of "effective bpfp" that directly protect communication routes leading to civil habitations and urban agglomerations (represented in green); "effective bpfp with avalanche starting protection function" are represented in red. Main and secondary forestal routes are represented in white.

***PRELIMINARY GENERICAL BPFP* SURFACE (hectares)**	***EFFECTIVE BPFP* PROTECTING CLASS 2 SURFACE (hectares)**	***EFFECTIVE BPFP WITH AVALANCHE STARTING PROTECTION FUNCTION* PROTECTING CLASS 2 SURFACE (hectares)**
3301.34	1 888.92	399.35

Table 2 Comparison between surfaces of "preliminary generical bpfp", "effective bpfp" protecting class 2, and "effective bpfp with avalanche starting protection function" protecting class 2. These areas have been calculated using GRASS r.report command.

7.5 Finding priorities among *effective bpfp*

To increase the detail of *effective bpfp* maps, more work can be done, focusing on the attribution of priorities: woodlands can receive a higher attention (that means a higher priority of sylvicultural treatment) according to the geomorphological conditions of their location. A higher priority was therefore assigned to the *effective bpfp* located in sensitive areas or in areas presenting geological risks. Analysing Pejo Valley geomorphology, a new map was created, where *effective bpfp* are classified according to the geomorphological conditions of woodland location. This map is extremely interesting, because it can provide a useful information about features and properties of the land exposed to natural risks.

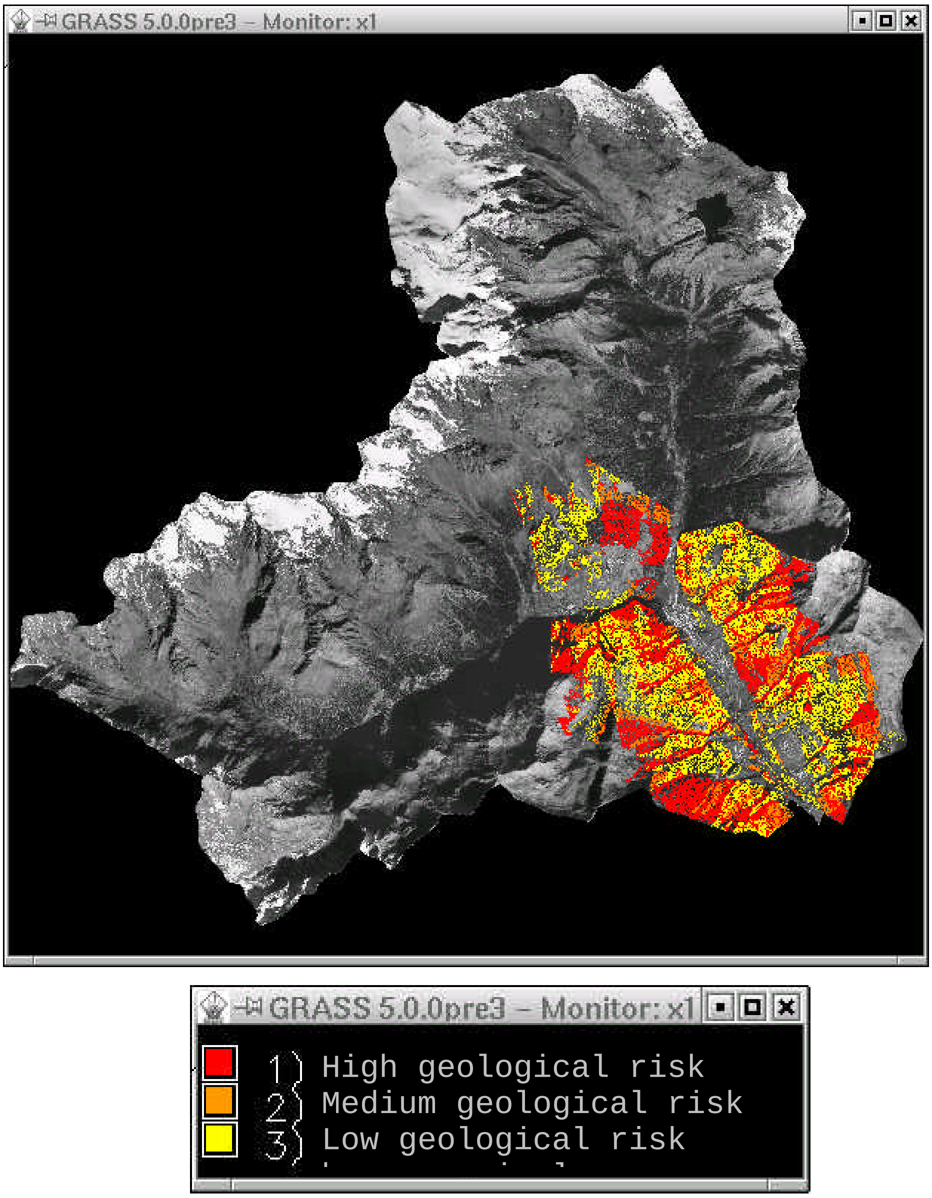

Figure 19 Map of "effective bpfp": in this map they are classified according to the geomorphological conditions (risk) of their location.

In the eventuality that the map of the geological risk is unavailable, in order to make this procedure applicable, a methodology to create an experimental geological risk map was developed, using thematic maps like the geological formations map, the geological instability map, the CLPV map, the photointerpretation of avalanches risk areas map and the probable starting areas of avalanches maps. By means of these thematic maps and considering the geological formation cropping up, its sliding tendency and the proximity of avalanches probable starting areas it is possible to identify the critic geological zones. A particular value was then assigned to all bpfp located in these areas, denoting an higher priority of attention of this bpfp.

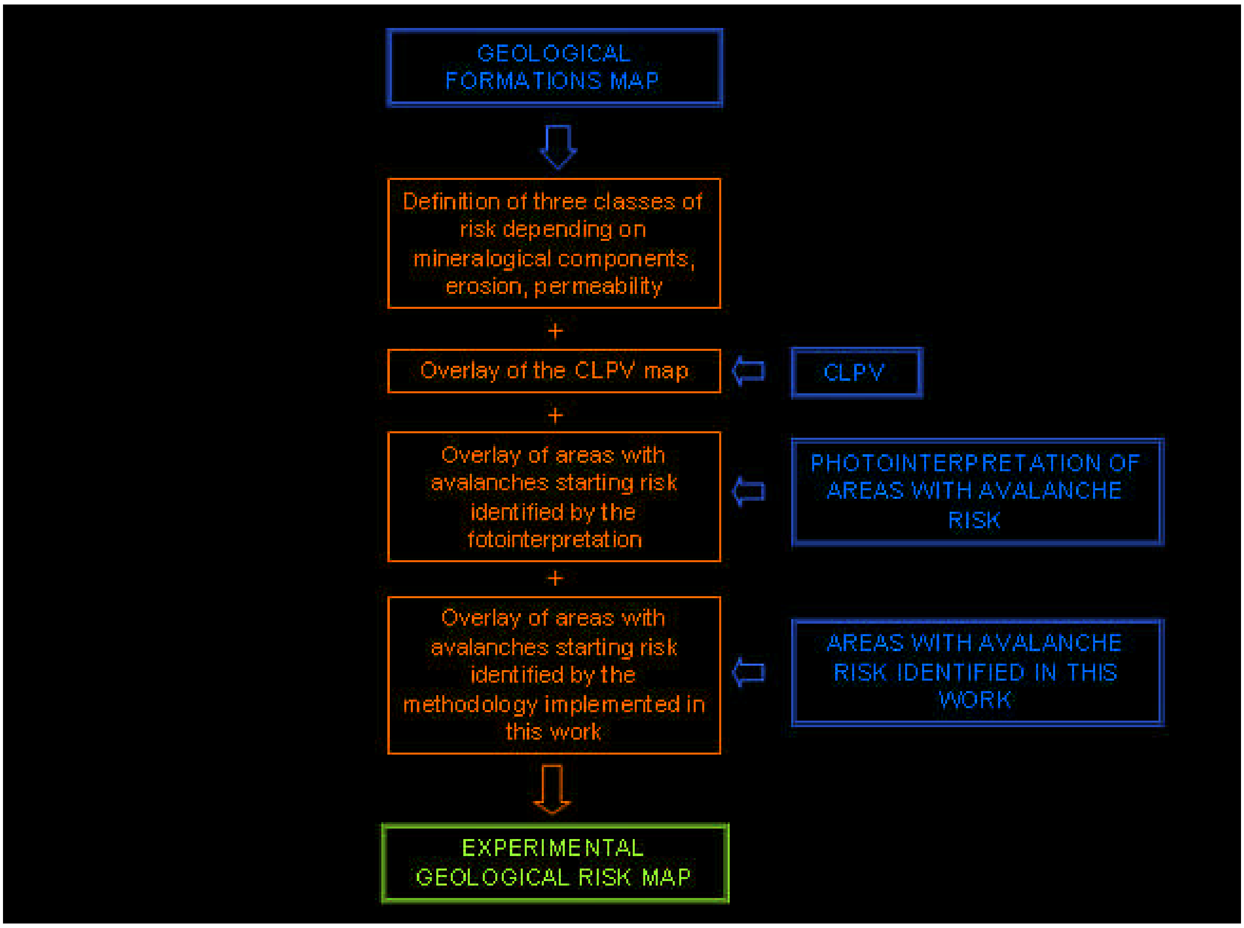

Figure 20 Scheme of the procedure to create a experimental geological risk map.

This methodology needed a calibration in order to obtain results more responding to reality. On-site inspections and the consultation of forestry technicians with a good knowledge of Pejo Valley territory also contributed to provide a huge quantity of information and to improve the methodology where necessary. The map generated with this methodology has then been compared to the real land condition through various surveys, and the results presented a high compatibility between reality and the maps created. This on-site verification showed that the implemented methodology identifies many probable avalanches starting areas that are not reported on the geological risk map; in these area the risk is kept at a potential level thanks to the presence of the vegetation. For this reason the geological risk map of the Geological Service was integrated with avalanches possible start areas found in this work.

8. Comparison between effective bpfp and protective woodland according to the forest management plans

At this point it's interesting to compare *effective bpfp* (the ones protecting class 1 and 2 objects) with protective woodland according to the forest management plans.

Woodland disposition in the two maps is very different: the protective woodland of the forest management plans are located just in zones with high altitude, while *effective bpfp* are mainly located at a medium altitude, over urban agglomerations or communication routes.

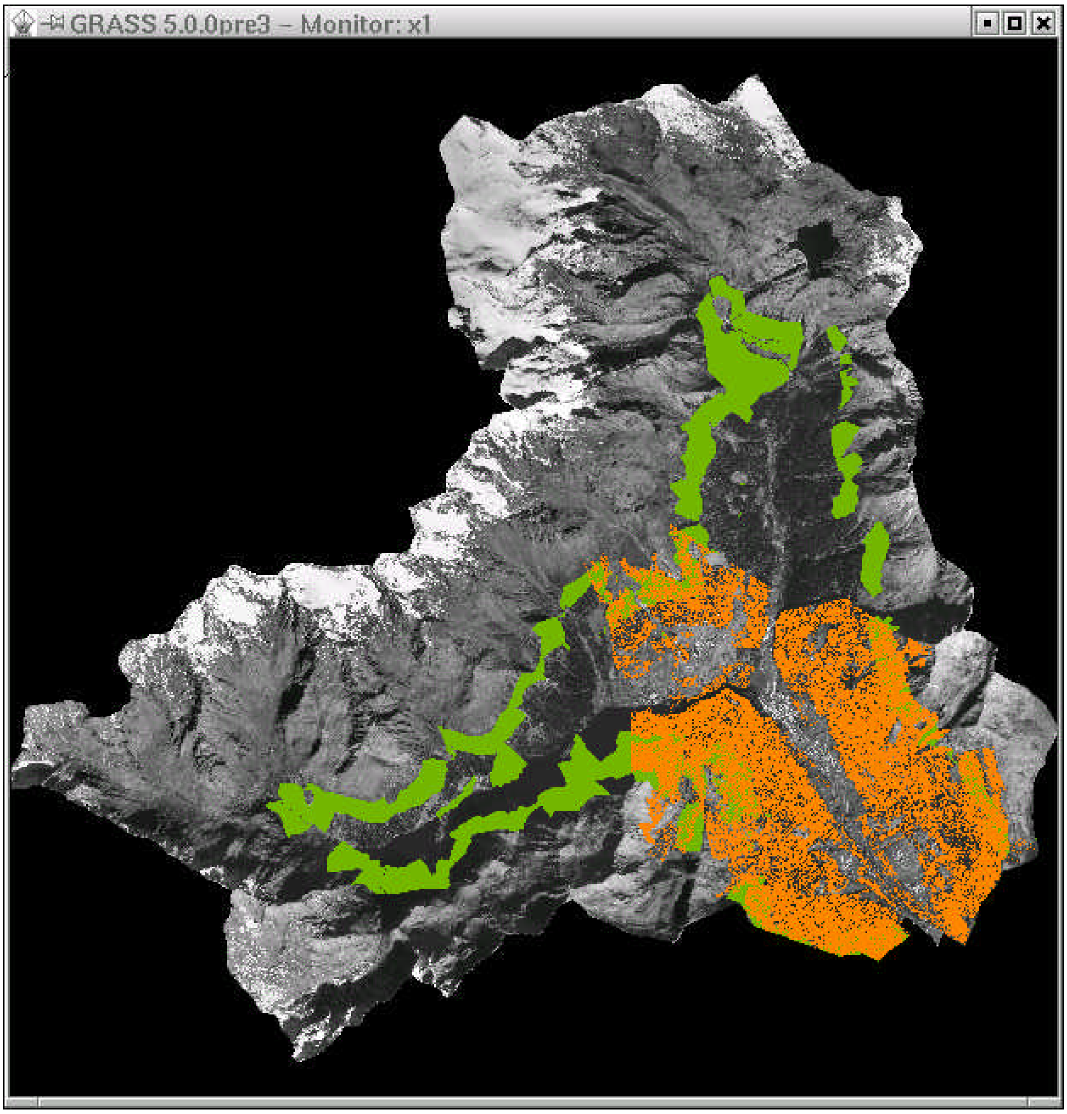

Figure 21 Comparison between "effective bpfp" (in orange) and protective woodland according to the forest management plans (in green).

Involved areas in the two cases are also quite different: 1888 hectares for the *effective bpfp* and 1678 hectares for the ones of forest management plans. This difference reflects the forest management plans philosophy in defining protection woodlands: only protection against generic hydrologic risk is considered, instead of a direct protection.

9. Results and conclusions

For the realization of this work, all concepts that define a bpfp had to be sketched, interacting with Swiss and Italian forestry experts both during the implementation and during the on-site validation of this new methodology: a verification had to be made in order to supply the lack of a specific normative and knowledge in Italy.

The implemented methodology allowed to quickly reach bpfp identification with standard procedures, portable to any other geographic area.

Many maps have been produced with the aim of discriminating bpfp on different criteria, giving a tool to make the sylvicultural planning easier.

The on-site verification showed how the implemented methodology can identify many avalanches possible start areas that are not reported on the geological risk map, but where the risk is kept at a potential level because of the presence of vegetation.

A comparison between *effective bpfp* (the ones protecting class 1 and 2 objects) and protective woodland according to the forest management plans emphasized the need of a review in the concept of protection in Italian forestry planning, regarding the role of forestry in risks prevention. The cartographic output of this new methodology can in this way be very useful, particularly for regional forestal plan redactions. Furthermore the maps produced can be a valid tool for territorial planning in mountain environment, for environmental impact studies or for the realization of environmental sensitivity maps.

The availability of a digital cartographic base for the identification of areas with priority of sylvicultural intervention and treatment allows the possibility to access to the incentives granted by the Rural Development Plan of the district of Trento, that has the specific purpose to give money contributions to all the interventions that can improve woodland protective capability from natural disasters. These incentives are part of the founds granted by the European Union, according to the regulation 1257 of 1999 (about Rural Development Plans) and the regulation of 2001.

Since this methodology is still under development, further studies must be carried out in order to test and setup the real applicability of the method to different areas.

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