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Development of harmonized indicators and estimation procedures for forests with protective functions against natural hazards in the alpine space

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Preface

The present study was developed in the context of Regulation (EC) 2152/2003 on the monitoring of forest and environmental interactions, the so-called "Forest Focus" Regulation.

The Forest Focus regulation centered specifically on the monitoring of the effects of atmospheric pollution and fires on European forests, previously addressed by Council Regulation (EEC) No 3528/86 of 17 November 1986 on the protection of the Community's forests against atmospheric pollution and Council Regulation (EEC) No 2158/92 of 23 July 1992 on protection of the Community's forests against fire. Furthermore, “Forest Focus” aimed at encouraging the exchange of information on the condition of and harmful influences on forests in the Community and enabling the evaluation of ongoing measures to promote conservation and protection of forests, with particular emphasis on actions taken to reduce impacts negatively affecting forests.

In order to promote a comprehensive understanding of the relationship between forests and the environment, the scheme also included the financing of studies and pilot projects aiming at the development of monitoring schemes for other important factors such as biodiversity, carbon sequestration, climate change, soils and the protective function of forests. The EC launched and financed a series of seven studies dealing with the following topics:

1. *Climate change impact and carbon sequestration in European forests*
2. *Development of a simple and efficient method field assessment of forest fire severity*
3. *Use of National Forest Inventories to downscale European forest diversity spatial information in five test areas, covering different geo-physical and geo-botanical conditions*
4. *Harmonizing National Forest Inventories in Europe*
5. *Development of harmonised Indicators and estimation procedures for forests with protective functions against natural hazards in the alpine space*
6. *Linking and harmonizing the forests spatial pattern analyses at European, National and Regional scales for a better characterization of the forests vulnerability and resilience*
7. *Evaluation of the set-up of the Level I and LevelI forest monitoring under Forest Focus.*

The specific objective of this study was to explore the possible contribution of the national forest inventories (NFIs) to assess forest protective functions, by identifying its key components based on the few on-going studies and processes (like INTERREG II, NAB, Alpine Convention, NaiS), by selecting useful indicators and surrogates, by harmonising definitions and estimation procedures based on existing NFI data, by proposing a strategy for monitoring and reporting some aspects of protective functions of mountain forests in the alpine space and by identifying features and usefulness of remote sensing techniques and field assessments for harmonised monitoring of protective functions.

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Executive summary

The importance of forests with protective functions has increased in the last decades due to settlement pressure and high vulnerability of society in Alpine regions. In this context, information on the spatial distribution of protective forests and monitoring its effect to prevent natural hazards becomes essential. However, indicators that describe their protective effect e.g. against avalanches and rockfall do not exist.

The project ProAlp aimed to develop science-based indicators and estimation procedures for forests with protective functions for the entire alpine region. Traditionally, national forest inventories (NFIs) deliver ground data on a national grid which serve the data and information needs on a regional basis. These needs are reflected by the plot density and the statistical design that correspond to the smallest possible information unit. However, concerning natural hazard processes, a statistical plot-based approach is not sufficient. Remote sensing techniques are an indispensable supplement of information and the applicability of remote sensing and geospatial interpolation techniques must be investigated.

In this study, new indicators were developed and applied in three regions using three different approaches: a statistical and two remote sensing approaches including coarse and fine scale (satellite imagery and Airborne Laserscanning (ALS) -data). Forest maps derived with remote sensing provided a basis for the investigations within this project. The harmonised indicators and their respective thresholds were first defined based on an intensive literature review and guidelines used in different Alpine countries. Then, hazardous processes and damage potential were modelled accordingly by geospatial models. The intersection of forest maps with the resulting damage and hazard potential maps indicated forested areas with protective function. Finally, the protective effect within these areas was determined using classic forest parameters like gaps, tree density, age or diameter depending on the scale.

The project ProAlp developed harmonized indicators and a methodology for estimation of forests with protective functions against natural hazards. This methodology included the mapping of hazard focusing on avalanche and rockfall and damage potentials for infrastructure like buildings, roads or railroads. Integration of NFI field data in remote sensing applications for up-scaling NFI point information proved to be a useful tool for the identification of protective effect on a large area. When using NFI data only (statistical approach) useful results are limited to small regions. For large areas the use of remote sensing data is preferable but also restricted. In this study only a coarse digital elevation model (DEM) was available for large areas which introduced uncertainty in the hazard modelling. Also, the upscaling of forest parameters with medium resolution data (Landsat data) resulted in lower accuracy. Higher accuracy was found for forest parameters and hazard maps derived from ALS data with the disadvantage of their high costs. Ideally, a full coverage of a high resolution digital elevation model and very high resolution data like ALS data would improve the application of the developed indicators and need to be tested in a future study.

Results and maps concerning the three system parts, hazard potential, damage potential and protective effect developed within ProAlp, must not be interpreted as concrete natural hazard indication mapping or risk zone planning. The intention of ProAlp was to develop indicators and procedures to derive the area of forest with protective function and to evaluate their protective effect in a scientific context. Delivered maps and figures are examples for the capability of the developed methods.

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Abbreviations and Acronyms

AHP	Avalanche Hazard Potential
ALPMON	Alpine monitoring system
ALS	Airborne Laser Scanning
APF	Forest with Protective Function against Avalanche
ArcGIS	Geographic Information Software from ESRI
BFW	Austrian Federal Research and Training Centre for Forests, Natural Hazards and Landscape BFW
BMLFUW	Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management
BOKU	University of Natural Ressources and Applied Life Sciences in Vienna
CCC	Coniferous crown cover
Cemagref	French Agricultural and environmental engineering research
CHM	Canopy height model
CMF	Convention on Mountain Forests
CORINE	Coordinated Information on the European Environment
COST	European Cooperation in the field of Scientific and Technical Research
DBH	Diameter at breast height
DEM	Digital Elevation Model
DIS-alp	Disaster Information System of ALPine Regions
DSM	Digital Surface Model
DTM	Digital Terrain Model
EEA	European Environment Agency
ECC	Evergreen crown cover
EFICS	European Forest Communication and Information System
ENFIN	European National Forest Inventory Network
FAHP	Forest Avalanche Hazard Potential
FOEN	Swiss Federal Office of Environment
GIS	Geographic Information System
Gozdis	Slovenian Forestry Institute
GSM	French silvicultural guideline for mountainous regions
IES	JRC Institute for Environment and Sustainability
IFN	French National Forest Inventory
INTERREG	Community initiative which aims to stimulate interregional cooperation in the European Union

ISDW	Initiative launched by Austrian BMLFUW concerning forest with protective effect
JRC	Joint Research Centre is a research based policy support organisation and an integral part of the European Commission
kNN	k Nearest Neighbour Method
LiDAR	Light Detection and Ranging
LFI	Swiss National Forest Inventory
LWF	Bavarian State Institute of Forestry LWF
MMS	Mean of maximum snow depth
NAB	Natural Potential of Alpine Regions
NaiS	Swiss guide for sustainability and success monitoring in forest with protective function
nDSM	Normalised DSM
NFI	National Forest Inventory
NMF	Network Mountain Forest
ONF	French National Forestry Office
ÖWI	Austrian National Forest Inventory
PER	French hazard zone map
PRH	Probable Residual Rockfall Hazard
pAPF	Forest with potential protective function against avalanche (similar to FAHP)
pRPF	Forest with potential protective function against rockfall
RockyFor.NET	Is a probabilistic tool that provides an estimate of the Probable Residual Rockfall Hazard (PRH) developed by Cemagref
RPF	Forest with protective function against rockfall
SilvaProtect-CH	Swiss protection forest project
SIR	A Salzburg institute for land use planning and habitation
TCC	Total crown cover
WEP	Forest development plan
WSL	Swiss Federal Institute for Forest Snow and Landscape Research WSL

1 Introduction – objectives and tasks

1.1 Background

The importance of forests with protective function has increased in the last decades due to settlement pressure and high vulnerability of society in Alpine regions. Therefore, the need of inventoring and monitoring protective functions of forests has increased subsequently. A harmonized approach to estimate and evaluate the protective effect of forest against natural hazards in the Alpine region has not been developed so far. A wide spectrum of local and regional attempts exists but no trans-national efforts on a detailed technical level have been sought.

1.1.1 Harmonization topic of National Forest Inventories in Europe

During the last few years NFIs readopted the challenge to work on harmonization on the European level. This work is based on the outcomes of the EFICS (European Forest Communication and Information System) Study of 1997. In 2002, an informal network between most of the European NFIs (European National Forest Inventory Network, ENFIN) has been established aiming to promote NFIs as comprehensive monitoring systems by collecting harmonized information about the forest ecosystem thus serving a broad spectrum of forest related policies. The first project launched within this network has been the COST Action E43: “Harmonization of National Forest Inventories, techniques for common reporting”. This COST Action aims at the harmonization of definitions and concepts of existing national forest resource inventories in Europe in order to produce comparable information. During its first year preliminary but comprehensive ideas of the harmonization process between NFIs from 26 countries were developed. This harmonization process forms one basis for this project, which is supported by COST E43. Although the issues of natural hazard science and risk assessment are not covered by the COST Action, the general harmonization procedures and alternatives are used within the Project ProAlp.

1.1.2 Overview on relevant projects and political documents

In many countries of the alpine space regional projects address the issue of indicators and estimation procedures for forest with protective functions against natural hazards (Examples: Natural Hazard Cartography in the Canton of Berne (CH), Safety Standards against Natural Hazards - Acquisition Methods of Spatial Data for detection of Natural Hazards (AT), Analysis of the Catastrophic Avalanche Winter 1999 (AT)). On the national basis projects like NaiS (Minimum maintenance measures for forests with a protective function) raise the issue of the use of large area monitoring systems for indicator development. NAB (Natural Potential for Alpine Regions) is a project of eight countries of the alpine space, which are developing a novel system for the prediction and preventive protection against floods, mudflow, slides and avalanches. Within the INTERREG (Community initiative which aims to stimulate interregional cooperation in the European Union) IIIC Project Network Mountain Forest (NMF) a more political based approach tries to advance the development of a network between the transnational regions in the Central Alps to lead to the development of a common transnational strategy in view of the mountain/forest with protective effect policy and related measures. The Alpine Convention concentrates on the protection and sustainable development of the Alps considering also their preservation and use. The Protocol on Mountain Forests is one of twelve protocols of the Alpine Convention. The Convention on Mountain Forests (CMF) aims to conserve mountain forests as close-to-nature ecosystem and to improve their stability. First studies on harmonized reporting within the Alpine region started with the second “Alpenreport” (a platform of combined expertise in a concentrated and variegated form) based on NFI data and the ALPMON project, which focused on the establishment of a landscape register. By means of the analysis of Landsat TM, SPOT and other high resolution sensors of alpine landscapes selected for their typical characteristics, ALPMON intends to develop a basic landscape register for an alpine monitoring system.

1.2 Objectives

The main objective of the ProAlp project is to explore the possible contribution of the National Forest Inventories (NFIs) and other forest monitoring systems to assess the protective functions of forests in the alpine space. The analysis carried out in this study should help to identify the protective functions of forests. In order to detect forests with protective functions, indicators and/or surrogates of these are selected. Furthermore, the study looks into the possibility of harmonizing definitions and methods to assess the protective functions of forests. It should help in establishing a strategy to monitor forest with protective effect and report on their protective functions. Finally, the study verifies the possibility of combining field data collection with remote sensing techniques as monitoring systems for the protective function of forests in order to reduce the high costs of field data collection.

1.3 General approach

This project aims to develop science-based indicators and estimation procedures for forests with protective functions for the entire alpine region. Traditionally, NFIs deliver spatially explicit ground data on a national grid which serve the data and information needs on a regional basis. These needs are reflected by the plot density and the statistical design that correspond to the smallest possible information unit. Thus, NFIs normally can deliver ground based data with relative high plot density in relation to other large area forest monitoring systems. However, for questions of natural hazard processes, a statistical plot-based approach is not sufficient. Therefore, remote sensing techniques are an indispensable supplement of information and the applicability of remote sensing and geospatial interpolation techniques must be investigated.

For the different tasks necessary for achieving the objectives, different spatial regions will be covered within three approaches:

1. Statistical approach: Harmonized indicators of the protective effect will be up-scaled from the NFI plot level to regional results.
2. Coarse mapping approach: Large area remote sensing harmonization techniques mainly for forest cover and forest type information relevant for the indicator development within the study areas (Landsat scenes) crossing national borders: Germany/Austria, Switzerland/Austria and Slovenia/Austria.
3. Fine mapping approach: Detailed in-depth study with high resolution remote sensing techniques including laser scanning and digital aerial photographs within smaller test sites in Switzerland and Austria.

To enhance classical inventory approaches concerning forests with protective function hazardous processes and damage potential have to be obviously incorporated in the evaluation method. Three system parts can be distinguished:

1. Hazard potential*: Avalanches and rockfall are the primary processes of interest within ProAlp. For the Alpine space harmonized methods to determine hazard potential areas are distinguished. Other dangerous processes like landslides, erosion and hydrological problems do not fall within the core issue of ProAlp. But these hydrological items of natural hazard problem area are taken into consideration.*

2. Damage potential*: Until now the integration of damage potential (various different types of endangered classes) has not been worked out systematically by forest monitoring services. Nevertheless, the key challenge of inventory systems concerning forests with protective function in mountainous areas will be the integration of damage potential to enable the forest to be part of the risk-based land use development control.*

3. Forest protective effect*: Classic indicators like gaps, density, age, tree diameter or regeneration have to be used to deduce mechanical stability parameters taking various processes into account.*

Table 2-1: *Overview of the different approaches and system parts including in-and output.*

Approach Subsystem	Statistical approach	Coarse scale RS mapping approach	Fine scale RS mapping approach	Hazard
Hazard potential	NFI, DTM	Forest mask (kNN), DTM	Forest mask (LiDAR), DTM	Avalanche
	Rock mask, DTM	Forest mask (kNN), Rock mask, DTM (1D)	Forest mask (LiDAR), Rock mask, DTM (2D)	Rockfall
Damage potential	DTM, Elements at risk	DTM, Elements at risk	DTM, Elements at risk	Avalanche
	DTM, Rock mask, Elements at risk	DTM, Rock mask, Elements at risk	DTM, Rock mask, Elements at risk	Rockfall
Forest protective effect	NFI data	NFI data + Parameter layer (Landsat)	Parameter layer (LiDAR + digital aerial photo)	Avalanche
	-	NFI data + Parameter layer (Landsat)	Parameter layer (LiDAR + digital aerial photo)	Rockfall
Output	Statistical estimates of protective effect	Maps of protective effect	Maps of protective effect	

The three approaches mainly differ in respect to the estimation of the protective effect. In case of the statistical approach the indicator values for the protective effect are derived out of NFI data solely. The coarse mapping approach applies the regionalisation of NFI plot information on to the whole area with the additional information from Landsat imagery. For the fine mapping approach indicators are derived from LiDAR and aerial photos. For estimation of damage and hazard potential the information used is independently of the approach. The fine mapping approach offers future perspectives for the case that fine scale information will be available for larger areas in a comparable form. The study areas for the fine mapping approach covers single valleys.

ProAlp has no focus on the development of new monetary evaluation methods. Experience from former studies will be a sufficient basis for the implementation. Results and maps concerning the three system parts hazard potential, damage potential and protective effect, which are developed within ProAlp cannot be interpreted as concrete natural hazard indication mapping or risk zone planning. The intention of ProAlp is a science based development of indicators and procedures to evaluate the protective effect of forests. Delivered maps and figures are only examples for the capability of the developed methods.

2 Forest with protective function: Review of the current situation

2.1 Terms and Definitions

One of the basics of harmonization of indicators and procedures is the use of the same terminology and definitions. Therefore, terms and definitions due to natural hazard risk and forest with protective function has been harmonized. As a result a glossary is attached to the report (Appendix I). Our common understanding of forest with protective effect is illustrated in figure 2-1.

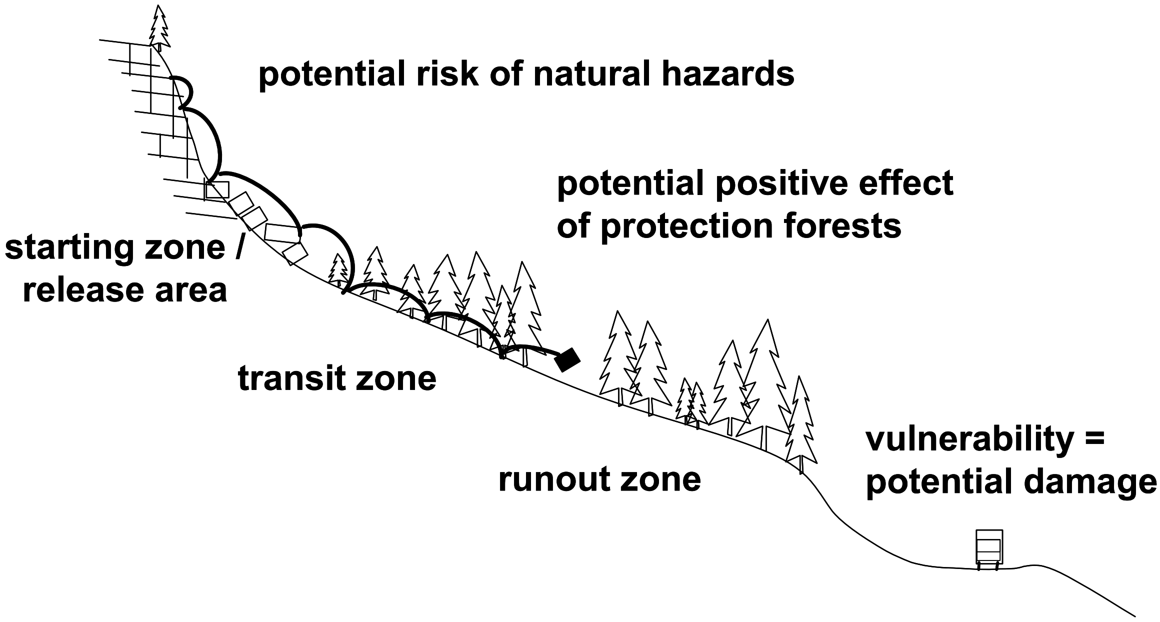

Figure 2-1: *Illustration of forest with protective effect, protecting infrastructure against natural hazards*

Forest with protective effect:

The MCPFE Report on Sustainable Forest Management in Europe (MCPFE 2007) defines forests with protective functions as forests, where “management is clearly directed to protect soil and its properties or water quality and quantity or other forest ecosystems, or to protect infrastructure and managed natural resources against natural hazards. Forests and other wooded land are explicitly designated to fulfil protective functions in management plans or other legally authorized equivalents. Any operation negatively affecting soil or water or the ability to protect other ecosystem functions, or the ability to protect infrastructure and managed natural resources against natural hazards is prevented.”

ProAlp focuses on forests protecting infrastructure and natural resources against natural hazards. Our common understanding of such forest with protective effect is illustrated in figure 2-1.The protection function implies that there is a potential risk of natural hazard, a potential damage, and an area in between which is covered by forest providing effective protection against the natural hazard at the site (Wehrli et al., 2007).

Forest with protective effect may be classified into forests offering direct and indirect protection (cf. Brang et al. 2006).

Forests with direct protective function *reduce or prevent the impact of natural hazards at places, where these processes would endanger settlements or important infrastructure without forests. Forest with protective effect therefore result from an overlay of natural hazard process area (hazard potential), endangered assets (damage potential) and forest area being able to reduce the impact of the natural hazard processes (protective effect).*

Forests with indirect protective function *also reduce or prevent the impact of natural hazards, not primarily at a local scale, but at a regional scale (water catchment area). The forest impact mainly depends on the proportion of forests (and on soil properties) at a landscape level, and the exact place of the forest is not that important. This makes it impossible to establish a relation between the protective effects of the forests and the damage potential.*

2.2 Synthesis of country reports

ProAlp members elaborated country reports in order to give an overview on legal framework, definitions, methods, data, its availability and ongoing processes and projects with respect to forest with protective effect of the countries of the alpine space.

2.2.1 Definition and mapping of forests with protective functions

National legal framework

In all countries of the alpine space, forests with protective effect are divided into forests with direct (Objektschutz) or indirect (Standortschutz) protection function (see Table II-1 in Appendix II).

Forests with direct protection function are forests which prevent natural hazards or reduce their impact. The main damage potentials are related to people, settlements and infrastructure. Austria and Slovenia additionally consider cultivated land as potentially endangered.

Forests with indirect protection are forests protecting the forest site or improving the capacity of hydrological retainment. Forests at high altitude or at timberline as well as forests susceptible to wind or water erosion (with successional karstification) and to landslides are considered to be important for the protection of forest sites.

Consequences of the designation as forest with protective effect

- In all countries of the alpine space, deforestation of forest with protective function is forbidden, and no permission of extraordinary deforestation (for example for nurseries) is given.
- In all countries, the forest owners are restricted in their forest management. Interventions which reduce the protective effects of forests can be forbidden by state forest service. The owners of forests with protective function have to tolerate measures which are necessary to maintain the protective functions.
- In Bavaria and Austria, forests with protective effect have to be officially registered.
- In all countries, subsidies can be given for adequate forest management in forests with protective effect. Subsidies are restricted to registered forests with protective effect in Germany and prioritised to forests with a direct protection function in Switzerland.

Natural hazards in relation to forest with protective function considered by forest law

In all countries, forest law considers gravitational natural hazards (where potential energy is important) and natural processes with negative impacts on forest site (Table II-2 in Appendix II).

- Gravitational natural hazards with direct impact on assets like avalanches, rockfall and landslides are mentioned in all countries by forest law.
- Natural processes with indirect impacts like flood, water and wind erosion are mentioned in most of the countries of the alpine space. Less legal consideration is attended to indirect impacts in France and Switzerland.

2.2.1.1.1 Mapping/modelling of forests with protective functions

There are different ways how forests with direct protective functions are mapped or modelled (see Table II-1 in Appendix II):

One widespread instrument of forest with protective effect mapping is the forest development plan (WEP), an instrument of forest use planning at a regional scale (Austria, Switzerland). The adequate scale is 1:10 000 to 1:25 000.

Natural hazard indication maps (Gefahrenhinweiskarte) give a regional/national overview over the potential of natural hazards. They are mostly established with expert knowledge, but increasingly supported by terrain models and GIS. The adequate scale is 1:10 000 to 1:25 000.

Risk zone planning (Gefahrenzonenplanung) is the planning instrument at the local level. It requires expert knowledge, an adequate scale of 1:5 000 to 1:10 000 and the use of models.

Delineation of forests with protective effect is mostly done by experts, increasingly based on models.

Forests with indirect protective functions depend only on the presence of a certain proportion of forest at the landscape level. A mapping or spatially explicit modelling is therefore not possible.

Assessment of the forests with protective effect by NFIs

In most countries, the forests with protective effect defined by NFI do not correspond to the forests with protective function resulting from the function planning process. In some countries (e.g. Austria), the definition of forest with protective function used in NFI does not correspond in some parts to the legal definition. NFIs are basically interested in classifying the plots into a category of official forest with protective function planning.

2.2.2 Natural hazards

2.2.2.1 Basic input data for characterizing the natural hazard potentials

i. Digital terrain models (DTM)

In general, digital terrain models exist for an entire country with the resolution ranging from 12.5 x 12.5 m to 50 x 50 m (see Table II-4 in Appendix II. The vertical accuracy of the DTM of Slovenia and Switzerland is ± 2 to 3 m and about 20 m in forested areas of Austria. The DTM SRTM (Version2) available for whole Europe has a resolution of 100 x 100 m with a horizontal accuracy of 16 m which is not detailed enough for the modelling of the hazard potential, because the slope cannot be derived in a sufficiently precise manner. Experiences from SilvaProtect-CH show that a resolution of 25 x 25 m or even 10 x 10 m is necessary for an adequate modelling of gravitational natural hazard processes (rockfall, avalanche).

ii. Landscape models (land cover/land use maps)

Landscape models correspond to the information of the official topographical maps 1:25 000, transformed into vector format. The available thematic layers differ from country to country (see Table II-5 in Appendix II).

In **Austria** for example, two layers (traffic and water bodies) exist countrywide. Additional digital landscape information is only available at a regional level. Data availability and quality differs considerably between the Austrian provinces (Bundesländer).

In **France**, landscape models are available from the data set of the Institut Géographique National (IGN). These data sets give information in vector format for classes of land use (forest, agricultural land) and for classes of road and traffic network, settlements and administrative limits.

In **Bavaria**, the landscape model ATKIS has six object category groups: settlements, traffic, vegetation, water bodies, relief and regions, subdivided in 110 object type and 350 attributes.

In **Slovenia**, the digital topographical map 1:25 000 is divided into:

Vector format: *traffic infrastructure (roads and railways), water bodies and relief;*

Raster format: settlements, relief, water bodies and land cover (forest and other).

In **Switzerland**, the landscape model VECTOR25 has 9 thematic layers: road & railway network, other traffic network, water bodies, primary land use, buildings, hedgerows and single trees, constructions and single objects. The thematic layers contain a total of 155 different object types.

All countries have digital data concerning the road and railway network, the buildings and settlements, the water bodies and the land use or land cover. But the object types may differ between the countries. Furthermore, there is no homogeneous digital database in Austria. Solving the harmonizing problem of creating and installing a common map on potentially endangered objects in the alpine space will be a challenge for further projects.

iii. Geological maps

Geological maps with a sufficiently high resolution (1:10 000 to 1:25 000) normally do not exist for the whole country. The resolution of 1:100 000 or 1:200 000, which is available for most countries, is not accurate for the modelling of natural hazard processes. Furthermore, in some countries distinction of geological units does not go far enough into detail.

iv. Soil maps

Soil maps with a high resolution (1:10 000 to 1:25 000) normally do not exist for the whole countries. Resolution of 1:100 000 or 1:200 000, which are available for the whole countries, are not accurate enough for the modelling of natural hazard processes. In some countries (e.g. Austria), detailed soil maps exist for intensively managed agricultural land area.

v. Climatological data

All countries have calculated spatially explicit models of the most common meteorological data, based on a net of well distributed climate gauging stations. The resolution of 1:800 000 (Switzerland) to 1:1 000 000 (Austria, Bavaria) may be too large for the modelling of hydrological hazards.

vi. Vegetation maps

The resolution of the (digitised) potential natural vegetation maps varies from 1:25 000 to 1:500 000. They are probably all based on assessments with the method Braun-Blanquet, but comparison between the countries will anyway be difficult.

The European forest types (EEA Technical report, No 9/2006) may be an alternative to the maps of potential natural vegetation of the countries, but are not very detailed. The alpine space mainly contains three forest types: beech forests, mountain beech forests and alpine coniferous forests.

vii. Forest maps (land cover/land use)

National forest maps show the current extent of the forest area. They result from topographical maps, from land cover/land use monitoring or from a special monitoring of forest area. The different sources often do not use comparable definitions of forest/shrub forest. Furthermore, there are differences between the countries concerning forest types and their definitions.

2.2.2.2 Models and indicators for calculating natural hazard potential

i. Avalanches (Lawinen; avalanches)

Starting zone (release area)*:*

Slope from 25°/28° to 55°/60°, regionally different minimal altitude from about 1 000 m a.s.l, area of at least 500 to 5 000 m², minimal length of 50 m (see Table II-6 in Appendix II). Other indicators of avalanche occurrence are maximum height of snow cover, relief classes, aspect, surface roughness, vegetation and durability of snow cover.

Run out area*:*

Different models are used, mostly 1-D (length) or 2-D (length, width)-models. The indicators used to calculate runoff-distances are slope, snow density, snow depth or snow volume and some friction coefficients.

ii. Rockfall (Steinschlag; chute de pierres)

***Starting zone**:*

Slope more than 34° in France and 41° in Switzerland respectively, rock cliffs from landscape model (see Table II-6 in Appendix II). Other indicators of rockfall occurrence: geology, presence of rocks.

***Run out area**:*

Different models are used, mostly RockyFor (Berger & Dorren 2007, Stoffel et al. 2006) and Zinggeler+GEOTEST.
The indicators used to calculate runoff-distances are the slope, relief, ground damping, block diameter and stand structure, and especially the number of trees for each diameter class.

Debris flow (Murgang, lave torrentielle)

In Austria, several models with different input parameters are in use. In Switzerland, the model MGSIM (ARGE GEOTEST, geo7, OEKO-B AG) was used for SilvaProtect-CH, which consists of 4 modules: 1) analysis of relief (catchment area, slope, aspect and flow path), 2) analysis of potential bed load, 3) identification of starting zones and 4) determination of run out areas.

The input data to model debris flows were in case of the SilvaProtect-CH land cover data (rocks, glacier, lakes, swamps/mires, forest) from VECTOR25, channel net, catchment area, slope, aspect, flow paths, all derived from DTM25/10, cohesion and friction angle derived from the Geotechnical map of Switzerland (GTK200), and the permeability from GTK200.

The process area **(transit and run out area)** of debris flows, in case of the SilvaProtect-CH, was calculated with the model dfwalk (Gamma 2000) based on the analytical Voellmy-method (Voellmy 1955, Bartelt et al. 1999). The model dfwalk is based on two parameters of cohesion, which must be derived empirically. It calculates the velocity of the debris flow along the flow path.

iii. Shallow landslide/erosion (oberflächennaher Rutsch/Erosion)

The Austrian ISDW-checklist considers geo-morphological indicators, mass movement classes and intensity of mass movement as being the most important indicators to define starting zones. Slovenia and Switzerland consider geology, slope and maximum 24-hour-precipitation as most important initiating factors (see Table II-6 in Appendix II).

The Swiss model SliDisp (Liener 2000) calculates the stability of slope (i.e. the starting zone of shallow landslides) with an “Infinite-Slope-Analysis” for every grid cell. The model SlideSim used to generate models of process areas (transit and run out areas), is similar to the analytical Voellmy-method.

The input data for the modelling of shallow landslide in case of SliDisp and SlideSim were slope, topoindex, both derived from DTM25/10), land cover data (rocks, glacier, lakes, swamps/mires, forest) derived from VECTOR25, cohesion and friction angle (Reibungswinkel), permeability and height of tephra derived from the bedrock of GTK200, and extreme rainfall during 24 hours, for a 100 years event (derived from meteorological data).

iv. Hydrologically important forest area (flood)

The most important indicators influencing the risk of flood, apart from the intensity of precipitations, are land use, soil type, soil state and vegetation type of the catchments. In Switzerland, the evaluation of protective effect of forests is published in Frehner et al (2006). The main idea of this concept is that different vegetation type offer different possibilities of interference. The water runoff can be influenced by maintaining the natural tree species composition of forests. The contractors of SilvaProtect-CH therefore tried to model the potential natural vegetation by means of GIS, comparable to Brzeziecki et al. (1993).

The input data herefore for the modelling of hydrologically important forest area were the slope and aspect derived from DTM25/10, land cover data (rocks, forest) derived from VECTOR25, the geotechnical map of Switzerland GTK200, the map of agricultural potential (Bodeneignungskarte) and the map of climatological aptitude (Klimaeignungskarte) from Swiss Federal Office of Statistics (BFS), and the hydrological atlas of Switzerland HADES (for the intensity of rainfall).

2.2.3 Damage potential

The damage potential is often subdivided into the following object classes (see Table II-7 in Appendix II):

- Residential area with settlements of different dimension
- Industry and commerce
- Public roads
- Railways
- Infrastructure of water and power supply
- Tourism and leisure
- Patrimony
- Agricultural areas and forest.

There are some differences between the countries, but the aim is everywhere the same: to protect people, assets and important infrastructure from the impact of natural hazards.

France has established a detailed system with a gradation within the same object class. In Bavaria, detailed damage potential classes have not been distinguished.

The landscape models of the five participating countries contain different thematic layers and object types. Digital layers with vector data for the traffic network (roads and railways) as well as for the buildings and settlements exist for all countries of the alpine space. Layers with other constructions are not common.

2.2.4 Protective effects of forests and indicators

Protective effects of forests

There are only small differences between the countries concerning the estimation of the effects of forests with protective function as listed at Table II-8 in Appendix II. Differences exist concerning the positive forest effect on rockfall in the starting zone (France and Austria) and on shallow landslides (Austria). In France, experts distinguish between single blocks of less than 1m^3, blocks between 1 to 5 m^3 and blocks with more than 5 m^3. A positive forest effect in the starting zone is only contributed in the case of rockfall with blocks smaller than 1 m^3. Austrian experts attribute a big influence of forests to reduce superficial landslides and erosion in the starting zone.

Methods to quantify the current protective effects of forests

Are there approved methods or models to quantify the current protective effects of forests?

a) based on deterministic or stochastic models

b) based on expert systems (silvicultural guidelines).

There are a restricted number of models based on processes (deterministic) or statistics (stochastic). The rockfall model RockyFor (Stoffel et al. 2005) can be considered as a deterministic model; the threshold values of the Swiss avalanche protective effect are based on a statistical model of avalanche occurrence in forested area. Most evaluation methods (ISDW, GSM - Guide des Sylviculture de Montagne (Gaugelin & Courbaud 2006), NaiS) are silvicultural guidelines based on experience that means expert systems.

Indicators of current and long-term protective effect

The indicators of the current protective effects of forests at a regional or national level are summarized in Table II-9. The most important indicators are gap size (length, width and size), crown cover, stand dimension (dominant diameter, dominant height), density (stem number, basal area) and tree species composition.

In Austria, France and Switzerland, aspects of mixture, structure, mechanical stability, damage and regeneration stability properties are taken into account in a fairly detailed way for the evaluation of the long-term protective effects (see Table II-10 in Appendix II). Bavaria and Slovenia have no silvicultural guidelines and therefore indicated only general information concerning the stability properties considered for the evaluation of the protective effect.

Austria has only fixed threshold values for stand mixture and proportion of young growth. In France and Switzerland threshold values have been set for most of the proposed indicators.

In Austria (ISDW) and Switzerland (NaiS), local evaluation of forest with protective function stability is made by using the existing silvicultural guidelines. At a national level, the 2nd Swiss NFI distinguished middle-term (stand structure, mechanical stability) and long-term (regeneration, mixture) aspects of ecosystem stability, using threshold values defined by NaiS.

ProAlp project partners decided to only deal with the current protective effect.

2.2.5 National monitoring and reporting systems in forests with protective function

National or regional monitoring systems

Most countries have no specific national or regional monitoring system (see Table II-11 in Appendix II). Austria (ISDW) and Switzerland (NaiS) have both silvicultural guidelines and try to evaluate the current state of forests with protective function with data of the National Forest Inventory.

Nearly all NFIs combine data from aerial photographs with data from field surveys. The grid space lies between 500 x 500 m (aerial photographs in Switzerland) and 8 x 8 km (field data in some “departments français”). This is sufficient for calculating protective effects of forests at a regional scale.

Reporting systems on forests with protective function

Austria and Switzerland integrated a chapter on forests with protective function in their NFI reports.

Austrian NFI report on forest with protective function presents per default area/proportion of forest with protective function, areas/ratio of stages of development, forest with protective function with regeneration, area of impairments/ damage of stands and existing stand regeneration, area/proportion of soil movements and stability of stands with forest with protective function .

The report of the second **Swiss NFI** clearly distinguishes between the current structure of forests and the subsequent protective effect on the one hand, and the indicators like mechanical stability, forest regeneration and naturalness of the mixture, influencing the middle- and long-term structure, on the other hand.

2.2.6 Questions and unsolved issues

Shortcomings within the existing framework at national scale

Austria:

In the Austrian framework of forest development planning and forest monitoring there is a lack of information concerning the following issues:

- Natural hazard potentials of forest covered areas subdivided by hazard types.
- Hazard potentials of external assets endangered from forest covered area.
- Quantity/quality of protective effects of forest.

France:

The most important lack of information within the French framework is:

- Mapping of run out zones, integrating the effect of forest, for all risks, except for rockfall.
- Zoning of forest with protective function at a national scale (this is due to the lack of harmonized and exhaustive forest data bases and the lack of an accurate digital elevation model (DEM) for the entire French territory).

Bavaria:

Forest with protective function in Bavaria is defined by law. The NFI does not collect all data which is needed to register the whole forest with protective function (see chapter 2.2.1.4). That means that the NFI underestimates the size of the area of forest with protective function in the Bavarian Alps. Apart from this, data exist for the age of forest with protective function, the composition of tree species, the regeneration and the ownership of the forest with protective function the structure, the growing stock and stem damages.

Slovenia:

Slovenia conducts a very intensive forest management system. Therefore most issues addressing the forests with protective function are being resolved within the frame of regular management-planning.

While the criteria and indicators of the production function (area, growing stock, increment) and the models for the control of its long-term stability (for example normal forest model) are sufficiently developed, criteria, indicators and models for the control of the other forest functions are still unknown and underdeveloped. Consequently, the judgments on sustainability of forest functions are often provided by speculation and are not based on facts.

Switzerland:

Swiss NFI does not acquire indications about the length and width of gaps. This information is important for the evaluation of the current protective effect of forests. Furthermore, there are no sufficient data concerning the tree species composition of regeneration.

Current research projects to close the gaps

Austria:

In the framework of ISDW Programme, NAB and DIS-alp project there are some efforts to improve and harmonize assessment and data situation (data integration) of natural hazard and issues of forest with protective function. Due to assessment of natural hazards and protective effects of forests methodical questions still exist. Apart from scientific work at BFW to improve estimation of runoff characteristics of vegetation types and snow gliding at the present no AHPctise oriented research regarding to these questions is recognizable.

France:

To close the gaps, Cemagref has initiated several research projects:

- Understanding of the interaction between forests and shallow landslides. The main objective is to develop a virtual experimental platform on the use of models integrating the effect of forest vegetation on soil fixation and on the hydrological cycle.
- Integration of trees in 2-D snow avalanche simulation models.
- Integration of trees in 3-D rockfall simulation modelling and on the coupling of forest stand growth models with rockfall trajectory models.
- The use of laser scanning for forest inventories, forest structure assessment and DTM construction.

Bavaria:

A project was started in July 2007 to test the possibility to map forests with protective function using GIS, a DTM and aerial photographs.

Slovenia:

The Slovenian Forestry Institute currently conducts two projects that could be interesting for the project ProAlp. One is ‘Water and Forest’, which, among other issues, tackles with forest structures (tree composition, developmental phase, vertical structure, soils) and their effects on hydrology. The other project directly addresses the forests with protective function as its aim is to compare the structures of differently managed stands (protective, normally managed, virgin forest) and to define indicators to be assessed in each of them.

Switzerland:

There is a research project at WSL to automatically identify and quantify gaps in closed forests. Furthermore, there is a research project to compare the evaluation of effects and stability of forests with protective function based on information of Swiss NFI with the evaluation done by experts.

2.3 Methods for characterizing forest with protective function

One main objective of the ProAlp is to elaborate practical indicators of natural hazard potentials and protective effects of forests in the alpine space. They will provide a basis for appropriate, cost efficient and valid monitoring of forests and their environmental interactions. In addition, knowledge of forest conditions and their protective effects can be enhanced.

The reporting of National Forests Inventories of alpine countries on protective effects of forests against natural hazards will be systematically improved by the use of uniform indicators and comparable quantification and weighting of relevant influence parameters determining natural hazard magnitude and frequency. He following chapters will include:

- Preparation and description of indicator selection:
- Current knowledge about factors influencing natural hazards and protective effects of forests.
- Validity and reliability of possible indicators and models.
- Data availability of all participating countries based on the synthesis of country reports.
- Documentation of the decision-making process – selection and argumentation of indicators.

2.3.1 Indicators and parameters

Indicators are

"... characteristics or data, with their help one is able to detect and analyse not immediately ascertainable aspects of spatial structure and of processes affecting landscape on indirect way (Leser et al. 1997 a)".

An indicator is a tool for describing and monitoring of conditions and processes of complex systems. Dependent on the complexity of the system only one or more indicators are necessary to sufficiently describe the system states. For this aggregation process various methods are available such as the multi-criterion decision making, physical or statistical models (depending on the available data and the level of measurement).

Indicators are also called parameters (in particular with physical models) or basic indicators (in multi-criterion decision making). A parameter is a control quantity with predictive quality for the system status or process sequences. With respect to the selection of natural space parameters to characterize forests with protective function, Pitterle & Perzl (1999) defined three main types of parameters:

- *Variable parameters: The magnitude of value changes with geographical position and/or temporally. Temporally variable parameters within constant space (e.g. meteorological parameters like precipitation) have a big impact in natural dynamic systems and models. But data collection often is difficult, because processes run either extreme slow or very fast. In a long-term context some temporary variable parameters can be seen as constant.*
- *Pseudo-constant parameters: These are temporary variable parameters, which are treated as constants for a defined period. Either the magnitude is taken for a defined point of time, or averages or extreme values of the size from a defined period are used.*

Constant parameters: only chemical and physical natural constants are actually constant parameters.

An important problem of choosing valid indicators in order to describe a complex system is the mutual influence of the system components. Therefore, characterisation is not possible with a unique indicator, since not all system components are usually known. Especially for protective effects of forests (e.g. tree stability or some soil and rock conditions) no indicators and methods for observation and quantitative data collection exist (Hartmann 1992). It is a key challenge to select those indicators, which have a key position in the system, whether they allow information about complete reaction chains or derivates from integration of a sequence of components (Hartmann 1992).

For the selection the following criteria must be considered (Stöder 1994, cited from Leser 1997b, pp. 112-113):

- Parameters shall be dependent on measured values directly.
- Parameters shall integrate sub-processes, which run coupled in nature too.
- Parameter values increase, with shorter operational steps of determination.
- Parameters shall be in relationship to regional characteristics.

The simplification of parameters in models is associated with the intended use and is subjected to the author's decision. They are also geared to the technical, material and infrastructural opportunities (possibilities) and limitations, which are set to the worker, resulting in simplifications (Leser 1997b).

Essential criteria for indicator selection are validity – the key component of the matter in substance – and the reliability and availability of data.

2.3.2 Basic principles for detection and estimation of protective functions

- ° The selection of indicators is crucial for the following natural hazard and forest items. Definition of natural hazard processes with regard to possible protective effects of forests.
- ° Selection of available and applicable methods of modelling starting zones. Determination of chronological probabilities of appearance of extreme precipitation (heavy snowfall, rain) relevant to processes.
- ° Classification of the hazard and damage potential and the protective effects of forest according to their size.
- ° Definition of reliable threshold values of natural dangers and protection fulfilment of forest stocks (yes/no).
- ° Determination of methods to model the run out zones of gravitational processes.

2.3.3 Transnational harmonized definition of hazard processes regarding possible protective effects of forests

In different alpine regions diverse natural hazards types are important. Due to various environmental conditions in the regions/countries the same natural hazard can be of variable importance, e.g. wind erosion can be considered as a problem in the eastern parts of Austria and in some parts of Slovenia but is of less importance in the inner alpine regions (see Table II-2 in Appendix II). In addition, the protective effects of forests in relation to hazard types and process zones are addressed in different ways by the countries (see Table II-8 in Appendix II).

Differences which became obvious in the country reports can be explained as follows:

- The different definitions of the natural hazard processes are due to varying interpretation of effect chains by the country experts. For example in Austria (NFI) erosion means interrill erosion. Under dense forest cover interrill erosion is not possible. Therefore, the protective effect of forest is seen as high (see Table II-8 in Appendix II). If erosion is defined as rill and gully erosion, protective effects of forest are low.
- The differences are also caused by various views of the relevance of natural hazard processes from different size. This is in conjunction with natural hazard classification.
- The differences result from various viewpoints how to delineate the process zones. Especially starting and transit zones are not sharply dividable for each type of natural hazard and local situation.

However, the reduction of the natural hazard processes listed in Table II-2 and II-8 (Appendix II) to initial key processes levels out differences.

Protective effects depend on the magnitude of processes – classification of hazard potential leads possibly to comparative adjustment of differences.

It is useful to limit all natural hazard types existing in the alpine space to few important and dangerous types (key processes):

Criteria for the selection of natural hazards with respect to the mitigation potential of forest (see Perzl 2005, Table 2-1 and 2-2):

- Main natural hazards in the alpine space (potential damage effect).
- Possible contributions of forests to reduce natural dangers (hazard events).
- Know-how about the processes – separability of hazard zones, hazard process and effect chains with respect to forest effects.
- Available data and methods (reliability of models, data).

Table 2-1: *Mitigation potential of forest for avalanche, rockfall and landslide*

Natural hazard type	Subtype	Potential protective effect of forest					
		Transit and run out zone			Starting zone		
		Potential damage effect	Determination of Protective effect	Protective effect	Determination of hazard potential	Determination of Protective effect	Protective effect
Avalanche		high	(-)	low	(+)	(+)	high
Rockfall		high	(+)	medium	(+)	(-)	low
Landslides, erosion	Spontaneous (shallow) slides	high	(-)	medium	(n)	(+)	high
	Permanent slides	high	(-)	low	(n)	(-)	low
	Channel bank failure and rill erosion	high	(-)	low	(n)	(+)	high

(+) ... determination is relevant and possible by NFIs
(-) ... determination is not relevant
(n) ... determination is relevant but not possible by NFIs yet (availability/reliability of data/methods)

(+) ... determination is relevant and possible by NFIs
(-) ... determination is not relevant or possible by NFIS (availability/reliability of data/methods)
(n) ... determination is relevant but not possible by NFIs yet (availability/reliability of data/methods)

Table 2-2: *Mitigation potential of forest for water runoff and soil degradation*

Processes with no differentiation in starting, transit and run out zones					
Type	Affected hazard types	Potential damage effect	Determination of hazard potential	Determination of Protective effect	Protective effect
Surface runoff	Flood, torrent debris flow, landslides, erosion	high	(n)	(n)	high
Soil degradation	Flood, torrent debris flow, landslides, erosion	medium	(n)	(n)	high

(n) ... determination is relevant but not possible by NFIs yet (availability/reliability of data/methods)

Due to Table 2-1 ProAlp concentrates on avalanche and rockfall because of their high potential damage effects and the protection potential of forests. Additionally it is possible to model the transit and run out zones for these hazards.

Also landslides belong to the group of natural hazards with complex causes and process effect chains (Figure 2-2).

The main types of landslides according to Swiss hazard zone planning (Perzl 2007a, according to Egli 2003, Keusen et al. 2003, BMLFUW/BFW 2006) are:

- Spontaneous mass movements *(debris slides/flows – rapid failure and fast movement mainly caused by heavy rain).*
- Permanent mass movements *(deep sited mass-creeps, infrequent/slow movements often superposed from spontaneous slides).*
- Channel bank failures *along the banks of stream channels, responsible for debris accumulation and debris flow.*

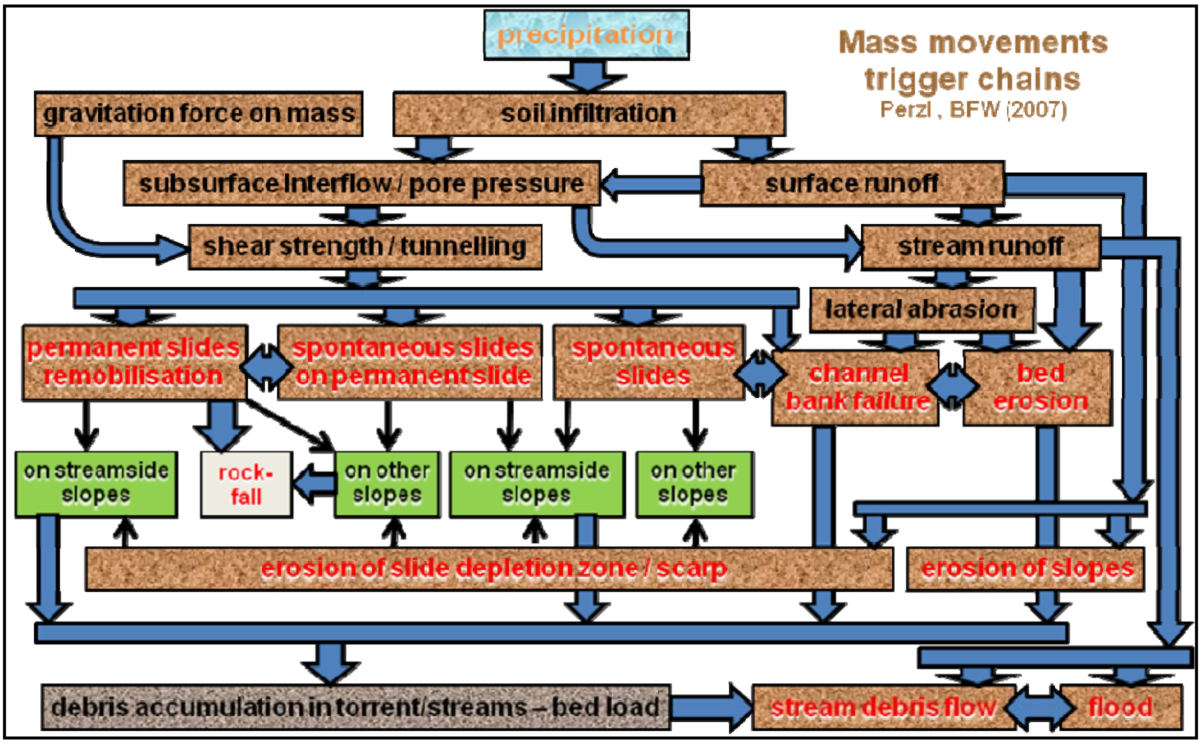

Figure 2-2: *Mass movement trigger chains (Perzl 2007).*

The following parameters are necessary to estimate the hazard potential of shallow landslides and debris slides (Duc 2007):

- Slope gradient from a DTM with a resolution of 25 x 25 m or higher.
- Other derived indicators from DTM, like Topoindex, relief.
- Geological or geotechnical maps, eventually with hydrogeological information.
- Indicators from geological maps, like shear angle, cohesion.
- Indicators from soil map, like thickness of tephra.

However, modelling hazard potentials and potential run out zones for **landslide** and **erosion** over the entire area of interest is quite difficult due to gaps in geological maps and soil database of most of the alpine countries. Furthermore, not all NFIs of alpine space collect data about erosion phenomena and soil conditions.

Torrent debris flow is a consequence of surface run off, landslide and erosion processes (Table 2-2, Figure 2-2). Therefore, it is not of primary importance to detect and estimate the hazard potential and the protective effect of forests. Against torrent debris flow, the protective effect of the forest is not direct. It is the same effect as for landslides and erosion (on streamside sites). The forest reduces the torrent bed load with debris and the debris flow by mitigation of landslides, erosion and surface runoff. Identifying or calculating the debris sources and the run out zones is not yet possible in most countries due to the missing geological and pedological database.

Surface runoff is an initial process of landslide, erosion, debris flow and floods (Table 2-2, Figure 2-2). **Soil degradation** (karstification, interrill erosion, wind erosion) results in surface runoff, debris flow and rockfall (Table 2-2, Figure 2-22). Because of the high mitigation potential of forests, the assessment of the runoff and soil degradation potentials as well as the protective effect of forests is desirable. Soil data are necessary for these tasks. But a nationwide soil database is not sufficiently developed in the most of the countries. Some NFIs like Austria or Switzerland (from soil maps) record the relevant soil information on sample plots. Other NFIs like France and Bavaria have no implementation of soil characteristics in their NFI survey program.

Due to the complexity of hydrological mechanisms and data availability it is not yet possible to model the hazard potential of landslides, erosion, torrent debris flow and flood with sufficient validity and to harmonise such approaches. Consequently, ProAlp focuses on development and harmonisation of indicators of forests with protective function against avalanche and rockfall.

Because of the large and causal importance of geology and soil conditions for many natural hazards (landslides, erosion, flood) the foundation of a standardized geological and pedological database for the alpine region is necessary. For this purpose NFIs have no competence and possibility. Inclusion and coordination of geological institutions is necessary.

2.3.4 Methods for modelling mass movement starting zones

Mapping of forests with direct protection function requires the calculation of the potential starting zones of natural hazards like avalanche and rockfall.

Duc (2007 a) summarized the main techniques for identification of the starting zones of landslides. The techniques also applicable for the identification of the starting zones and the frequency of avalanche and rockfall are:

a) Distribution analysis: direct mapping of mass movements and their starting zones (gives information on landslides which occurred in past).

b) Qualitative analysis: direct methods in which indicators from geomorphologic and/or climatic maps are renumbered to a hazard map (expert-based).

c) Geostatistical analysis: indirect methods in which statistical analyses are used to obtain predictions of the location of hazard starting zones from mapped parameters.

d) Deterministic analysis: indirect methods in which parameter maps are combined in slope or snow stability calculations.

e) Frequency analysis: indirect method in which meteorological records or hydrological models are used for correlation with known hazard zones, to obtain threshold values with a certain frequency; for identification of starting zones it is necessary to combine frequency analyses with geostatistical analysis.

Distribution analysis is not sufficient for the detection of all potential starting zones, because only sites of hazards which occurred in the past are captured.

Statistical and deterministic methods like geostatistical and frequency analysis require a representative database of georeferenced natural hazard event data. Because of the lack of event data parameterization and calibration of the models is adapted for the natural situation and data availability of the test regions of model development mainly. Suitable event databases for the whole alpine space are not available.

Therefore, the ProAlp method of detection starting zones is an expert-based qualitative approach (multicriterion evaluation of indicators).

2.3.5 Classification of hazard potential and protective effect

There are three main possibilities to express the **hazard potential** and the **protective effect**:

- Binary.
- Qualitative ranking.
- Quantitative ranking.

The **hazard potential** is an expression of the possibility (probability) and probable intensity of natural hazards events.

The simplest way to express this possibility is a binary decision: a natural hazard event is possible or not possible (0/1).

Qualitative and quantitative rankings classify the hazard potential with respect to the expected frequency and intensity of the hazard event. Rankings are used at hazard zone mapping in Austria, France and Switzerland (see Belitz et al. 1997).

In general, three or four classification levels are applied (Table 2-3 and Table 2-4). The levels of endanger of settlement areas are derived from calculated probable intensity and frequency of natural hazards. The French hazard zone map (PER) additionally includes the benefit of endangered objects, if the level of endangering is medium (Table 2-4).

In Austria an adjustment of the hazard zone mapping according to the Swiss system with 3 levels of danger (red, blue and yellow) is in discussion (see Table 2-4).

Table 2-3: *Classification of intensity and chronological probability of avalanches at hazard zone mapping of St. Gallen/Switzerland (cited from Egli 2003)*

Avalanche intensity			Expected value of event frequency (chronological probability)		
Notation	Colour code	Criterion (Pressure P)	1-30 years	30-100 years	100-300 years
			frequently	rarely	very rarely
High	dark green	P > 30 kN/m²	red	red	red
Medium	light green	3 < P < 30 kN/m²	red	blue	blue
Low	yellow	P < 3 kN/m²	blue	blue	yellow

Table 2-4: *Comparison of the classification schemes of hazard zone mapping of the alpine countries of ProAlp-Project (arrangement based on Belitz et al. 1997). Colours and alphanumeric codes represent different levels of endangering depending on expectation values of intensity and frequency of hazard events*

Numeric code and colour of map representation of endangerment levels of settlements and infrastructures by natural hazards					Level of endangerment	Object benefit (France)
Austria	Germany	France	Switzerland	Slovenia		
no colour	---	no colour	no colour	---	no	---
yellow	---	blue	1-yellow	---	low	---
yellow	---	blue	2-blue	---	medium	low
yellow	---	red	2-blue	---	medium	high
red	---	red	3-red	---	high	---

In most countries definitions of classes concerning possible damage and permitted land use are similar. Definitions of criteria and their practical calculation are, however, different. The Austrian hazard zone mapping has defined an average return duration of up to 10 years for frequent events, the Swiss model of up to 30 years. In Austria hazard events with an average return duration of more than 10 years are calculated with the expectation of the intensity of an event with a chronological probability of 100 (for flood) or 150 years (for avalanche). In Switzerland the expected values of intensities of events with chronological probabilities of 30, 100 and 300 years are used for calculation.

The country reports of ProAlp project show, that silvicultural guidelines of countries either use a binary system (only with threshold values of topographic indicators like Switzerland – NaiS, Frehner et a. 2005; France – GSM, Cemagref/CRP/ONF 2006) or ordinal scales (derived from thresholds and class boundaries of topographic indicators like Austria – ISDW) for expression of hazard potentials. Definitions for hazard potential according to the Austrian ISDW-system are shown below (Table 2-5).

Table 2-5: *Ordinal classes for assessment of hazard potential – Austrian ISDW-system (BMLFUW/BFW 2006)*

Level of hazard potential	Description of hazard potential (potential frequency/probability and intensity)
0	No significant danger respectively no importance of hazard type because of low basic susceptibility of the site
1	Low (infrequent and small events are possible – but only under highly instable variable system conditions probable)
2	Medium (infrequent and large events or frequent and small events are possible - also under more stable variable system conditions)
3	High (frequent small and large events are possible– also under almost stable variable system conditions)

The qualitative ranking of the hazard potential is related to the susceptibility of the forest site for hazard initiation. According to Kienholz et al. (1998) there are to components of susceptibility:

Basic susceptibility: Permanent or long time tendency or readiness to (dangerous) processes. The basic susceptibility depends on geomorphologic characteristics like slope steepness, surface roughness and soil conditions.

Variable susceptibility: This is the temporally fluctuating tendency or readiness to (dangerous) processes due to changing factors like atmospheric conditions and soil moisture.

The variable susceptibility and more or less short-time impacts of trigger events like heavy rainfall (floods, torrent debris flow, landslides), heavy snowfall (avalanches) or earthquakes (rockfall, landslides) constitute variable system conditions.

Variable system conditions have a large influence on the initiation and magnitude of natural hazard events. If the basic susceptibility to a certain type of natural hazard of a forest site is very high, small trigger events initiate a hazard event already. Therefore at a higher level of basic susceptibility also a higher frequency and intensity of hazard events is probable. A low basic susceptibility is able to buffer the impact of trigger events within some limitations (Figure 2-3). Therefore on sites with low basic susceptibility the overload of the system (overlapping of impacts and unfavourable ecosystem conditions), resulting to the trigger of a natural hazard, is less probable.

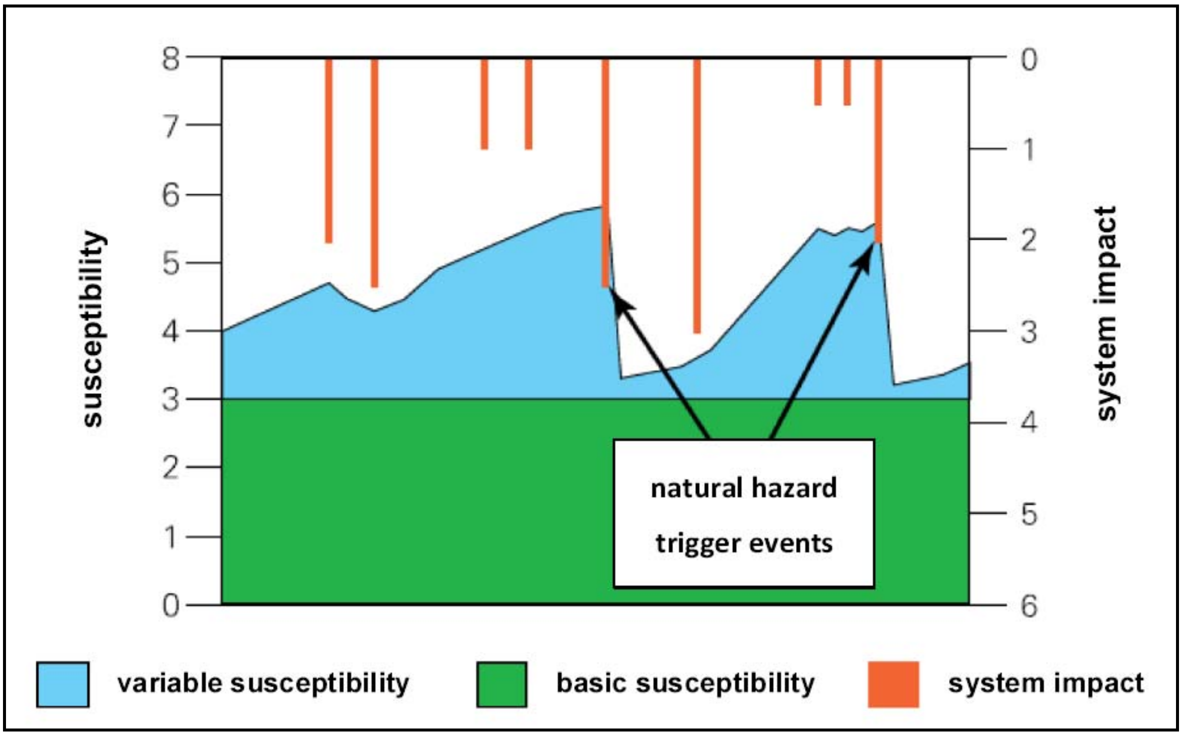

Figure 2-3: *Natural hazard initiation – relationship between susceptibility und system impacts according to Kienholz et al. (1997).*

However, it is very difficult to quantify the variable natural hazard susceptibility of a forest site and to calculate the probability of trigger events with certain magnitudes like heavy rain and earthquakes. The database is not existent or available. Therefore it is only possible to define the hazard potential due to the basic susceptibility.

The advantage of a ranking of the hazard potential due to the basic susceptibility for natural hazards is the possibility to adapt landuse and forest management with respect to the probable frequency and intensity of hazard events (Perzl 2008).

A quantitative ranking of the hazard potential (of the basic susceptibility) is not possible. For that purpose extensive geostatistical and frequency analyses based on long-time observations would be necessary. A sufficient database for the whole alpine space is either not existent or available.

Therefore, the ProAlp approach is a qualitative ranking of the hazard potential based on indicator evaluation by expert knowledge (Table 2-6).

Table 2-6: *ProAlp approach of ordinal levels for estimation and representation of hazard potential of a natural hazard type*

Levels of hazard potential (basic susceptibility)		
Key number colour	Notation	Description
0	No or very low basic susceptibility	Events are improbable
1	Low basic susceptibility	Small and infrequent events are possible. They occur only under highly unfavourable variable system conditions.
2	Medium basic susceptibility	Events are possible more frequently; under highly unfavourable variable system conditions medium events are possible, large events are improbable - they are expected seldom.
3	High basic susceptibility	Events are possible frequently; small to large events are possible also under more favourable variable system conditions.

At level "0" events of a certain hazard type are improbable. They occur very rarely. If all types of natural hazards are in the level "0", the wooded area is not a forest with protective function with regard to the investigated natural hazard processes.

At level "1" natural hazards occur only under highly unfavourable variable system conditions (high variable susceptibility and/or impact, for instance heavy rain and snowfall after weeks with precipitation above average, wetting of snow cover because of rain/thaw, earthquake and storm). Events are infrequent and rather small. The level also includes the probability of frequent, but very small events.

Level "3" is the common domain of natural hazards also under more favourable variable system conditions. They are probable with increased frequency in every magnitude. Also large events have to be expected with a higher frequency.

It has to be taken into account that the protective effect of forest is not considered at the definition of the hazard potential. The basic susceptibility is a result of climatic, geotechnical, topographic and edaphic factors. As already mentioned before it is not possible to calculate the probabilistic frequency and intensity of a hazard event from indicators of the basic susceptibility. Therefore it is not possible to exactly define the frequency and magnitude of the occurrence of a hazard event according to Table 2-6.

The qualitative classification according to Table 2-6 is in general suitable for all hazard types. But for some hazard types like rockfall for example it is very difficult to derive estimations of frequency and intensity of hazard events from indicators. There is no satisfactory possibility to estimate the frequency of rockfall (see Kalberer 2007). Assessments of probable rockfall intensity require data about potential rock diameter. At present no data concerning the potential size of rocks exist.

Therefore the hazard potential classification according to Table 2-6 is only applicable for avalanche release but not for rockfall. For rockfall only the hazard potential area but neither the probabilistic frequency nor the intensity are considered in ProAlp.

For avalanche release it is supposed that:

- Frequent events are consistent to the probability of occurrence of about less than 30 years.
- Large events are consistent to the magnitude of an event with a probability from more than 30 years.

The **protective effect** of forest depends on hazard type, hazard potential (basic and variable susceptibility) and on impacts on ecosystem as well as on forest structure. It is also possible to express the protective effect binary or with a qualitative or quantitative ranking. There are only few physical or statistical models to quantitatively calculate the protective effect of forest. For some hazard types such models had been developed. But these are expensive expert-systems with special data requirements normally (and for larger areas) not available (Perzl 2008).

Therefore in silvicultural guidelines binary or qualitative rankings based on thresholds of forest structure are used. For example the Swiss silvicultural guideline NaiS (Frehner et al. 2005) defines 3 levels of protective effect implicitly:

1. Low level – the minimal demands on forest structure are not achieved.
2. Medium level – the minimal demands on forest structure are achieved.
3. High level – the ideal demands on forest structure are achieved.

The approach of the Austrian ISDW-system is similar (Table 2-7). The characterisation of the protective effect of the forest is made by three levels. On the contrary to NaiS the hazard potential is used as indicator for protective effect. Therefore there is another level “0”. It expresses that because of very low basic susceptibility no-one hazard potential exists. So no protective effect of forest is required.

Table 2-7: *Ordinal classes for assessment and representation of protective effects of forests according to the Austrian ISDW-system (BMLFUW/BFW 2006)*

Level of protective effect	Description of protective effect
0	No significant hazard potential (hazard potential = 0)
1	High level: sufficient protective effect
2	Medium level: reduced, not sufficient protective effect
3	Low level: very low protective effect

The interpretation of the level of protective effect is a matter of risk analysis and must consider the hazard potential, the frequency and intensity of impacts (trigger events) as well as the damage potential. A high protective effect is not always required but for the case of extreme climatic and geogenic impacts desired. Whether the protective effect is sufficient or not depends on the damage potential in relation to the vulnerability and presence probability of assets. At a low level of hazard potential and damage potential a medium level of protective effect may be sufficient, because only small hazard events are probable. The scientific foundations and the database are, however, still insufficient for a comprehensive risk analytical approach.

Because of the advantages of rankings for harmonised reporting four levels of protection are proposed (Table 2-8).

Table 2-8: *Ordinal levels for the estimation of protective effects of forests*

Level of protective effect of forest within ProAlp		
colour (numeric code)	Notation	Description
0	Not relevant	No significance of hazard type (level of danger = "0")
🟩 1	High	Protective effect is sufficient also under conditions of high variable susceptibility for natural hazards of ecosystem
🟨 2	Medium	Protective effect is only sufficient at medium variable susceptibility for natural hazards of ecosystem
🟥 3	Low	Protective effect is not even sufficient at medium variable susceptibility for natural hazards of ecosystem

The protection level "high" means an ideal structure of forest with respect to natural hazards. The level "medium" corresponds to a minimal requirement on forest structure, which is adequate at medium or low magnitudes of variable causal factors (in common case). The level "low" indicates not enough protection and already critical situations at medium level of variable susceptibility and/or climatic and geogenic impact. But in general the medium “B” level provides enough protection for the avoidance of greater damages to the infrastructures.

It has to be taken into account that the protective effect of forest is limited. Therefore an A level of protection does not mean absolute safety. Climatic or geogenic impacts are able to overstrain the protection capability of forests even if their structure is ideal.

The levels of protection according to Table 2-8 do not take into account stability of forests and sustainability of forest growth.

2.3.6 Methods for calculating run out zones of gravitational processes

Mapping of forests with direct protective function requires the calculation of the potential run out length of the mass movement. A forest is only a forest with protective effect if a mass movement, initiated from the forest site, is able to reach human assets like settlements and infrastructures (forest with direct protective effect).

There are several methodologically different approaches to calculate the run out distances (zones) of gravitational hazard processes like avalanches and rockfall. For avalanches following models with pros and cons are currently used:

A) Statistical Models

A1) Energy Line Angle or Generalized Gradient Method (Heim 1932)

Pro: simple; only DTM necessary; no release depth needed; no separate simulation program needed.

Con: avalanche path must be known; rough estimation of run out distance along predefined profile; 2-D modelling without predefined avalanche path (profile line) is possible but very rough; no information about velocity or pressure; no consideration of deflection dams or similar relief elements possible.

A2) Topographic regression model (i.e. Lied et al. 1995)

Pro: simple; only DTM (profile) necessary; no release depth needed; no separate simulation program needed, relative good approximation of run out along predefined profile.

Con: no information about velocity or pressure; 2-D modelling without predefined avalanche path (profile line) is possible but very elaborate; no consideration of deflection dams or similar relief elements possible.

B) 1D Models

Pro: Simple; based on DTM only; good results of run out distance; pressure and velocity information available along the entire profile.

Con: Avalanche path must be known; release depth necessary; only along predefined profile; simulation program (i.e. Aval-1-D) necessary; 2-D modelling without predefined avalanche path (profile line) is possible but very elaborate and labour intensive; no consideration of deflection dams or similar relief elements possible.

C) 2-D Models

Pro: Now avalanche path must be predefined (real 2-D modelling); good for complex terrain and starting zone; good results of entire out shape; pressure and velocity information available along avalanche path (area); divergent run out paths; deflection dams possible.

Con: Special parameters (Coulomb friction μ and turbulent friction coefficient ξ) must be known or estimated by expert; release fracture width necessary.

E) 3-D Models

Pro: Comparable with 2-D (flow part) but 3-D information of powder part available too (they handle not only the dense flow part of avalanches like all other models – a moving avalanche may have two main components: a dense flow part and a superimposed powder part of very low density).

Con: Complex input parameter estimation necessary; high computational time; complex interpretation of results.

Selection of method:

For harmonized indication and reporting of hazard potential within ProAlp, models will be restricted to statistical methods (energy line and generalized gradient method respectively). More comprehensive models partly require input data – e.g. the potential block diameter (rockfall) or expectation values the of new snow depth (avalanche) – which are not available or are not free of charge.

The Energy Line Angle Concept (Energielinien-Modell) has been developed by Heim already in 1932 for rockfall run out calculations.

The Energy Line Angle is the angle of the connecting line from the release point (e.g. a DTM pixel or an NFI plot with avalanche release potential) and the outer edge of the run out zone of a mass movement with the horizontal plan. The intersection between the terrain profile and the line determined by the angle from the release point yields to the maximal stopping point (Dorren 2003). Scheller (1970) termed the angle “generalized gradient” (Pauschalgefälle).

Körner (1976) has observed a correlation between the mean friction and the energy line angle for avalanches. The mean friction affects the run out length. He used the concept for avalanches for the first time.

Heim (1932) recognized that it is possible to determine the run out length of rockfall with two angles of the energy line:

- The geometric angle α_g is calculated from the horizontal projection of the shortest distance between the release point and the end point of the mass movement.
- The travel angle α_f (Fahrböschungswinkel) is calculated from the length of the horizontal projection of the line that follows the true trajectory. The travel angle is always flatter than the geometric angle, because the true trajectory is curved and therefore the ratio of height and length (Figure 2-4) is smaller.

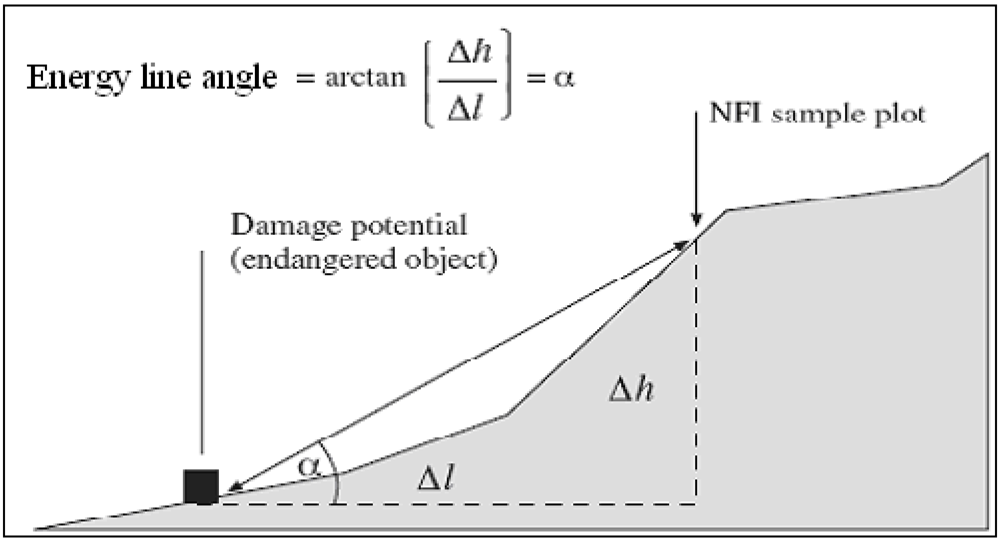

Figure 2-4: *Concept of the Energy Line Angle Method (Heim 1932): Δh = total of all flow direction heights, Δl = total of all lengths. (Figure: Mani & Balmer (1996) cited from Brassel & Lischke (2001)).*

The geometric angle is affected considerably stronger by the form of the terrain. Therefore the travel angle is often preferred. But the geometric angle can be more easily determined in the field. This is an advantage to be not neglected for data collection and model evaluation. Meißl (1998) observed for rockfall areas that the geometric angle and the travel angle differ from each other by less than 1 degree.

The magnitude of both angles is dependent on the hazard type, the mass components (type of rockfall source, geology, geometrical shape and size of boulders) and on the relief (curvature, roughness and steepness of slope).

Field observations show that the magnitude of the angle is in most cases within a certain range and above a certain limits with little variation (see Tables 2-9 and 2-10). Therefore, it is possible to estimate roughly the run-out length/zone of gravitational processes, if starting zones are known.

Table 2-9: *Energy Line Angles of rockfall from several authors*

Author/Source	Energy Line Angle: Travel angle (in brackets geometric angle)	
	minimum or range	mean
Onofri & Candian (1979)	28,3° - 40,7°	---
Grunder (1984)	32.6° - 33.4°	---
Moser (1986)	33° - 42°	---
Domaas (1985, cited from Toppe 1987)	32°	---
Gerber (1994)	33° - 37°	---
Meißl (1998)	29° - 47.5° (29.5° - 48.5°)	38° (38°)
Heinimann et al. (1998)	33° - 37°	---
Focardi & Iotti (2001)	27° - 29°	---
Laboyedoff & Labouise (2003)	33°	---
Corominas et al. (2003)	26° - 54°	---
Dorren et al. (2005, 2006)	(31.9° - 38°)	---

Table 2-10: *Energy Line Angles of avalanche from several authors*

Author, source, number of avalanches, s = small avalanches, b = big avalanches	Energy Line Angle: Travel angle (in brackets geometric angle)	
	minimum or range	mean
Perla & Martinelli (1976)	20° - 35°	---
Lied (1979) cited from Zenke (1985), n = 423	17° - 46°	31°
Hildebrandt (1981) cited from Zenke (1985), n = 56, b	17° - 44°	32°
Laatsch et al. (1981)	21° - 35°	---
Zenke (1985), data from EISLF (1978-1982), n = 50, s	22° - 39°	28°
BUWAL (1993, cited from Brassel & Lischke 2001)	22°	---
Lied et al. (1995), n = 80	(17° - 35°)	(27°)
Schnetzer (1999), n = 17, s	32°- 41°	37°

The Energy Line Angle method is applicable for avalanches, rockfall and spontaneous landslides. But the method may be used only for a rough preliminary estimation of run out distances. Application is possible with standard GIS tools and grid calculation programs. Several programs and applications have been developed (e.g. rockfall: Cemagref, Meißl 1996, Guzetti et al. 2003; avalanche, rockfall and landslides: Mani & Balmer 1996, avalanche: Klebinder, Fromm & Perzl 2006, unpublished).

Resolution and accuracy of DTM affect the results of all run out calculation methods. At least a DTM resolution of 25 x 25 m is necessary.

3 Harmonized definitions and indicators

3.1 Forest definition

Within Cost Action E43 comprehensive studies for harmonising the forest definition took place. A so called “reference definition” (Vidal et. al, 2008) was developed based on the four core variables minimum size, minimum crown cover, minimum width and minimum tree height according to the FAO approach. Also the thresholds were selected in accordance to FAO 2000. The main difference to FAO definition is the fact the Cost E43 included many sub definitions and additional explanations leaving minimal space for subjective interpretation.

Within ProAlp the suitability of the reference definition for forest had to be checked in relation to the possibilities of deriving starting zones and protective effect. The main weakness for the starting zone derivation is the rather low crown coverage of the reference definition with only 10%. Areas with tree crown covers between 10 and 30% have no protective effect. Additionally alpine countries exclude such areas in their national definitions the minimum crown coverage was set to 30%. The tree height was fixed between 2 and 5 m of the actual situation depending on the estimation procedure of the protective effect. Within CostE43 it is 5m at maturity in situ. The other thresholds where fixed according to Cost E43 reference definition (Table 3-1).

Table 3-1: *Comparisons of forest definitions*

	E43 Reference definition	ProAlp definition
Minimum area	0.5 ha	0.5 ha
Minimum crown cover	10%	30%
Minimum tree height	5m	2m / 5m
Minimum width	20m	20m

3.2 Indicators and classification

The ProAlp approach to the classification of indicator values consists of two levels:

- Determination of thresholds.
- Quantification of process relevant magnitudes.

In general, 3 and 4 classification levels (levels of danger) are applied (Tables 3-2 and 3-3). The levels of danger of settlement areas are derived from intensity and frequency of dangerous processes.

In Austria an adjustment of the hazard zone mapping according to the Swiss system with 3 levels of danger (red, blue and yellow) is in discussion (see Table 3-2).

Table 3-2: *Cassification of intensity and chronological probability of avalanches at hazard zone mapping of St. Gallen/Switzerland (cited from Egli 2003)*

Avalanche intensity			Expected value of event frequency (chronological probability)		
Notation	Colour code	Criterion (Pressure P)	1-30 years	30-100 years	100-300 years
			frequently	rarely	very rarely
High	dark green	P > 30 kN/m²	red	red	red
Medium	light green	3 < P < 30 kN/m²	red	blue	blue
Low	yellow	P < 3 kN/m²	blue	blue	yellow

The French hazard zone map (PER) additionally includes the benefit of endangered objects, if the level of endangerment is medium (Table 3-3).

Table 3-3: *Comparison of the classification schemes of hazard zone mapping of the alpine countries of ProAlp-Project (arrangement based on Belitz et al. 1997). Colours and numeric codes represent different levels of endangerment depending on expectation values of intensity and frequency of hazard events*

Code and colour of map representation of endangerment levels of settlements by natural hazards (colour and numeric code)					Level of endangerment	Object benefit
Austria	Germany	France	Swiss	Slovenia		
					no	---
yellow	---	blue	1-yellow	---	low	---
yellow	---	blue	2-blue	---	medium	low
yellow	---	red	2-blue	---	medium	high
red	---	red	3-red	---	high	---

In most countries definitions of classes concerning possible damage and permitted land use are similar. Definitions of criteria and their practical calculation are, however, different. The Austrian hazard zone mapping has defined an average return duration of up to 10 years for frequent events, the Swiss model of up to 30 years. In Austria hazard events with an average return duration of more than 10 years are calculated with the expectation of the intensity of an event with a chronological probability of 100 (for flood) or 150 years (for avalanche). In Switzerland the expected values of intensities of events with chronological probabilities of 30, 100 and 300 years are used for calculation.

The country reports of ProAlp show that silvicultural guidelines of countries either use threshold values (Switzerland - NaiS, France - GSM) or ordinal scales (Austria – ISDW) for hazard potentials and protective effects of forests.

Table 3-4: *Suggestion of ordinal levels for estimation and representation of hazard potential of a natural hazard type*

Level of danger/ level of hazard potential		
Key number colour	Notation	Description
0	No danger	Events are improbable
🟦 1	Low danger	Events are possible, they are infrequent and small – they occur only under highly instable variable system conditions
🟥 2	Increased danger	Events are possible, they occur more frequently, small and large events are possible also under more stable variable system conditions

At danger level "No danger" events of a certain hazard type are improbable or occur very rarely. If all types of natural hazards are in the danger level "0", the wooded area is not a forest with protective effect with regard to the investigated natural hazard processes.

At danger level "Low danger" natural hazards occur only under very supporting conditions of variable susceptibility (for instance extreme rain and snow precipitation, wetting of snow cover because of rain/thaw, earthquake and storm). Events are infrequent and rather small. The level also includes frequent, but very small events.

Danger level "Increased danger" is the common domain of natural hazards also under more stable conditions of variable susceptibility. They occur with increased frequency in every magnitude or they are infrequent, but intense.

It is difficult to calculate the frequency of a hazard event by indicators. Therefore it is not possible to define the frequency and magnitude of the occurrence of a hazard event according to Table 3-4. However a simplified classification of event frequency is suggested:

- Frequent events are consistent to the probability of occurrence of about less than 30 years.
- Rare events are consistent to the magnitude of an event with a probability from more than 30 years.

Table 3-7: Proposal for ordinal levels for the estimation of protective effects of forest

Level of protective effect of forest within ProAlp		
Key number colour	Notation	Description
0	Not relevant	No significance of hazard type (level of danger = "0")
1	High	Protective effect is sufficient at superior or extreme magnitudes of variable susceptibility
2	Medium	Protective effect is only sufficient at medium or below magnitudes of variable susceptibility
3	Low	Protective effect is not even sufficient at medium or below magnitudes of variable susceptibility

The protection level "high" means an optimal structure of forest in respect to natural hazards. The level "medium" corresponds to a minimal requirement, which is only adequate at medium or low magnitudes of variable causal factors (in common case). The level "low" is in common cases not enough protective and already critical at medium level of variable causal factors.

These levels of protection do not take into account stability of forests and sustainability of forest growth.

3.2.1 Avalanche

An avalanche *is a rapid down slope movement of a large mass of snow. Snow-slide is a term used to describe the same phenomenon, although the term avalanche has become more common (Schaerer 1981). Spontaneous avalanches mainly occurre because of heavy snowfall but also due to other climatic impacts on snow cover like rain or temperature.*

Figure 3-1: *Avalanche motion on the 13th of May 2008 in the Kaprun Valley, Salzburg, Austria (photo: Johann Berger, Verbund AHP Werksgruppe Kaprun-Salzburg). A large wet snow flow avalanche with snow dust cloud released from still snow covered starting zone above the timberline.*

There are – among many others – two main avalanche classification criteria (see Unesco 1981):

- Classification by release mechanism:
  - Slab avalanche: Simultaneous release of a cohesive snow layer (slab) characterized by a distinct fracture line (or crown fracture) at the top of the avalanche.
  - Loose snow avalanche: An avalanche (of dry or wet snow with no or low cohesion) starting from a point fanning out downhill and leaving an inverted V-shaped scar.
- Classification by volume of snow deposition and track length (see Table 3-5).

Some other important classification characteristics of avalanches are:

- The position of the gliding surface or weak layer in the starting zone: within the snow cover (surface-layer avalanche) or on the ground (full-depth avalanche).
- The amount of liquid water in the snow: dry- or wet-snow avalanche.

Rapid movements of water saturated snow are called slush-flow or slush-avalanche. The term snow slide or sluff is used for small avalanches running less than 50 m slope distance or with a volume smaller than 100 m³ (Figure 3-2, Table 3-5).

Table 3-5: *Avalanche size classification (Glossary snow and avalanches, WSL, http://www.wsl.ch).*

term		run out classification	damage potential classification	quantitative classification
Size 1	sluff	small snow slide that usually cannot bury a person but push over a cliff	relatively harmless to people	length < 50 m volume < 100 m^3
Size 2	small avalanche	stops within the slope	may bury, injure or kill a person	length < 100 m volume< 1000 m^3
Size 3	medium avalanche	runs to the bottom of the slope	may bury and destroy a car, damage a truck, destroy a small building or break a few trees	length < 1000 m volume < 10000 m^3
Size 4	large avalanche	runs over flat areas (significantly less than 30°) of at least 50 m in length, may reach the valley bottom	may bury and destroy trucks or trains, large buildings and forested areas	length > 1000 m volume > 10 000 m^3

Figure 3-2: *Sluffs and small avalanches which occurred on the edge of forest terrain on the 10th of November 2007 in the Klostertal Valley, Vorarlberg, Austria. Photo: Perzl (2007*

There are three sections of an avalanche path. The starting zone of an avalanche is also called release area. The runout zone is the terrain where an avalanche decelerates and stops. The transit zone, also called track, refers to the part of the path between the release area and the runout zone.

The main operational steps of avalanche danger detection with respect to forest function are:

- Analysis of hazard potential (basic susceptibility) for avalanche release without consideration of forest cover:
  - Detection of potential avalanche starting zones (potential release areas, AHP).

  - Characterisation of starting zones: assessment of release probability (without consideration of forest cover) and prediction of the release size.

- ° Modelling of avalanche track and runout zone (avalanche trajectory) for determination of damage potential (without forest effect in transit zones).

- ° Assessment of protective effect of forest in the starting zone.

Due to the insufficient braking efficiency of forests against avalanches – they only can stop or slow down sluffs and small to medium avalanches (Bartelt & Stöckli 2001, Margreth 2004) – the assessment of the protective effect of forest in transit and runout zones is secondary (Perzl 2005). Moreover scientific state of knowledge about retarding efficiency of forests is not sufficient yet. Therefore, the main target is to detect the avalanche starting zones (AHP) and to estimate the protection function of forest against avalanche release (Margreth 2004).

3.2.1.1 Indicators of avalanche hazard potential

The first step of the assessment of an avalanche hazard potential is to detect the potential starting zones (potential release areas – AHP)

There are two basic opportunities to map and model AHP, Figure 3-3:

- Discrete representation of starting zones: The mapping or modelling of self-contained areas (polygons) with avalanche release potential.
- Grid representation of not self-contained starting zones: The spatial unit is the grid cell of the DTM. For every cell it is determined whether it contains a potential starting zone. Cells with avalanche release potential are not filtered and aggregated to self-contained regions.

Discrete representation is necessary for simulation of avalanche tracks with physical models.because such models require the potential release mass of an avalanche. The potential release mass is a function of release zone area and snow cover fracture depth. The main problem of this method is to set suitable thresholds for minimal starting zone size (see Table 3-9: minimal area and length of starting zone) and to split big potential release areas in smaller portions.

Usually, within AHPs avalanches occur on smaller portions. Therefore it is necessary to split big AHPs and to define splitting criterions. Otherwise results of avalanche simulations are not realistic. Bertogg (2001), Gruber (2001) and Maggioni et al. (2002, 2003) developed methods for automatic definition of standard AHPs by spatial modelling from a DTM. A modification of this method was used for detection of AHPs at SilvaProtect project in Switzerland (see Giamboni 2008). The method concerns extreme avalanches with a chronological probability of 300 years. AHPs smaller than 5000 m² are filtered out (see Table 3-9). The results of these sophisticated methods of automatic AHP mapping may be full of errors (Giamboni 2008). The methods may not be valid for all kinds of avalanches and all regions of the alpine space. They strongly depend on the DTM resolution and its quality. Discrete mapping is suitable for detection of the larger AHPs of big slab avalanches over timberline above all. But it is still not possible to detect the exact position of snow cover fracture lines within the AHPs.

By using distributed grid representation it is neither necessary to define threshold values for the size of AHPs and to split them nor smoothing techniques are required. The resolution of the DTM defines the smallest avalanche release area. The uncertainties of this approach are similar but the influences of GIS smoothing and filter techniques on the results are smaller.and the approach is simpler. Dependent on the resolution of the DTM it is also possible to detect the release zones of small slab and loose snow avalanches. Grid representation is sufficient for the use of topographic models for calculation of avalanche trajectories. Topographic models like the Energy Line Method do not need the release mass for model input. But topographic models are substantially more inaccurate than physical models.

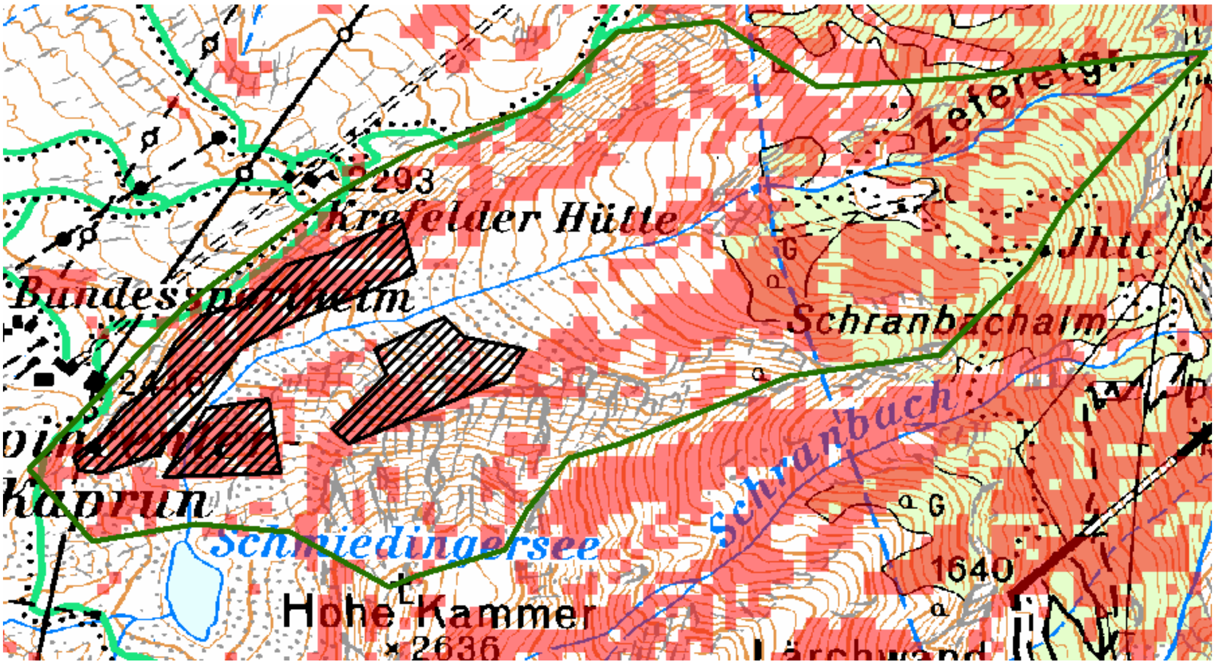

Figure 3-3: *Not self-contained grid representation of AHPs (red zones) automatically derived from a 25 m DTM and AHPs mapped by an expert (discrete representation – black hatched polygons). The mapping of the expert focused on release areas over the timberline only responsible for extreme avalanches within the green edged catchment. The grid representation considers all AHPs (in and out of forests) without size limitations with respect to probable avalanche intensity.*

AHPs can be detected by climatic and geomorphologic indicators. Indicators and threshold values of different systems for detection and characterization of starting zones are shown in Table 3-6 (based on the ProAlp Country Reports see chapter 2.2.2).

Table 3-6: *Indicators of avalanche hazard potential (basic susceptibility)*

Model Indicator input data	Austria	France	Germany (Bavaria)	Slovenia	Switzerland
Model / guideline	ISDW	Cemagref 1996 (GSM 2006)	expert	ZRC-SAZU	SilvaProtect
Minimal altitude [m]	700 - 1250[1]	1000, 1300[1]	800	1200	900/1100/1200[1]
Depth of snow cover [m]	≥ 0.7			≥ 1	
Slope gradient	> 25° [2]	28°- 55°	25°- 55°	21°- 60°	28°- 60°
Minimal length of starting zone [m]		50	50		50
Minimal area of starting zone [m²]		500			5000
Large scale geomorphology (plan curvature)					x [3]
Medium scale geomorphology (slope length)	x		x		
Low scale geomorphology [4]	x		x		
Surface roughness	x		x		
Ground vegetation	x		x	x	
Exposition		(SE, S, SW)	x	SE, S, SW and also but less E, NW	
Durability of snow cover				≥ 75 days	
Climatic zone				x	

[1] Depends on geographic/climatic region.

[2] Austria: At ISDW the lower limit is 25°. There is no upper limit of the slope gradient of avalanche prone terrain. BFW experts recommend a range of 28° to 55°.

[3] Switzerland: At SilvaProtect plan curvature is taken into account by exclusion of main ridges.

[4] Low scale geomorphology = surface roughness and ground vegetation. Roughness by ground vegetation can be seen as part of surface roughness.

Altitude and snow depth (Perzl 2006, 2007):

Determination of altitude is simple and reliable. Therefore, silvicultural guidelines and natural hazard assessment systems use often altitude for indication of avalanche prone terrain. Altitude is an indicator/surrogate of two factors of avalanche initiation:

- Kinetic head (Energiehöhe).
- Snow depth (release depth).

Both are indicators for the frequency and quantity of avalanche release. Smith & McClung (1997) noticed a significant Pearson`s correlation (R = 0.64) of the altitude of starting zone and the frequency of spontaneous avalanche release of 25 avalanche tracks in British Columbia, Canada.

Afterwards McClung (2003) investigated the mean avalanche frequency of 190 avalanche paths and the mean avalanche magnitude of 146 avalanche paths. He could find a highly significant positive correlation of starting zone elevation with the mean avalanche frequency and magnitude in single and multivariate relationship of investigated possibly indicative parameters.

Science-based information about threshold values of altitude concerning avalanche release is rare in literature (e.g. Konetschny 1990, pp. 107-111; Meyer-Grass & Schneebeli 1992; Smith & McClung 1997; Luzian 2002; Perzl 2008). Most of them are related to the snowfall and snow cover conditions in smaller regions.

Langenegger (1979) mentioned as one of the first limit values of altitude concerning avalanche starting zones. From the practical experience and knowledge of Swiss foresters a threshold value of 700 m has been assumed in a check list of forest protection functions.

Wullschleger (1982) mentioned the fact of avalanche release (rather small and infrequent) below 900 m in Switzerland too. BUWAL (2000) assumes avalanche release potential in broad leaf and mixed forests above 700 m for Switzerland. Damage avalanches occurred in Austria in some regions from about 600 m upwards (Schnetzer 1999, Luzian 2002, Perzl 2008, see Figure 3-4).

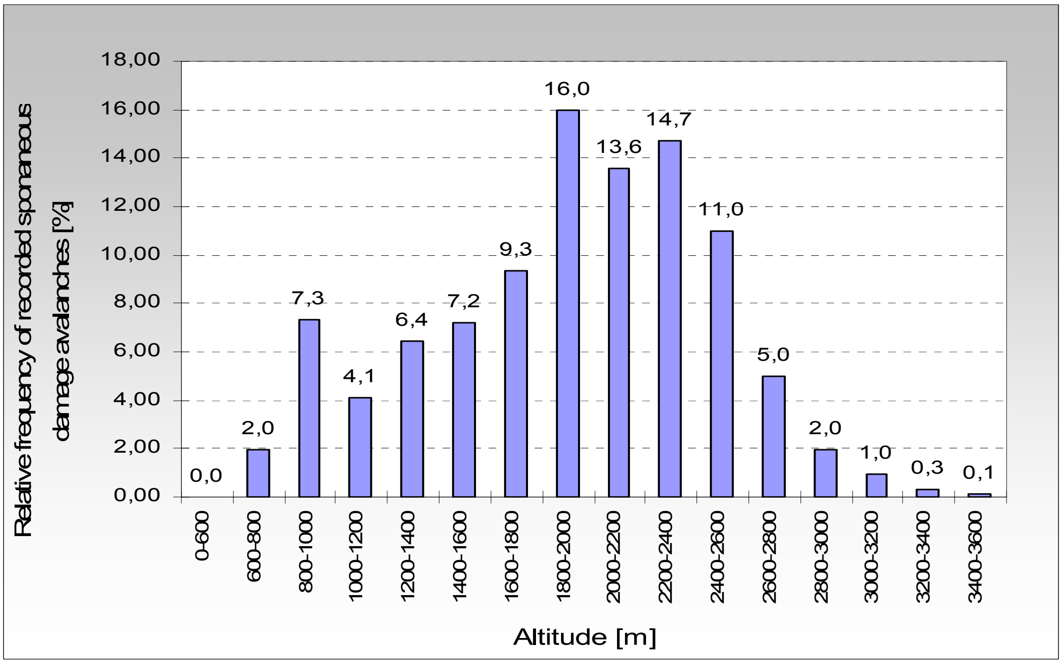

Figure 3-4: *Relative Frequency of recorded spontaneous damage avalanches in Austria dependend from altitude, n = 1533, observation period 1973/74-2005/2006, BFW avalanche database, Perzl (2008).*

The hazard potential model of Tyrolean forest with protective effect controlling system (see Perzl 2005), the 2nd Swiss Forest Inventory (LFI2, Brassel & Lischke 2001, Duc et al. 2004), the French silvicultural guideline GSM (Cemagref/CRPF/ONF 2006) and many other models (e.g. Wullschleger 1982, BUWAL 2000) use the altitude as an indicator and threshold value for the avalanche release potential and to separate forests with protective effect from forests without protective function. But there is only little information about minimum altitude of avalanche starting zones obtained from long term observation and statistical frequency analysis in literature. Threshold values of assessment models of alpine countries vary (see Table 3-6).

The Swiss Forest Inventory (LFI2) defines different threshold values of altitude depending on climatic region, because expectation values of snowfall of climatic zones are different. For the Swiss Northern Alps the threshold value of significant avalanche release is 900 m, for the Interior Alps 1100 m and for the Southern Alps 1200 m. These values have been implemented to Swiss nationwide avalanche modelling (SilvaProtect) and the validity of these thresholds could be confirmed by regional avalanche experts (Gruber & Baltensweiler 2005, Giamboni 2008). However, in Austria and in Swiss Canton Schwyz experts noticed avalanche activity also below 900 m.

The altitude thresholds for France are 1000 m (French Northern Alps), 1 300 m (French Southern Alps) and 1 500 m (Pyrenees), for Slovenia 1200 m and for Bavaria 800 m (see ProAlp Country Reports: Binder 2007, Duc 2007 b, Nicola et al. 2007, Perzl et al. 2007, Polanšek et al. 2007).

Instead of altitude as an indicator, the Austrian guidelines (ISDW) use the mean maximum of snow depth of snow cover region for the assessment of forest hazard potentials and protective effects since altitude is a surrogate of snow cover conditions BMLFUW/BFW 2006, Perzl 2008). The amount of snow, snow cover conditions and the slope gradient are the primary factors for the occurrence of avalanches. The mean of maximum of snow depth (MMS) is a value calculated by Austrian Hydrological Service by default for periods of 10 years and Climatic Normal Periods (CLINO) of World Meteorological Organisation (e.g. CLINO 1961-1990). MMS is the mean of the maximum value of the snow depth of the winter season (the total depth of snow cover – not the depth of new snow respectively snowfall = Neuschneehöhe) and is a good representation of the level of snowfall (snowfall, snow depth and durability of snow cover) highly correlated with altitude and extreme values (R = 0.96) of snow cover depth. Therefore, at ISDW the MMS is calculated from altitude by regional regression equation (13 snow cover regions on the basis of snow cover zoning by Wakonigg (1975) and Schöner & Mohnl 2003, 2006).

Smith & McClung (1997) noticed a high correlation between avalanche frequency and maximum water equivalent of snow cover (R = 0.84). Therefore an indication of MMS for frequency and potential avalanche release depth can be estimated. Perla & Martinelli (1976) verified that significant avalanches occur at a minimum snow depth of 1 m.

In Austria, depending on the snow cover region, an extreme value of total snow depth of 1 m may develop at locations with a MMS level between about 0.25 and 0.71 m (CLINO period 1961-1990). Perzl (2008) noticed - from data of the Austrian BFW avalanche damage database - that not one single spontaneous damage avalanche release has been reported below the line of 0.7 m of MMS in all Austrian snow cover regions since 1973. An MMS of 0.7 m corresponds to altitudes of about 670/1250 m depending on the region. But between the MMS level of 0.7 and 1.0 the avalanche events are rather rare and small (wet sluffs and small avalanches).

Therefore, the Austrian ISDW system uses the 0.7 m MMS as threshold and following classification of avalanche hazard potential with respect to MMS:

- Low level of hazard potential: MMS ≥ 0.7 m.
- Medium level of hazard potential: MMS ≥ 1.0 m.

- High level of hazard potential: MMS ≥ 1.5 m.

The differences about altitude threshold values for avalanche hazard potential of ProAlp countries result from:

Differences of snowfall and other climatic influence factors (snow depth, consistency of snow because of temperature and rain) in alpine regions at the same altitude.

Different perception and definition of the magnitude of significant avalanches (e.g. ISDW considers also small avalanches, but SilvaProtect refers to extreme avalanches only).

Conclusions:

- Altitude is a good indicator of the basic susceptibility for avalanches compared to snowfall and snow depth. The determination of altitude is simple and reliable. There are no suitable snow cover maps of the Alpine region available. The altitude is highly correlated to snow depth. But also other climatic conditions impact the susceptibility for avalanches It is possible to adapt altitude thresholds by expert knowledge.
- Threshold values are different in each region of the Alps – harmonization is possible by classification of hazard potential with respect to the same hazard size (approximately same frequency and intensity of avalanche release) by expert.

It is necessary to use spatially adapted thresholds and rankings of altitude with respect to avalanche release potential.

Slope gradient:

Besides snow depth the slope gradient is the most important indicator of avalanche prone terrain. Deep snow and steep slopes are the essential elements for initiating and propagating avalanches which occur in mountain regions throughout the world (Schaerer 1981). The Slope gradient is an indicator for avalanche release frequency and avalanche size.

One may find many statements about slope gradients and avalanche frequency in literature (e.g. Working Group on Avalanche Classification 1973, Perla & Martinelli 1976, Perla 1977, Schaerer 1981, Gabl & Lackinger 1988, Konetschny 1990, Meyer-Grass & Schneebeli 1992, Smith & McClung 1997 and McClung 2001 etc.). Many statements in literature (e.g. Munter 2003) are connected directly to human triggered avalanches which are not primary relevant for the project questions. This information is partly meaningful for spontaneous avalanche hazard potential of forest terrain.

Statements in literature concerning slope gradient range and avalanche release frequency as well as ProAlp countries thresholds (Table 3-6) are different for several reasons:

They are related to different types of avalanches (e.g. slab and loose snow avalanches, human triggered and spontaneous avalanches).

They are related to different land use units or rather investigation units, e.g. minimum and mean slope gradient of avalanche starting zones in forests are mainly higher than on other land.

Terrestrial measurement of slope gradient as well as the derivation from DTM (different preparation techniques and resolutions of DTMs) is different. The slope length (terrestrial measurement) and the DTM resolution of slope gradient measurement are not defined and standardized for scientific and practical purposes. Some terrestrial measurements and statements in literature represent maxima, others means of slope gradient. Often avalanches release from terrain breaks with significant differences of the slope gradient up- and downhill. A standardization of slope measurement for scientific and practical work is necessary.

A differentiation between primary and secondary avalanche release is necessary; secondary release is possible on slopes of less steepness.

Snow entrainment is already possible at little slope gradient. It increases with avalanche size.

The slope gradient threshold depends also on snow conditions and surface roughness.

Climatic conditions, snowfall and snow depth of observation periods of the individual studies had been different.

Climatic conditions of observation regions are different (e.g. in some regions rainfall is more frequent, therefore snow cover and soil moisture is higher and avalanches occur on slopes from less steepness).

Interpretation of literature statements about slope gradient and avalanche release has to consider the above mentioned aspects. The main tenor in literature is summarized in Table 3-7.

Table 3-7***: Dependency of avalanche frequency and*** *release size from mean slope gradient*

Mean slope gradient	Release of spontaneous avalanche: relative frequency - probability	
	Slab avalanche	Loose snow avalanche
< 20°	possible but unusual, very infrequent – **highly improbable**, only if snow is highly instable and wet on smooth slopes or secondary	
20° - 25°	very infrequent / **improbable**, only if snow is highly instable on smooth slopes or secondary	very infrequent/**highly improbable**, only if snow is highly instable on smooth slopes or secondary
25° - 28°	very infrequent/**less probable**, only if snow is highly instable on smooth slopes or secondary	
28° - 35°	frequent (common) / **probable** if snow is instable	very infrequent/**less probable**, only if snow is instable
35° - 45°	frequent (common) – **probable** at moderate snow stability / very frequent (common) – very probable if snow is instable	frequent (common) – **probable**, only if snow is instable
45° - 55°	frequent (common) – **probable** also at moderate snow stability	very frequent (common) – **very probable** also at moderate snow stability
55° - 60°	infrequent – **less probable** also when snow is instable	very frequent (common) – **very probable** also at moderate stability, but **mainly small** sluffs
>60°	very infrequent – **improbable**	very frequent (common) – **very probable** but **only small** sluffs

Conclusion:

The common slope range of avalanches is from 28 to 55 degrees. Under consideration of alpine periphery the probable slope range of significant avalanches may reach from 25 to 60 degrees. But release of significant avalanches on slopes lower than 28 degrees is highly improbable. Avalanche release frequency (probability) increases distinctly from about 35 to 55 degrees (see Figure 3-5).

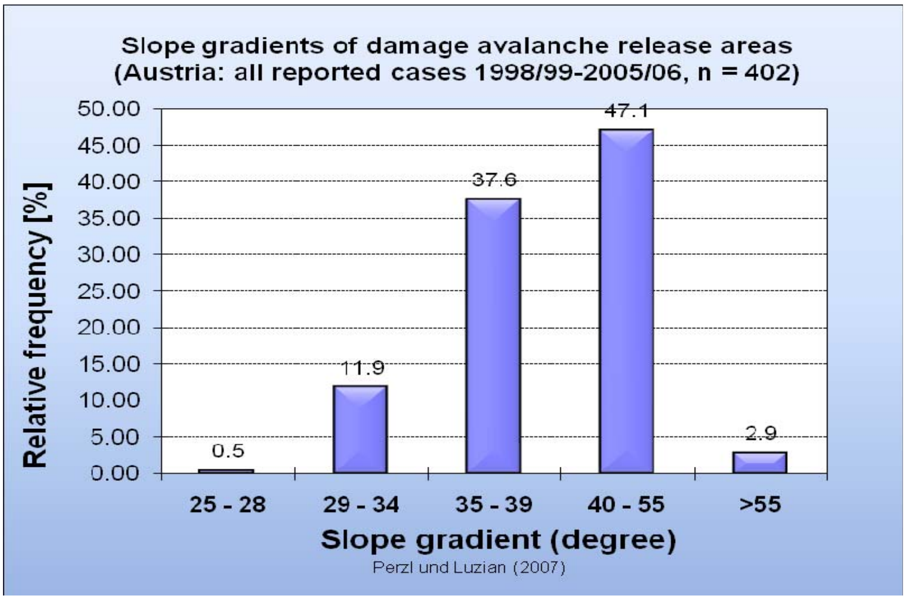

Figure 3-5: *Slope gradients of starting zones of hazarduous avalanches in Austria (from Perzl 2007).*

<u>Minimal downhill length and minimal area of starting zone:</u>

France, Germany and Switzerland defined threshold values of 50 m of slope length in order to model starting zones by GIS.

The thresholds for the minimum size of the starting zone in France (500 m²) and Switzerland (SilvaProtect, 5 000 m²) are quite different.

The length and the area of a starting zone are no indicators of the possibility of an avalanche release. An avalanche release is also possible on slopes with a length less than 50 m and from areas smaller than 500 m² (Figure 3-6). Pürstinger et al. (2003) mapped release zones between 460 and 20700 m² endangering a railway for example.

These thresholds are filter criteria for GIS spatial modelling to avoid the consideration of very small avalanches in order to minimize the number of avalanche path simulations.

The Swiss threshold refers to extreme avalanches with a return period of 300 years but disregards smaller avalanches which are frequent in alpine periphery zones and under forest cover (see Gruber & Baltensweiler 2005).

Meyer-Grass & Schneebeli recorded release depths of 20-150 cm of dry slab avalanches and 5-120 cm of wet snow-slides in forest, in the mean 100 and 30 cm. A plan area of 500 m² is covered from a snow panel of about 570 m² at a slope gradient of 28° and of about 870 m² at 55°. If the snow depth (release depth) is 150 cm the avalanche could have a release volume of 860 to 1 300 m³. Avalanches from about 1000 m³ are able to injure people.

Definition of thresholds for the minimal length and area of potential avalanche starting zones is difficult. Also a small avalanche from an embankment may reach a street and injure a person. This is a question of accepted risk. It is also possible, that a small avalanche from a slope shorter than 50 m initiates a bigger avalanche on slopes below normally to steep or to flat for avalanche release. But normally avalanches from slopes smaller than 25 to 30 m are not able to kill people or to damage vehicles and buildings (see also medium scale topographic factors).

Figure 3-6: *Small avalanche – sluff release on November 10th 2007 on a terrain face with a slope length of about 25 to 30 m. Snow avalanche formation is also possible from slopes shorter then 50 m, but the avalanche is small, if the slope gradient decrease distinctly or rather on terrain with concave – convex alternation of terrain curvature. Photo: Perzl (2007).*

Conclusions:

- Length and area of starting zones are no indicators of avalanche release probability. They are thresholds to avoid the consideration of very small avalanche release.
- Release zones smaller than 25 to 30 m are normally not able to kill people or to damage vehicles and buildings. Therefore a threshold length and width of 25 m is a careful value and corresponds to the minimal DTM resolution available in ProAlp countries.

Large scale topographic features:

An important large scale topographic indicator of AHPs is the plan curvature (see Gruber 2001, Maggioni et al. 2002, 2003). None or smaller avalanches initiate from a terrain with strongly convex plan curvature like ridges. From flat and slightly concave terrain like channel heads avalanche initiate more frequent and larger. Plan curvature affects the snow depth because of wind drift and snow accumulation. Therefore, ridges are often free from snow and huge amounts of snow are deposited in depressions. Because of the smaller wind velocity on forest terrain the differences are less significant and not so variable like spatial snow cover distribution of high altitudes above the upper timberline. But additionally the curvature influences snow mechanics. Snow cover areas with high shear strength develop often on trailing edges of ridges in the transition zone of convex and flat or slightly concave terrain. Therefore, on these locations avalanche initiates and the shear fracture enlarges to the flat or slightly concave terrain.

Gruber (2001) and Maggioni et al. (2002, 2003) defined thresholds for the plan curvature calculated with ESRI ArcGIS applicable with DTMs of 50 m resolution:

Plan convex area: plan curvature > + 0.2

Flat area: - 0.2 < plan curvature < + 0.2

Plan concave area: plan curvature < - 0.2

Evaluations with a 25 m resolution DTM from North Tyrol within ProAlp yield to these results:

Significant plan convex area: plan curvature > + 0.2

Slightly plan convex, flat an slightly plan concave area - 0.2 < plan curvature < + 0.2

Significant plan concave area: plan curvature < - 0.2 plan curvature > - 2

Extreme plan concave area (channelled terrain, gullies): plan curvature ≤ - 2

Beside the plan curvature an influence of the profile curvature on the hazard potential is probable (Maggioni et al. 2003). Pfister (1997) and Bebi (1999) assume that terrain breaks with convex profile curvature are favoured for avalanche initiation. The influence of profile curvature is in conjunction with medium scale topographic features and is probably strongly superposed by plan curvature.

Conclusions:

- The most important large scale topographic indicator of AHPs is the plan curvature. Calculation of plan curvature is possible from the DTM and can be done using standard GIS tools.
- The influence of profile curvature is not yet sufficiently clarified.

Medium scale topographic features:

The basic susceptibility for the initiation of big slab avalanches of significantly structured, irregular terrain is reduced. On such rough slopes the development of big and continuous snow panels is not possible. The same is valid for embankments with a short slope length.

There are the following basic types of medium scale topography with respect to avalanche initiation Schnetzer 1999, BMLFUW/BFW 2006):

- ° terrain with alternation of small channels and ridges.
- ° terrain with a high density of terrain breaks in flow direction (high alternation of slope gradient).
- ° humpy or hilly terrain and hybrids of a and b
- ° homogeneous terrain.

An indicator of medium scale terrain irregularity is the slope length. This is the length of the slope between terrain breaks in flow direction. This parameter is an indicator of potential release mass of avalanches, especially of release width. The slope length also affects water runoff and soil erosion. Therefore the slope length is an integral part of many environmental analyses, particularly erosion models.

In Austrian silvicultural guideline (ISDW) the indicator “slope length” is called “relief class”. The medium scale geomorphology (the slope length) is estimated by expert in the field, because of the problems of slope length calculation. The ISDW “relief class” is defined as the maximum length of the slopes between terrain breaks within a terrain section of homogeneous large scale topography. Three classes of slope length are in use:

1) Maximum slope length ≤ 50 m – small avalanche release zones – braking of velocity by terrain – decreased hazard potential.
2) Maximum slope length > 50 and < 100 m – medium avalanche release zones – mitigation of velocity by terrain – increased hazard potential.
3) Maximum slope length ≥ 100 m – large avalanche release zones – no braking of velocity by terrain – high hazard potential.

Slope length is as an indicator of hazard potential at ISDW, but not a threshold value, because avalanche release is also possible on slopes with a length less than 50 m. There are no quantitative statistics available about slope length and frequency as well as size of avalanches. In literature only controversial qualitative descriptions about the influence of medium scale topography are stated. But an influence of slope length on avalanche release and above all – on avalanche size and velocity – is very probable:

- The height of fall of avalanches in mountain forest areas is normally less than 150 m, in average about 100 m (Konetschny 1990; see also Jaccard et al. 1991). Beside the forest effect this could be also an effect of the irregular forest terrain with many terrain breaks. According to Zenke (1985) the energy line gradients (travel angles) of irregular avalanche paths with many significant terrain breaks in flow direction are higher than gradients of smooth terrain. This lets one conclude on a braking effect of terrain with short slope lengths.
- For maximum acceleration of an avalanche the continuous slope length must be more than 50 m (30 to 70 m; see De Quervain 1978, Frey et al. 1987, Burkard 1990).

Avalanches from a slope (starting zone) shorter than 50 m do not cause any damage in general (Figure 3-6). The minimum reported run length of damage avalanches in Austria (BFW damage avalanche database) was about 140 m (fall height 85 m, n = 70, Perzl 2007, unpublished).

Slope length calculations from DTM are still very problematic. Generating the slope length poses the largest problem in using the Universal Soil Loss Equation (USLE) from Wischmeier & Smith (1978) for erosion assessment, especially when applying it to real landscapes within a GIS (Hickey 2000). Numerous approximate solutions have been developed for calculation of erosive slope length (see Schäuble 1999). The main problem is the definition and determination of terrain breaks. The best estimates are obtained from field measurement, but these are rarely available or practical. For calculation of the medium scale topography with respect to avalanche hazard potential no validated models exist. For this purposes a DTM resolution of 10 m is necessary at least.

Conclusions:

- Slope length is an indicator of terrain roughness and therefore of potential avalanche release size as well as of the braking efficiency of the terrain.
- It is not possible to sufficiently calculate slope length with respect to avalanche hazard potential.

Small scale topographic features surface roughness and ground vegetation:

Surface roughness (including ground vegetation) is a very important factor of avalanche release prone terrain especially if snow depth is low. A high roughness of surface can prevent from avalanche release, if obstacles are not covered from snow. But in each case a high roughness of surface decrease the release depth of an avalanche and prevents full-depth avalanches (see Figure 3-7):

- Konetschny (1990) noticed: 80 % of forest avalanches release on smooth or medium smooth surface.
- Schaerer (1981): ground surface obstructions, e.g. boulders, stumps, logs, shrubs must be covered with some minimum snow depth before an avalanche can slide:
  - Smooth ground: 30 cm.
  - Average mountain terrain over timberline (dwarf shrubs): 50 cm.
  - Rough ground with boulders: 120 cm.

Figure 3-7: *Slab avalanche release scarp (altitude 1100 m, slope gradient 37 degrees, smooth gras layer, release depth 80 cm) is also a result of surface roughness (including the typ of herbaceous layer). On smooth surfaces full-depth avalanches can occur – rough surfaces prevent from snowgliding and full-depth avalanche but not from surface layer avalanches. Photo: Perzl (2006).*

McClung (2003) found a highly significant negative correlation between avalanche frequency and ground roughness height at Rogers Pass, British Columbia, Canada. Starting zone roughness was also significant negative correlated in multivariate relationship of parameters. According to McClung (2003) this denotes a possible relation of roughness to snow supply. Correlation between roughness and avalanche size had not been investigated.

The main problem of the implementation of this indicator in hazard potential assessment models is the measurement of the small scale surface roughness. Field mapping is the only reliable method currently.

Conclusion:

- Small scale surface roughness is an indicator of the hazard potential, especially for the potential release depth. The influence of surface roughness decreases with increasing snow depth and slope gradient.
- It is not possible to determine small scale surface roughness including ground vegetation with remote sensing techniques. Small scale surface roughness is an important parameter of water runoff calculation. For this purpose the possibilities of remote sensing techniques should be intensively investigated.

Exposition:

Regarding the influence of exposition on avalanche occurrence two aspects must be considered (Schaerer 1981):

- Orientation to wind (snow accumulation): avalanches are more common on the leeward than on the windward side of slopes.
- Orientation to sun: exposure of slopes to sun has little influence on average avalanche frequency, but must be considered in the day to day evaluation.

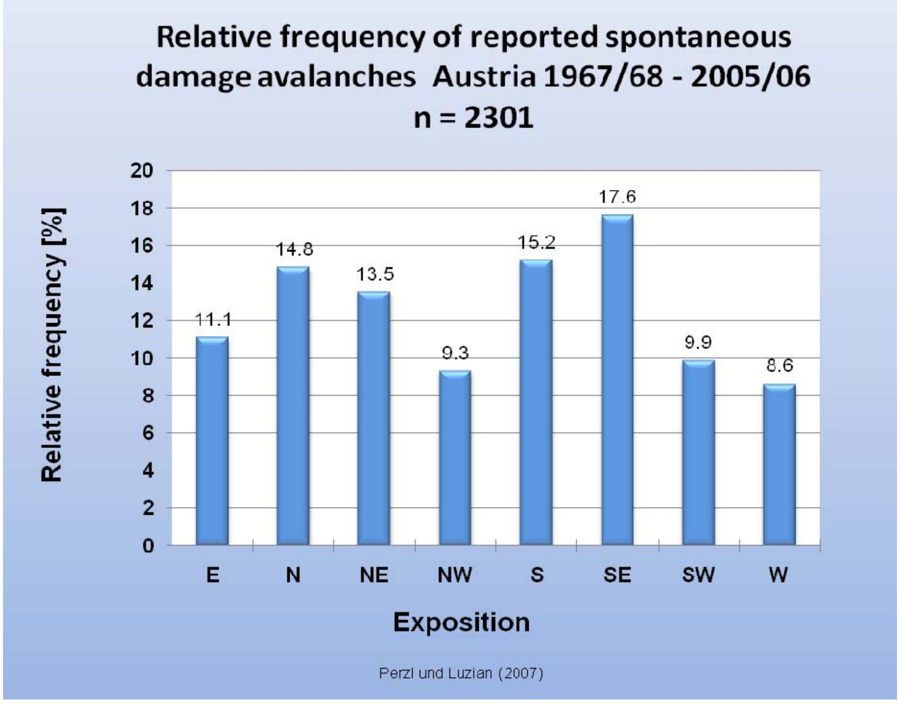

Figure 3-8: *Exposition and relative frequency of avalanches in Austria (BFW damage avalanche database, Perzl 2006, unpublished. Does not fit to text in figure!!*

There is an influence of exposition to avalanche frequency and size but in general avalanches are possible on slopes with any exposition (see Figure 3-8). Avalanche frequency of different expositions is not considerably various.

McClung (2003) could find no significant correlation of exposition with mean avalanche frequency and avalanche magnitude in multivariate relationship of parameters.

Conclusion:

- Exposition is not suitable for the indication of an avalanche prone terrain. It is not possible to model or quantify the contribution of exposition to snow depth and snow cover conditions. The distribution of events is too steady for practical assessment of avalanche hazard potential. But exposition an important factor of day by day evaluation.

Durability of snow cover:

Longer duration of snow cover means higher probability of hazard event (longer time of risk and damage potential presence). But the durability of snow cover is autocorrelated to snow depth.

Other indicators:

In literature some other indicators for avalanche prone terrain are mentioned. Several authors stated, that avalanches release more frequent in zones of terrain where the slope gradient changes (e.g. Imbeck 1986, Konetschny 1990, Sommerhalder & Meyer-Grass 1992, Kaltenbrunner 1993, Bebi 1999). This is a relation to the effect of the profile curvature. Changes between different slope gradients are often very subtle, but even such slight changes of only 2 to 5 degrees may trigger avalanches. This indicator is very sensitive and it is difficult to combine it with other influence factors. But the indicator is suitable for analysis of avalanche release starting zones in detail.

Summary – indicators of avalanche hazard potential:

The following indicators of avalanche hazard potential are suitable for harmonized reporting in the alpine space:

- Altitude: regional threshold values and a classification with at least 2 altitude levels are suggested.
- Slope gradient: threshold values: 28° to 55°, a ranking related to the hazard potential according to *Table 3-7* is suggested.
- Plan curvature: threshold values – 2.0 and + 0.2 are suggested.

Some other indicators are valid but data are not available or determination is not possible or reliable now.

Above all with respect to avalanche hazard potential NFIs should collect comparable data about surface roughness (including ground vegetation) on plots in future.

3.2.1.2 Indicators of avalanche protective effect

Many studies and publications deal with the influence of forest on avalanche release. But only few publications are based on original field data collection and analysis. There is no harmonized scientific monitoring system installed. Survey characteristics and forest structure are not standardized regarding to natural hazards. Therefore, it is often difficult to compare the scientific results of local and regional studies.

In order to evaluate the avalanche release protective effect of forest several systems have been developed. Most of this methods provide a binary decision (protective effect is sufficient or not sufficient), some also a qualitative ranking of the protective effect. But there is no method to determine the avalanche release protective effect of forest in terms of release probability and release size quantitatively taking into account the variable snow cover conditions.

Pfister (1997) und Bebi (1999) developed logistic regressions to determinate the probability of an avalanche release in a forest. Model inputs are several stand characteristics and two site characteristics (slope gradient, terrain break). Snow depth and altitude are not taken into consideration. The result of the regression function is the probability for avalanche release, a value between zero and one hundred percent. Authors assume sufficient protective effect of the forest if the probability is smaller than 50 %. Like many other models these regressions are based on the data of Swiss forest avalanche project from 1985/86 until 1989/90 (Meyer-Grass & Schneebeli 1992).

Meyer-Grass & Schneebeli (1992) worked out critical and demand values of forest stand characteristics by multivariate statistics with data from 118 avalanche release zones and 131 reference plots without avalanche initiation (Table 3-8).

Table 3-8: *Parameters, critical (crit.) and ideal (idea.) values of avalanche release danger according to Meyer-Grass & Schneebeli (1992)*

Parameter	Forest type									
	Deciduous forest		Mixed forest: deciduous, coniferous trees		Evergreen coniferous forest		Mixed forest larch, stone pine		Larch forest	
	crit.	idea.	crit.	idea.	crit.	idea.	crit.	idea.	crit.	idea.
Crown cover (%)	<80	>80	<70	>70	<35	>50	<30	>50	<35	>50
Stem number per ha	>450	>550	<280	>300	<190	>210	>200	>280	>180	>230
Gap width (m)	>5		>5	none	>10	<5	>10	<5	>10	<10
Ground vegetation (%)	>50	<35	>50	<50						
Slope gradient(°)	>38		>42		>38		>35		>32	

These demand values base on observations from limited representativeness:

Also on terrain with no forest cover relatively few avalanches occurred in the observation period.

Results are representative for the snow cover conditions of the observation period.

The sample stands have been only representative for a small portion of total forest area.

Some other important studies deal with the avalanche release protective effect of forest but without definition of threshold values:

Konetschny (1990) investigated forest avalanches in the Bavarian Allgäu Alps. Besides the Swiss forest avalanche study these investigations are the most extensive analysis of forest and avalanche interaction.

Smith & McClung (1997) investigated 46 partly forest covered avalanche paths and McClung (2001) 76 avalanche releases from clearcuts in British Columbia. But these studies deal with forest conditions without detailed differentiations of stand characteristics.

Three case studies from limited spatial extent were carried out in Austria:

1. Fiebiger (1978) and Schnetzer (1999) investigated avalanches in montane deciduous and mixed forest of the northern Austrian Alps.
2. Höller (1999, 2004) examined factors of snow gilding in sub-alpine larch forests of the Austrian Central Alps on basis of several years of snow gliding measurements.
3. A still important summarizing of forest effects on snow and avalanche – although not up to date – is the work from Frey (1977).

The findings of the studies about the influence of forest characteristics on avalanche occurrence are partly controversial. The main problem of the investigation and evaluation of avalanche release protective effect of forest is the high variability of climate, snow conditions, site and stand characteristics. For evaluation of the forest protective effect four silvicultural guidelines are available now:

Swiss NaiS (Frehner et al. (2005).

Swiss decision support system for management of wind thrown forests (BUWAL 2000) is similar to NaiS, but the evaluation of some stand characteristics like gaps is different.

French GMS (Cemagref/CRPF/ONF 2006)

Austrian ISDW (BMLFUW/BFW 2006).

Silvicultural guidelines from Austria (ISDW), France (GSM) and Switzerland (NaiS) use several indicators for the assessment of this avalanche protective effect of forest. Germany (Bavaria) and Slovenia have no corresponding guidelines. The indicators from different guidelines are quite similar; mainly the denomination of the indicators differs. In this way it is possible to group them (Table 3-9).

Table 3-9: *Indicators of avalanche protective effect of forests of ISDW, GSM and NaiS guidelines*

Indicator (stand characteristic)	Austria (ISDW)	France (GSM)	Switzerland (NaiS)
Hazard potential	x		
Crown cover	x	x	x
Stand composition (tree species)	x	x	x
Fraction of evergreen conifers	x	x	x
Dimension (development stage)			x
Dimension (tree height)	x	x	
Density (stem number)	x		
Density (basal area)		x	
Gap length		x	x
Gap width	x	x	x
Laying deadwood (in gaps)	x		(BUWAL 2000)

Below indicators and thresholds are discussed with respect to the guidelines and literature statements.

The protective effect of forests does not only depend on stand characteristics but also result from the interaction of variable environment factors (weather), constant site factors (e.g. slope gradient, surface roughness) and forest stand elements (e.g. crown coverage, stem density).

Therefore, in the Austrian ISDW system the hazard potential is a factor of the protective effect. The hazard potential is an aggregation of more or less dangerous or protective site conditions. A minor hazard potential (e.g. because of a less slope gradient or because of high surface roughness) is an indicator of a higher protective effect of the same stand in proportion to a higher hazard potential. For example, the roughness of the site (boulders, terrain depression) and the roughness and obstacles of the stand (e.g. stumps, trees) together have an impact on the mitigation of snow gliding and avalanche release. Especially the slope gradient affects the protective effect of a forest stand.

This concept is also realized partly under NaiS and partly under GSM guidelines (e.g. the dependency of gap size from slope gradient).

Crown cover – stand composition – fraction of evergreen conifers:

The crown cover is one of the most important protective elements of forest stands against avalanche release because of snow interception and climatic modification of snow cover (see Imbeck 1987, Höller 1999 and 2004, Schneebeli & Bebi 2004):

- Snow interception by branches results to a high irregular snowpack around the trees; therefore the formation of gliding layer is reduced around trees.
- Wind is a major factor of avalanche formation, but it is not possible to assess the wind influence on hazard potential; crown coverage of forest stands causes a significant reduction of wind speed in comparison to open areas; the effects of this reduction are minor

snow accumulations in terrain depressions and on terrain edges which are dangerous sources of avalanche formation.

- The climatic modification effects (radiation, snow and snow surface temperature) of the crown cover mitigates the formation of surface hoar on snow cover; surface hoar is the basis of gliding layers in the snow cover and a major cause of slab avalanche formation.

Such tree induced disturbances of snowpack layering are most pronounced below evergreen trees; the effect is less visible in the case of deciduous trees which tend to intercept less snow due to their much reduced snow trapping capacity in winter (Schneebeli & Bebi 2004). Additionally, the climatic modification effects of coniferous tree coverage are higher.

Therefore, the evergreen crown coverage can be supposed to be the essential protective element and an indicator of forest's protective effect against avalanche formation.

There are different ways to express the crown cover respectively different components of forest crown cover:

- Total crown cover (TCC) = crown cover of all trees of a stand (coniferous and deciduous species and dead wood).
- Conifer crown cover (CCC) = crown cover of coniferous trees of a stand.
- Evergreen crown cover (ECC) = crown cover of coniferous trees except Larix species.

Assumptions on the critical and ideal value of crown coverage are different in literature:

- Konetschny (1990): avalanches even occurred in dense evergreen stands (up to a crown coverage of 70 %), but mainly in light stands and 80 % in deciduous stands.
- Meyer-Grass & Schneebeli (1992):
    - Critical crown cover: dependent on forest type from > 35 to > 80 % (Table 3-12).
    - Ideal crown cover: dependent on forest type from > 50 to > 80 % (Table 3-12).
- Experienced data from Austrian practitioners (ISDW): minimal evergreen crown cover 40 to 70 % depending on slope gradient and altitude.

Demand values of crown cover of silvicultural guidelines:

- Swiss NaiS (Frehner et al. (2005): total crown cover > 50 %.
- French GMS (Cemagref/CRPF/ONF 2006), in evergreen forests crown cover is linked to the slope gradient:
    - Slope gradient of 30 degrees: evergreen crown cover of more than 30 %.
    - Slope gradient of 35 degrees: evergreen crown cover of more than 50 %.
    - Slope gradient 45 degrees: evergreen crown cover of more than 70 %.
- Austrian ISDW (BMLFUW/BFW 2006), crown cover is dependent on avalanche release potential (= Gefahrenstufe; derivated from slope gradient, snow depth/altitude, slope length and surface roughness):
    - Low hazard potential: minimal evergreen crown cover 0 % to 70 % (ideal) dependent on total stem density.
    - Medium hazard potential: minimal evergreen crown cover 0 % to 60 % (ideal) dependent on total stem density.

- High hazard potential: minimal evergreen crown cover 0 % to 50 % (ideal) dependent on total stem density.

ISDW accounts sufficient protection even with an absence of evergreen crown cover, if total crown cover respectively stems density is high (about 50 to 100 %). Because of reduction of stem density with increase of the stand age, therefore a minimum of evergreen crown cover of 30 to 40 % is recommended in each case of avalanche prone terrain. Swiss guideline BUWAL (2000) also assumes a sufficient protective effect of stands with no ECC in case of stands with stem number of 450 stems per hectare at least.

Beside TCC there is an influence of the stem number. Only in coniferous forests the stem number is highly correlated with the crown cover. In deciduous forests also with dense canopy the stem number may be low. The interspaces between trees can be so big that avalanches may initiate although the TCC is high (Konetschny 1990, Schnetzer 1999). Literature statements about critical tree interspace range from 5 to 10 m.

Conclusions:

The crown cover is the most important indicator of the protective effect. The protective effect increases with the crown cover, especially with the ECC. Even on sites with high hazard potential an ECC of about 70 % is able to prevent avalanche initiation. In many cases an ECC of about 50 % or a TCC of about 70 % are enough to prevent from significant avalanche release. The demand values of TCC and ECC depend on the hazard potential. They range from 40 to 70 %. There are clues that there is now big difference between the protective effect of ECC and CCC. Nevertheless the question is not unambiguously cleared yet.

Dimension – development stage and tree height:

Trees can only contribute to protective effects like snow interception; snow pack modification and mechanical anchorage of snow cover, if they are not covered by snow and pushed on ground by snow cover gliding forces (Figure 3-7). Two combined interactions result in snow covering of trees:

- The height of the trees is too small; the trees are snowed in – snow depth is larger than the trees.
- Due to vertical snow load, snow creeping and snow gliding forces, the trees are bended down to ground and then they are covered with snow.

Both effects result from tree dimension (tree height, stem diameter and growth habit) and site factors like high snow depth, snow density, slope gradient, soil moisture, little surface roughness and smooth herbaceous layer.

Therefore, this interaction is a complex and not completely explained function of several factors. But snow and forest scientists early developed a rule of thumb:

- Saeki & Matsuoka (1968): for resistance against snow covering the height of trees must be about twice of snow height (to have more than 50 % of trees of deciduous forest above snow cover).
- In der Gand (1968): height of trees must be about snow height (maximum snow height).
- Frey (1978): height of trees (European Larch) must be about 1.5 to 2 times higher than (maximum) snow height.

Conclusions:

In general, forest trees have avalanche protective effects if the medium height of the trees is about twice of the maximum snow depth. Since it is not possible to get models or maps of snow depth all over the Alps, a generalization is necessary:

- In deeper zones of the Alps with low level of snow depth and on slopes not stepper than 35° trees from a minimum height of 2 m are protective against avalanche initiation.
- In higher zones of the Alps and on steeper slopes trees from a minimum height of 5 m are protective against avalanche initiation.

Density – stem number and basal area:

Stem density (N): number of trees per hectare.

Deciduous forest stands are able to protect from avalanche formation through snow cover anchorage, too, if the stem number and the diameter of stem (the basal area) is high enough. Therefore, the assessment of protective effects needs to combine crown cover and stem number, because the number of stems can be quite different in a forest stand with a similar crown cover percentage.

A sufficient stem number is important in deciduous and mixed forests and in regions with higher frequency of winter rainfall or wet snow cover:

- Konetschny (1990): avalanches also occurred in stands with a stem number exceeding 1 600 individuals per hectare but mainly occurred in stands with less than 200 stems per hectare (wet snow in Bavarian Alps).
- Meyer-Grass & Schneebeli (1992): observations (and calculations depending from slope gradient): 180 to 550 (50 to 1100) stems per hectare with a diameter at breast height (DBH) larger than 16 cm are necessary to prevent from avalanche release.

The information about the necessary stem density is quite different. Comparison is difficult, because they often refer to very different site and stand situations (Table 3-10 and

Table 3-11).

Table 3-10: *Stem densities necessary to prevent from avalanche formation: results from different authors (cited from Frey 1977 and Perzl 2005), values from Salm's function for snow depth 2 m and without snowgliding conditions*

Stand type	Diameter [cm]	Slope gradient	Ishikawa et al. (1969)	Saeki & Matsuoka (1970)	Salm (1978)	Meyer-Grass & Schneebeli (1992)
larch timber crop	43.4	30°	N = 8	---	N = 328	
		50°	N = 206	---	N = 2 349	
spruce pole crop	22.8	30°	N = 28	---	N = 402	
		50°	N = 748	---	N = 3 004	
stone pine timber crop	36.0	30°	N = 11	---	N = 361	
		50°	N = 300	---	N = 2 539	
in general				30°- 40° N 200-900 >2-5 cm	30°- 50° N 300-2 000 >16.0 cm	30°- 50° N 50-1 100 >16.0 cm

Table 3-11: *Critical stem numbers dependent from gap length and slope gradient calculated from Pfister (1997) by multiple regression (critical avalanche probability = 50 %)*

critical stem number in mixed and deciduous forests (dbh >16 cm)									
Mean	gap length [m]								
slope gradient	0 m	10 m	20 m	30 m	40 m	50 m	60 m	70 m	80 m
30°	-	-	85	384	683	982	1281	1580	1879
35°	-	136	435	734	1033	1332	1631	1930	2230
40°	187	486	785	1084	1383	1682	1981	2281	2580
45°	537	836	1135	1434	1733	2033	2332	2631	2930
50°	887	1186	1485	1784	2084	2383	2682	2981	3280

Findings on stem number and avalanche release in literature are quite different, because it is difficult to isolate snow cover anchorage by stems from other effects of forest (e.g. interception of crown cover) at field observation and data analysis. Therefore some statements are founded on theoretical calculation. Demand values of crown cover of silvicultural guidelines:

Switzerland (NaiS): *No consideration of stem density – only crown cover is important.*

France (GSM): Differentiation of stem density demands by stand type, slope gradient and mean DBH:

- Evergreen stands (spruce, pine) e.g.:
  - Young stand DBH 5 cm, slope gradient 30°, N =1270.
  - Tree timber DBH 40 cm, slope gradient 30°, N = 100.
- Deciduous, larch and mixed stands e.g.:
  - DBH 5 cm, slope gradient 30°, N =2 550; slope gradient 40°, N = 5 090.
  - DBH 40 cm, slope gradient 30°, N = 180; slope gradient 40°, N = 410.

Austria (ISDW): *Differentiation of required stem density depending on the crown cover of coniferous, the hazard potential (slope gradient, snow depth/altitude, surface roughness) and the DBH (Table 3-12).*

Table 3-12: *Crown cover stem densities necessary to prevent from avalanche formation according to ISDW system*

Hazard potential avalanche release	Minimal limits for sufficient protection		
	Evergreen crown cover in %	Stem density large timber – young/pole stand DBH > 50 - 3 cm	Minimal gap width according to slope gradient
3	≥ 70	---	≤ 10 to ≤ 45 m
	≥ 40 – 70	400 – 3 500	
	- 40	500 – 8 000	
2	≥ 60	---	≤ 10 to ≤ 55 m
	≥ 40 – 60	300 – 2 500	
	<40	400 – 6 000	
1	≥ 50	---	≤ 10 to ≤ 55 m
	≥ 40 – 50	200 – 2 000	
	< 40	400 – 4 000	

Conclusions:

Stem density is important for avalanche protective effect of forest especially in forests with low crown cover of evergreen trees (deciduous and mixed stands) and in regions with snow gliding and wet snow. Therefore, threshold values of crown coverage by coniferous and stem density must be combined.

Statements in literature about the required stem number for avalanche protection are very various and not comparable. With the question after the critical and ideal stem numbers for avalanche protection there are still big uncertainties.

Determination of stem number is difficult. Variation of stem number in mountain forests is high. Additionally the local spatial distribution has an influence on avalanche protection. To this problem there is still no secure knowledge.

Gaps – gap length and gap width:

A gap is an interruption of crown cover in a forest. It is generally described by:

- The width parallel to terrain contour lines,
- The gap length in flow direction and
- The form of the gap.

In forestry two kinds of measurement of gap dimensions are in use:

- Total dimensions: gap width and length is measured directly (e.g. NaiS, ISDW).
- Relative dimensions: gap width and length is expressed in proportion to the height of surrounding stands (e.g. GSM).

Size measurement either refers to the distance between border stems (ISDW) or to the distance between the crowns edges (NaiS, GSM).

There is no standardized gap definition. Each country and almost each forest inventory or monitoring system use other gap definitions. Therefore, harmonization of gap definition is important for comparison of scientific results and NFIs information.

The minimal size of gaps for prevention of avalanche occurrence and damages is an essential item of mountain forest management. The critical gap size (minimal gap size without danger of avalanche initiation) affects the size of cuttings for stand regeneration and furthermore regeneration development, costs and commercial effectiveness of forest with protective effect management. Hence, the allowed gap or cutting size in forests with protective effect against avalanches has been discussed early in forest literature and above all by practitioners.

Many scientists and practitioners have noticed that avalanches prefer to initiate in gaps:

- Laatsch (1977) observed frequent avalanche initiation in gaps in Bavarian mountain forests. He noticed a relation between the slope gradient and the gap width prone for avalanche release.
- Konetschny (1990) did not discover any influence of gap length and width to avalanche occurrence, but confirmed higher release probability in gaps and smaller avalanche events from smaller gaps.
- Meyer-Grass & Schneebeli (1992) noticed the dependency of avalanche occurrence from gap width (5-10 m), but they could not find a relation between gap width and slope gradient like Laatsch (1977).
- Schnetzer (1999) observed a correlation between avalanche initiation and stem distance (gap width).
- Höller (1999) noticed that avalanches occur from snow gliding in gaps from a diameter of 8 m in subalpine larch forests.
- Schneebeli & Bebi (2004) pointed out a relation between permitted gap width and crown cover of the surrounding stand and slope gradient.

Recommendations of national silvicultural guidelines:

<u>NaiS (Frehner et al. 2005):</u>

Indicators: slope length, slope width and slope gradient.

Measurement: total dimensions from crown cover edges, minimum of crown cover interruption 10 x 10 m.

Frehner et al. (2005) recommend threshold values for the minimal gap length depend on slope gradient, although Meyer-Grass & Schneebeli (1992) could not find any relation between gap length and avalanche initiation. If the gap length is shorter than the threshold value in the NaiS there is no limitation to the width of gaps, even if the gap length is larger than the values recommended by Meyer-Grass & Schneebeli (1992) for avalanche prevention. Exceeding the threshold of gap lengths, limits for the gap width are established (see Table 3-13).

Table 3-13: *NaiS: critical gap lengths and widths for avalanche initiation (Frehner et al. 2005)*

Minimal requirement for avalanche prevention			Ideal requirement for avalanche prevention		
Slope gradient	Gap length		Slope gradient	Gap length	
	Conifers	Mixed, deciduous		Conifers	Mixed, deciduous
≥ 30°	< 60 m		≥ 30°	< 50 m	
≥ 35°	< 50 m	< 50 m	≥ 35°	< 40 m	< 40 m
≥ 40°	< 40 m	< 40 m	≥ 40°	< 30 m	< 30 m
≥ 45°	< 30 m	< 30 m	≥ 45°	< 25 m	< 25 m
Coniferious stands: If gap length is bigger, gap width must be < 15 m Mixed and deciduous stands: If gap length is bigger, gap width must be < 5 m			Coniferious stands: If gap length is bigger, gap width must be < 15 m Mixed and deciduous stands: If gap length is bigger, gap width must be < 5 m		

Obviously the approach of Frehner et al. (2005) starts from the assumption that avalanche initiation in gaps is harmless, if the avalanche cannot reach a critical velocity because of the gap length. Basics for the critical gap length have been calculated by De Quervain (1978), Frey et al. (1987) und Burkard (1990).

GSM (Cemagref /CRPF/ONF):

Indicators: gap length and gap width.

Measurement: relative dimensions from crown cover edges.

GSM recommendations of critical gap dimensions in avalanche starting zones:

- Gap length: ≤ 1.5 x height of the surrounding stand.
- Gap width: ≤ 0.70 x height of surrounding stand.

ISDW (BMLFUW/BFW 2006):

Indicators: gap width, tree composition of stand (quota of wintergreen crown cover).

Measurement: total dimensions from stem to stem, minimum of crown cover interruption 15 x 15 m.

Table 3-14: *ISDW: critical gap lengths and widths for avalanche initiation (BMLFUW/BFW 2006)*

Mean slope gradient	Critical gap width evergreen stands	Critical gap width Deciduous and mixed stands
25° - 28°	> 55 m	> 30 m
> 28°	> 45 m	> 25 m
> 34°	> 35 m	> 20 m
> 39°	> 25 m	> 15 m
> 44°	> 15 m	> 10 m

Because of unreliability and inaccuracies of gap length calculations from critical avalanche velocity and difficult gap length measurement in the field, ISDW focuses on prevention of avalanche initiation. Therefore, only the gap width is used as indicator for the protective effect. Slab avalanche scarps occur parallel to the contour line (Kaltenbrunner 1990). Critical gap widths (Table 3-14) are dependent on slope gradient and stand type and result from expert-interrogation (Perzl 2006). ISDW also takes into consideration the protective effect of lying timber stems in gaps, because of the increased surface roughness.

The critical dimension of gaps depends on several factors like slope gradient, snow depth, friction coefficient and stability as well as crown cover of forests on the bottom and around the gap. Dependent on the parameter assumptions results of theoretical calculation (see De Qervain 1978, Burkhard 1990) can vary widely and interpretation is difficult. Critical gap lengths recommended by Frehner et al. (2005) are considerably smaller then avalanche run out distances from gaps calculated by Gubler & Rychetnik (1990). They are also substantially smaller than forest avalanche run out lengths observed by Konetschny (1990) and Jaccard et al. (1991) and smaller then indications on critical gap length by McClung & Steizinger, published in Weir (2002). BUWAL (2000) states the same values than NaiS. But unlike NaiS the gap width is limited to 15 m in each case.

Conclusions:

A harmonised definition of gaps is necessary. For practical reasons a definition by total dimensions is suitable. It is suggested to define gaps as an interspace of the canopy from 10 to 10 m width and length in forest with a mean crown cover from more than 60 %. Below 60% crown cover it is not possible to detect gaps.

Gaps are dangerous weak points in forest structure regarding to avalanche initiation and mass acceleration. In addition, maximum gap dimension is an indicator of the protective effect of the forest. For avalanche initiation (slab avalanches) gap width seems to be the more important factor, while gap length affects the velocity, run out length and pressure of avalanche movement.

It is not unambiguously clarified, whether gap width or the gap length is more important for avalanche protection. Statements in literature are quite different, but it seems that in zones of more than about 10 to 20 m width without crown canopy avalanches are likely to initiate. Small gaps may be relatively harmless, if the gap length is limited to a range from 30 to 60 m dependent from the slope gradient.

Because of uncertainties of a combination of gap width and length and of the problems of calculation of gap widths from remote sensing data only gap lengths according to NaiS has been selected for ProAlp.

Deadwood:

At ISDW system the protective effect of lying deadwood in gaps is considered for avalanche release protection. Swiss studies on forest sites after windthrow (Frey & Thee 2002,) have proved that the avalanche protective effect of laying deadwood is very high. As long as the height of the deadwood layer is about equal than snow height no avalanches can initiate from slopes up to 39°. But therefore the density of deadwood must be sufficient too. Dead standing trees have also an avalanche protective effect like deciduous trees or larch in winter. With increasing decomposition of deadwood the avalanche protective effect decreases.

Determination of deadwood is difficult. Above all the height and the stem number of lying deadwood cannot be detected with remote sensing techniques. Austrian and Swiss NFIs collect data about deadwood on the plots. But because of the high variation approximations are not possible.

Summary – Indicators for avalanche protective effect used for ProAlp:

The following indicators are suitable for harmonised reporting because of validity and data availability as well as reliability:

- Total crown cover of trees higher than 2 or 5 m (depending on hazard potential).
- Conifer crown cover of trees higher than 2 or 5 m (depending on hazard potential).
- Hazard potential (basic susceptibility).
- Gap width.

For the reason of downscaling possibilities gap width was only taken into account for the fine scale approach.

The thresholds of these indicators are listed in the following table (Table 3-15).

Table 3-15: *Thresholds for the evaluation of the protective effect - avalanches*

Avalanche hazard potential (AHP)	Conifer Crown Coverage (CCC)	Total Crown Coverage (TCC)	Level of protective effect of forest
3	≥ 70 %	≥ 70 %	1 – Sufficient protective effect
	40-69 %	≥ 70 %	1 – Sufficient protective effect
		≥ 50 %	2 – Very little protective effect
		< 50 %	3 - Not sufficient protective effect
	< 40 %	≥ 80 %	1 – Sufficient protective effect
		≥ 60 %	2 – Very little protective effect
		< 60 %	3 - Not sufficient protective effect
2	≥ 60 %	≥ 60 %	1 – Sufficient protective effect
	40-59 %	≥ 60 %	1 – Sufficient protective effect
		≥ 40 %	2 – Very little protective effect
		< 40 %	3 - Not sufficient protective effect
	< 40 %	≥ 70 %	1 – Sufficient protective effect
		≥ 50 %	2 – Very little protective effect
		< 50 %	3 - Not sufficient protective effect
1	≥ 50 %	≥ 50 %	1 – Sufficient protective effect
	40-49 %	≥ 50 %	1 – Sufficient protective effect
		≥ 40 %	2 – Very little protective effect
		< 40 %	3 - Not sufficient protective effect
	< 40 %	≥ 60 %	1 – Sufficient protective effect
		≥ 50 %	2 – Very little protective effect
		< 50 %	3 - Not sufficient protective effect
0	---	---	0

3.2.2 Rockfall

Above all, forest is protective in the transit and run out zones of rockfall through braking the energy and velocity of the boulders. The effects of forest in rockfall starting zones are not well-known (Kalberer 2007). In rockfall starting zones forests have effects which could promote but also reduce rockfall initiation. An evaluation of all these partly contrary influences of a forest stand on rockfall initiation is very difficult (Jahn 1988, cited from Kalberer 2007)

Detection of starting zones

The first step of the assessment of rockfall hazard potential is to detect the potential starting zones and to estimate the size of rocks susceptible to fall from the cliff.

Multi-resolution analysis of slope gradient in known existing rockfall source areas in five sites in France, two in Austria, one in Switzerland and one in Liechtenstein, provided the threshold values presented in Table 3-16 for determining rockfall source areas in Digital Elevation Models (DEMs) with different resolutions.

Table 3-16: *Slope gradient of rockfall source areas*

Site	Resolution (m)	min (º)	max (º)	mean (º)	std (º)
ABW (Austria)	1	28.7	78.7	60.3	6.5
	2	35.0	77.2	60.3	5.7
	5	47.9	72.0	59.8	4.4
	10	45.3	65.8	58.1	4.5
	25	39.3	57.7	51.4	4.2
	50	39.4	51.1	43.8	5.2
Maurienne 1 (France)	1	60.0	83.2	66.9	5.1
	2	25.9	80.8	64.9	5.7
	5	35.8	75.3	60.7	6.3
	10	30.0	68.4	56.2	7.4
	25 upscaled	32.4	57.3	48.5	6.3
	25 downscaled	17.6	47.7	39.6	7.7
	50	13.5	45.3	33.3	14.1
Maurienne 2 (France)	1	45.0	83.0	55.2	8.2
	2	30.2	80.8	54.4	8.4
	5	26.7	75.3	52.0	8.5
	10	24.5	68.4	49.6	8.1
	25 upscaled	17.4	57.3	42.7	8.8
	25 downscaled	11.7	49.4	38.5	8.2
	50	13.5	46.2	38.5	9.2
Vic-sur-Cere (France)	5	31.6	71.2	57.5	7.1
	10	41.6	63.9	52.4	5.9
	25	32.1	48.8	41.6	5.6
Wipptal (Austria)	5	0.0	89.6	48.5	14.7
Steg (Lichtenstein)	2	19.0	83.8	52.5	13.5
	5	0.0	84.1	51.0	19.7
Plaffeien (Switzerland)	1	32.2	57.5	48.6	3.6
	10	24.1	50.7	42.2	6.1
Mont-Dore (France)	2.5	22.9	72.9	46.2	14.0
	10	23.9	56.9	40.2	8.8
St.Martin le Vinoux (France)	5	45.7	45.7	45.7	0.0

Based on these data a regression analyses led to the following threshold slope gradients in table 3-20 while the respective empirical relation can be formulated as:

$$\text{Slope\_threshhold} = 55 * \text{resolution (DEM)}^{-0.075}$$

Table 3-17: *Threshold values for determining Rockfall source areas in DEMs with different resolutions*

Resolution/cell size (m)		Threshold slope gradient (º)
1		55
2		52
5		49
10		46
25		43
50		41

For the derivation of starting zones of rockfall two different slope thresholds were used:

- Outside the forest mask and inside the rock mask a slope threshold of 43° was applied.
- Inside the forest mask a slope threshold of 39° was applied.

In the Swiss landscape model as well as in the Austrian digital map only few rock faces have occurred within the forest polygons. To find an alternative for identifying rockfall start zones within forests we decided to use only a slope gradient threshold of 39°. To account for underestimation of slope gradients due to higher errors in digital terrain models of forested slopes the threshold inside the forest mask is lower than outside the forest mask.

At present no data exist concerning the potential size of rocks. Also NFIs cannot survey the potential size on sample plots but actual size with restricted informative capability. Therefore, it is necessary to use generalized rock diameters due to most frequent rock diameter of rockfall events. This volume is about 0.5 to 1.0 m³. Currently no comprehensive statistics of the distribution of the size of rockfall depositions exist. But some case studies (Gsteiger 1989, Waibel 1997, Stoffel et al. 2006) show a predominating size of rocks (mean diameter) between 0.008 and 1.0 m³ (in the mean 0.6 m³), however big dispersions. Swiss and Austrian NFI collect data about the size of rockfall depositions at present. For the coarse scale no stone size was taken into account, while for the fine scale different thresholds for the protective effect according to stone size were used.

Derivation of transit zones

The second step of hazard potential assessment is to determine the transit and run out zones of rockfall from release zones. The rockfall hazard potential of the transit and run out zone can be classified by using values of generalized gradient and mean gradient of slope between starting zone and damage potential, since terrain steepness is essential for rockfall movement. Energy line angles can be used to define zones with different probable frequency and intensity of rockfall within the transit zones. A higher energy line angle means a higher probability of surpassing of smaller and bigger rocks. A lower gradient means a lower probability of surpassing rocks but with higher size. For ProAlp we defined the energy line angle with 31°.

Estimation of the protective effect of forests

For the assessment of protective effects of forests against rockfall the Rockfor.NET model from Cemagref is adaptable to NFI plot data and RS possibilities for downscaling.

Rockfor.NET calculates the Probable Residual Rockfall Hazard (PRH) under a forested slope. PRH is the percentage of rocks that surpasses the forested area of a slope. In order to calculate the PRH of a slope at a NFI sample plot some additional parameters would have to be collected by remote sensing and GIS analysis techniques.

Parameters / indicators necessary for rockfall protection assessment of forests by Rockfor.NET:

- Mean gradient of slope between starting zone and damage potential.
- Length of the forested slope.
- Length of the non-forested slope.
- Stand density.
- Basal area (DBH)
- Tree species composition.

Summary: For ProAlp finally following indicators and thresholds were used to determine the protective effect of forests against rockfall:

- Length of the forested slope (> 200m)
- Gap lengths in slope direction in relation to the forested slope length (<25%)
- Basal area
- Trees/ha and DBH

The thresholds are listed in Table 3-18 and Table 3-19.

Table 3-18: *Thresholds for the evaluation of the protective on the coarse scale – rock fall*

Basal area	Level of protective effect of forest
≥ 25 m^2/ha	1 – Sufficient protective effect
15 – 25 m^2/ha	2 – Very little protective effect
< 15 m^2/ha	3 - Not sufficient protective effect

Table 3-19: *Thresholds for the evaluation of the protective on the fine scale – rock fall*

Stone size	Trees/ha	DBH	Trees/ha	DBH	Trees/ha	DBH
Small	>600	>12 cm	>400	>12 cm	≤400	≤12 cm
Medium	>400	>24 cm	>300	>24 cm	≤300	≤24 cm
Large	>200	>36 cm	>150	>36 cm	≤150	≤36 cm
Protective effect	1 - Sufficient protective effect		2 - Very little protective effect		3 - sufficient protective effect	

4 Approaches of delineating forests with protective functions and of estimating their protective effect

Several steps are necessary to delineate forests with protective functions and to estimate their protective effect:

1. Forest mapping
2. Hazard modelling/mapping
3. Damage potential mapping
4. Mapping of forests with protective function by combining forest, hazard and damage potential maps using special GIS techniques to assign forest areas to endangered assets.
5. Estimation of the protective effect of these forests.

Within this project different analysis methods were compared and assessed for different types of data at two different scales.

Coarse scale: The approach on this scale provides an overview and screening over large areas. Landsat satellite images were used to derive general land cover and forest type information. With the kNN-method it was possible to downscale parameters from NFI data. A special aspect was the combination of NFI data from neighbouring countries: Together with cross-national remotely sensed image data, the fusion of NFI data from different countries was possible.

Fine scale: Detailed analysis of high-spatial-resolution remotely sensed image data (aerial photos and airborne laser scanner data) was carried out. Besides forest mapping, different parameters characterising the protective effect were derived. The analysis also included automated stereoscopic photogrammetric techniques.

The steps hazard modelling/mapping and damage potential mapping were elaborated independently of the scale. Forest mapping, mapping of forest with protective functions and their protective effect were derived with different methods on different scales.

Additionally to the derivation of the protective effect of forests with remote sense techniques, a so called “statistical approach” was used, where only NFI data formed the basis for protective effect calculations.

4.1 Coarse scale

k-nearest-neighbour (kNN) method

The k-nearest-neighbour method (kNN) is widely used for predicting and mapping forest attributes making use of field inventory data (e.g. from national forest inventories) and remote sensing data. The basic idea of kNN is quite simple: There are a number of pixels that coincide with the field plots where forest information is available. These pixels may be called plot pixels. For any other pixel that is not a plot pixel the forest attributes are to be predicted.

The spectral signature of such a pixel is compared with the spectral signatures of plot pixels in the same image. Those k plot pixels are selected that are most similar to the pixel under consideration. k is an integer, usually between 1 and 10. A common similarity measure is the Euclidean distance computed in the multispectral feature space. Varying importance and scaling of spectral features can be considered by weighting them individually in the calculation of the distance measure.

The forest information at the k plot pixels (i.e. nearest neighbours) is used to assess the forest attributes of the pixel under consideration. In this way, predictions of all the forest attributes that have been surveyed at the plots are obtained for all pixels. The predicted variables can be both continuous (regression problem) and categorical (classification problem; Figure 4-1), using either the k-nearest-neighbours' mean or mode. The weight of each neighbour can be a function of its spectral distance to the pixel under consideration.

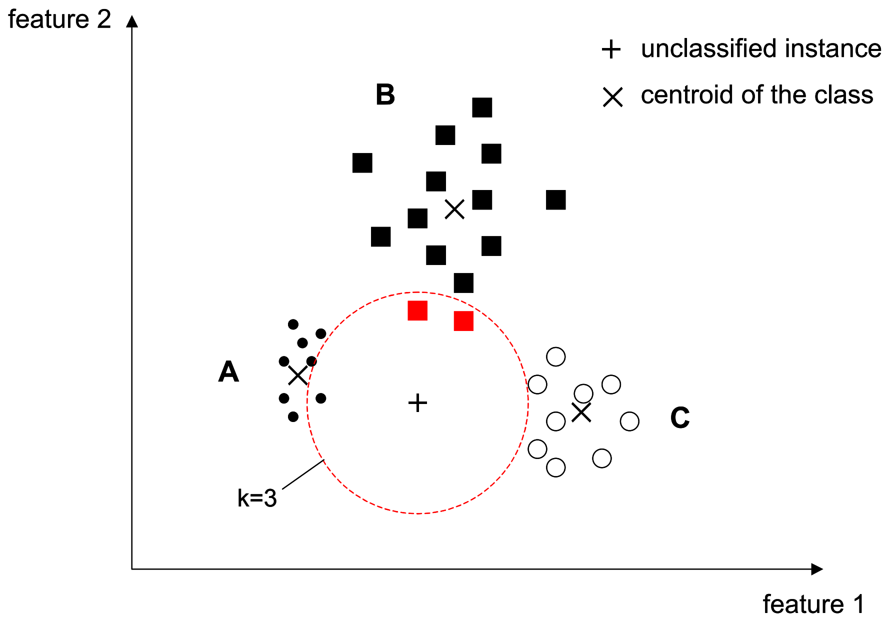

Figure 4-1: *kNN-classification in the 2-dimensional feature space. The instance to be classified is assigned to class B.*

Promising features of the kNN-method are the following:

- kNN is simple to implement but powerful if some preconditions are fulfilled (e.g. sufficient amount of representative field data).
- As no assumptions are made regarding the distributions in feature space, deviations from normality do not harm the accuracy of the predictions.
- The kNN-method may include spatial information into the prediction process. Varying site properties, e.g. climate and soil, that are responsible for gradients and local characteristics of many forest attributes such as forest composition, can be taken into account by restricting the selection of plot pixels to those from strata with similar site properties. Furthermore, a search radius both in horizontal and in vertical dimension can be defined to spatially restrict the search for the k nearest neighbours.

Before the kNN classification of a satellite image is executed some pre-processing has to be applied. The corresponding work steps are described in 5.2.1.

4.2 Fine scale

One main difference between the two scales is the fact that for the fine scale NFI data are not used directly for downscaling. For the derivation of a forest mask at fine scale airborne laser scanning (ALS) data were used. From the raw data (first pulse and last pulse) a regular raster was interpolated with a raster size of 2.5 m for the Test site F2 (Switzerland) and 1 m for Test site F1 (Austria). Using the difference between the digital surface model (DSM) from the first pulse data and the digital terrain model (DTM) from the last pulse data a normalised DSM (nDSM) was calculated (Figure 5-9, B). Buildings and artificial objects were filtered using standard topographic maps and so the nDSM could be used as a canopy height model (CHM). The indicators to estimate the protective effect were estimated directly from Lidar data and with the use of empirical relationships derived from a combination between Lidar data and NFI plot data.

4.3 Statistical approach

In general two different methods for the derivation of the protective effect can be thought:

Direct use of the plot information of the NFIs

Indirect use of plot information of the NFIs in combination with RS data (4.1.)

The first approach estimates the indicator values for the protective effect directly from the plot assessments followed by a statistical up-scaling procedure for larger regions with enough plots for ensuring the quality of the statistical estimates. Thus this procedure is referred herein as statistical approach. The second method uses the NFI data as information to be downscaled to each pixel of remote sensing images (4.1.). Afterwards maps can be developed and statistics can be calculated.

Mainly the second approach is used within ProAlp because large regions are necessary to enable sufficient statistical qualities of the estimates. A second shortcoming of the statistical approach is the fact it can only be used to estimate the protective effect for avalanche release areas. The protective effect against Rockfall can only be derived on the transit zone of the rocks thus concerning an area which cannot be covered by NFI plots. On the other hand the statistical approach has the advantage that the indicator values do have higher precision because of direct measurements in relation to the estimated pixel values.

Due to the fact that in the statistical approach no mapping procedure of the forest with protective function was carried out the results are presented already in this chapter for the test side C1a (Northern Tyrol, Table 4-1). Sixty-four sampling plots were factored in and the result shows that nearly 1/3 of forests with protective function have a sufficient protective effect. On the other side 42% of these forests don't have a sufficient protective effect.

Table 4-1: *Protective effect of forests out of statistical approach for test side C1a*

Protective effect	%
1 - Sufficient protective effect	27 %
2 - Very little protective effect	31 %
3 - Not sufficient protective effect	42 %

These findings can be compared to the results that are provided within the coarse scale approach (table 5-32). As can be seen the results are quite similar for the portion of sufficient protective effect although the ranges of the test sides do not coincide completely.

5 Modelling and mapping of forests with protective function and its effect at different scales

5.1 Test sites

The remote sensing part of ProAlp concerns the harmonisation of procedures for the estimation and monitoring of the protection function of forests at different scales.

On the coarse scale four test sites where established (C1 – C4), including five cross-border areas (C2-1, C3-1, C3-2, C4-1, C4-2). On the fine scale two test sites (F1, F2) where established.

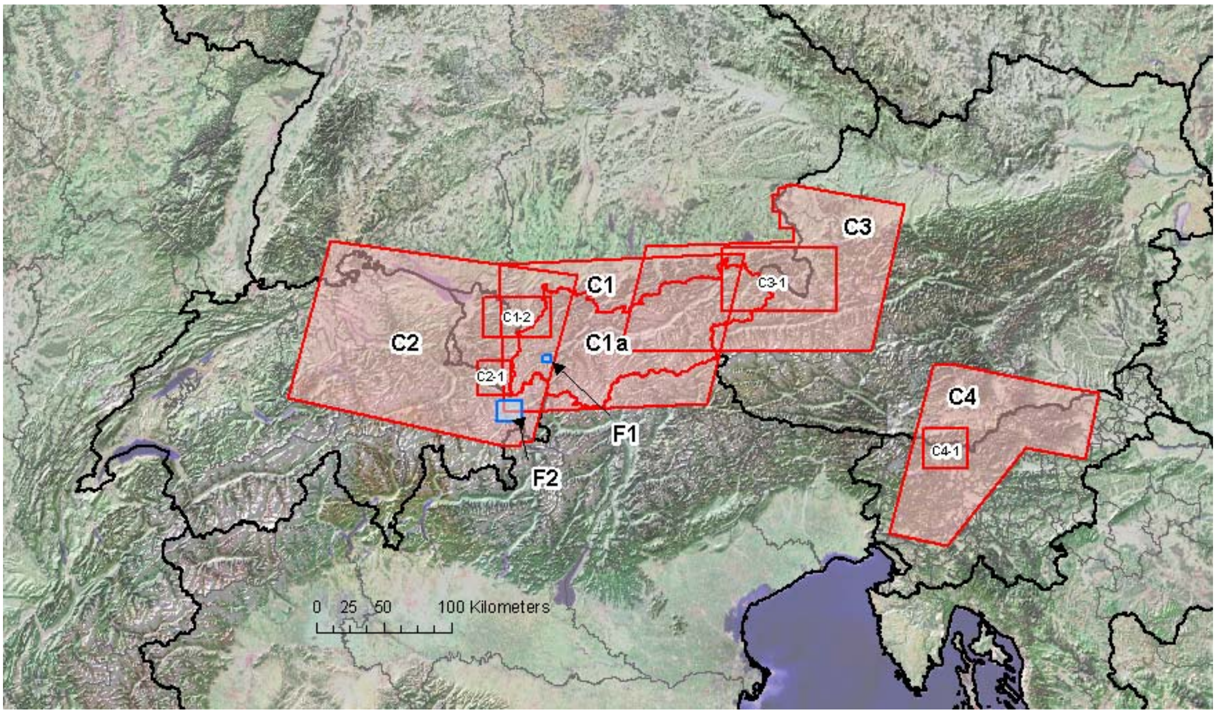

Figure 5-1: *Test sites for evaluating remote sensing techniques. C1-C4 coarse scale remote sensing data. F1-F2 fine scale remote sensing data.*

Different goals where intended in different test sites for the coarse scale (Table 5-1).

Table 5-1: *Completed work steps relating to ProAlp test sides (coarse scale)*

Steps/Test site	C1	C1a	C2	C2-1	C1-2	C3	C3-1	C4	C4-1
Forest Map	x	x	x	x	x	x	x	x	x
Hazard Modelling Avalanche	x	x	o	x	x	o	x	o	o
Hazard Modelling Rockfall	x	x	o	x	o	o	o	o	x
Damage potential modelling	x	x	o	x	x	o	x	o	x
Forest with protective function	x	x	o	x	x	o	x	o	x
Protective effect	x	o	o	o	o	o	x	o	o

For the two fine scale sites (F1 and F2) all the steps were carried out on both sites.

5.1.1 Coarse scale

C1: Parts of Northern Tyrol and Vorarlberg (Austria) and parts of Bavaria

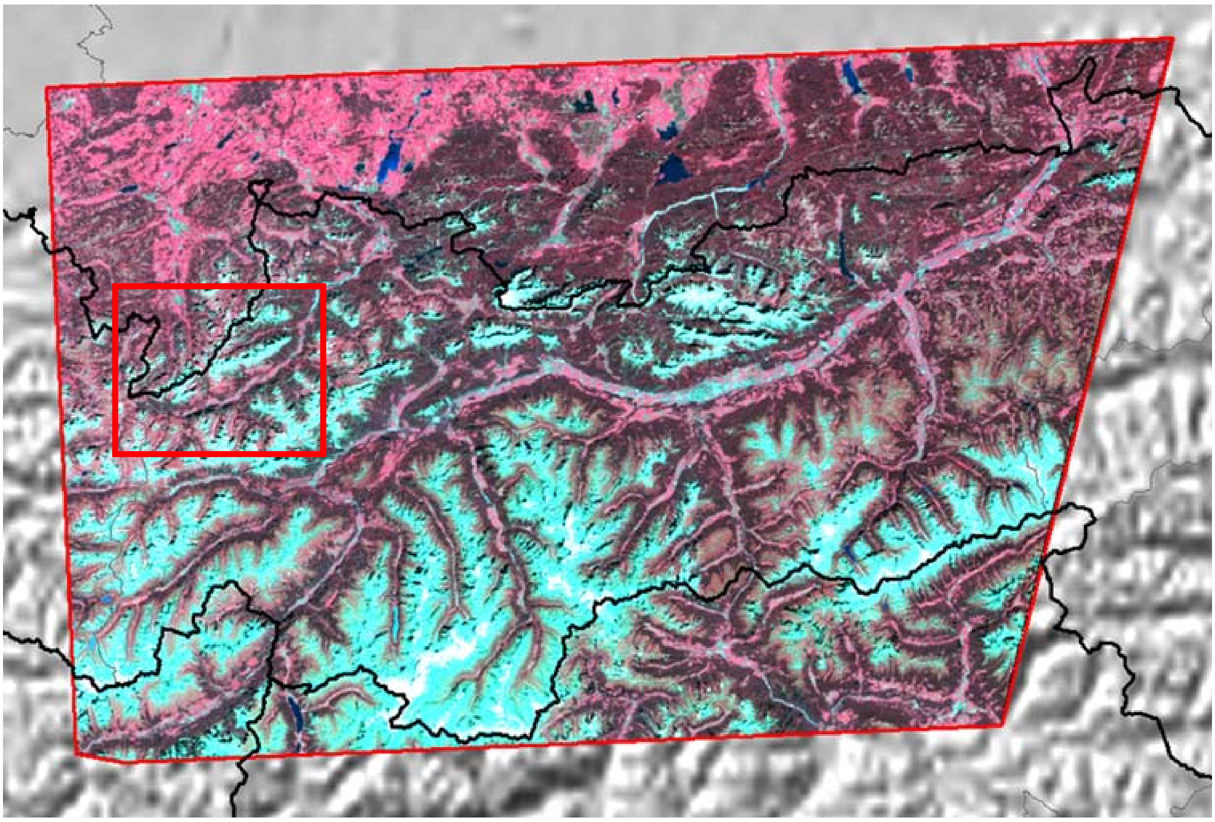

Figure 5-2: *Test site C1 – Parts of Northern Tyrol and Vorarlberg (Austria) and parts of Bavaria*

Location	Top:	2780390		
	Left:	4310791		
	Bottom:	2587550		
	Right:	4545001		
Coordinate Reference System:			ETRS_1989_LAEA	
Size		~9800 km²		
RS Material	Landsat ETM 7+	193_027	13.9.1999	30m
Training data:	700 forest plots from Austrian NFI			
DTM		30m		

Sub site C1-2:

Location	Top:	2720000		
	Left:	4310000		
	Bottom:	2680000		
	Right:	4360000		
Coordinate Reference System:			ETRS_1989_LAEA	
Size		3000 km²		
RS Material	Landsat ETM 7+	193_027	13.9.1999	30 m
DTM		25 m		

C1a: Northern Tyrol (Austria)

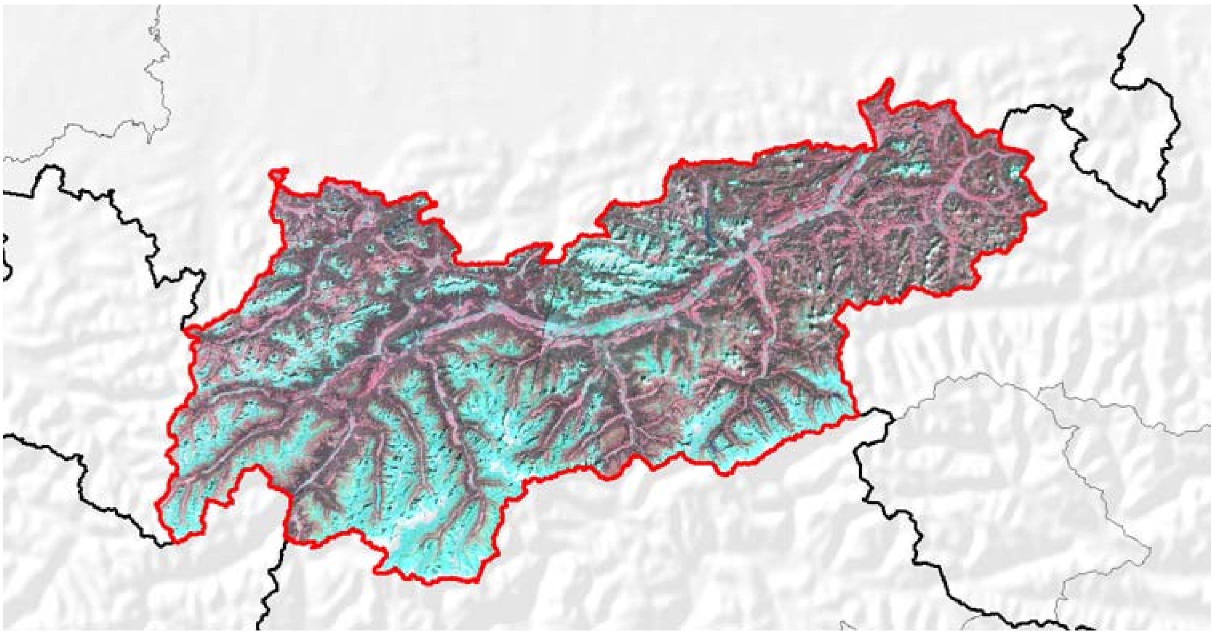

Figure 5-3: *Test site C1a – Northern Tyrol (Austria).*

Coordinate Reference System:			ETRS_1989_LAEA	
Size		~10’700 km²		
RS Material	Landsat ETM 7+	192_027	26.8.2001	30m
	Landsat ETM 7+	193_027	13.9.1999	30m

Training data: 193_027: Austrian NFI, 700 forest plots; 192_027: Austrian NFI, 1450 forest plots

DTM	30m

The test site for Austria to investigate forest with protective effect concerning rockfall and avalanches was Northern Tyrol. Two Landsat scenes were needed to get a forest map of the whole area of Northern Tyrol. Furthermore data from 4’340 Austrian forest inventory plots was available for the area that was covered by the Landsat scene 192_027 and data from 2’570 inventory plots was available for the area covered by the Landsat scene 193_027. This data was used as reference data for the kNN-estimation. The reason for taking one large test site was the fact that it was used for the statistical approach, which needs a representative sample of NFI plots falling into forest with protective function.

The radiometric topographic correction was done by using a digital terrain model (DTM) of Austria with a resolution of 30m.

C2: Cross-border Austria – Bavaria – Switzerland

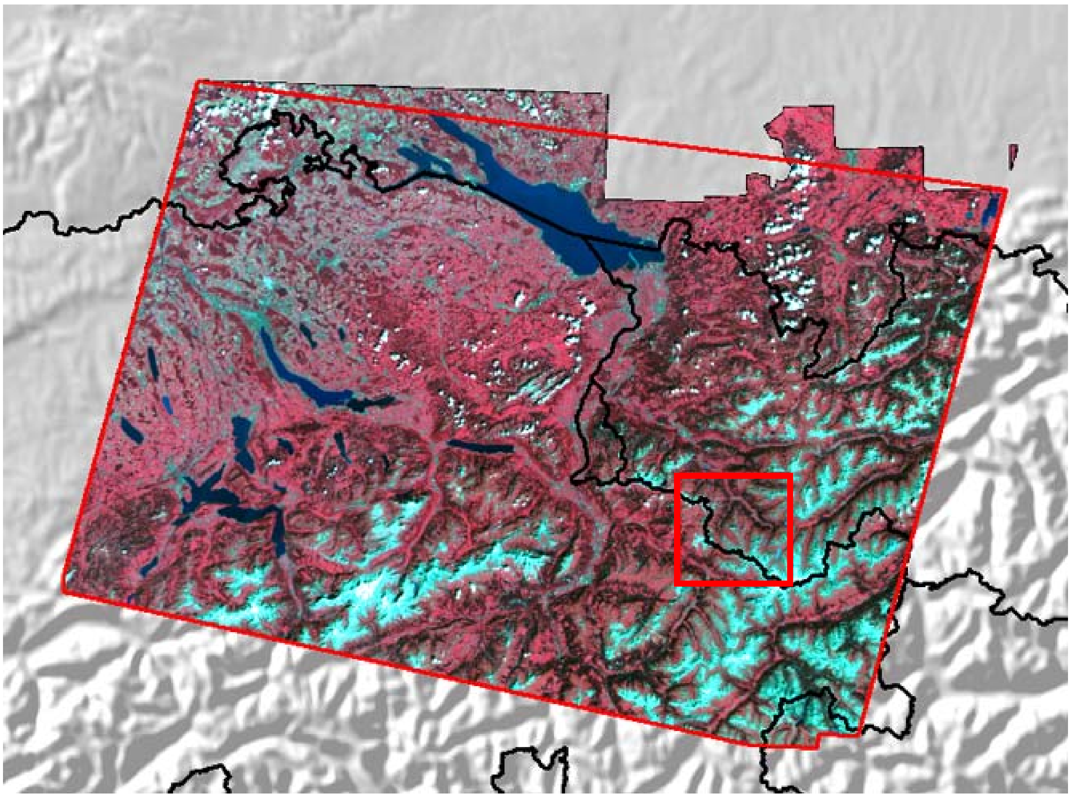

Figure 5-4: *Test site C2 and C2-1 – Cross-border Austria – Bavaria –Switzerland.*

Location	Top:	2780390		
	Left:	4310791		
	Bottom:	2587550		
	Right:	4545001		
Coordinate Reference System:			ETRS_1989_LAEA	
Size		~23600 km²		
RS Material	Landsat ETM 7+	194_027	24.8.2001	30m
DTM		30m		
Training data:		975 NFI Plots (Austria) 640 NFI Plots (Bavaria) 53'000 NFI Plots (Switzerland)		

Sub site C2-1:

Location	Top:	2662500		
	Left:	4305515		
	Bottom:	2637510		
	Right:	4330505		
Coordinate Reference System:			ETRS_1989_LAEA	
Size		625 km²		
RS Material	Landsat ETM 7+	193_027	13.9.1999	30 m
DTM		25 m		

C3: Cross-border Austria – Bavaria

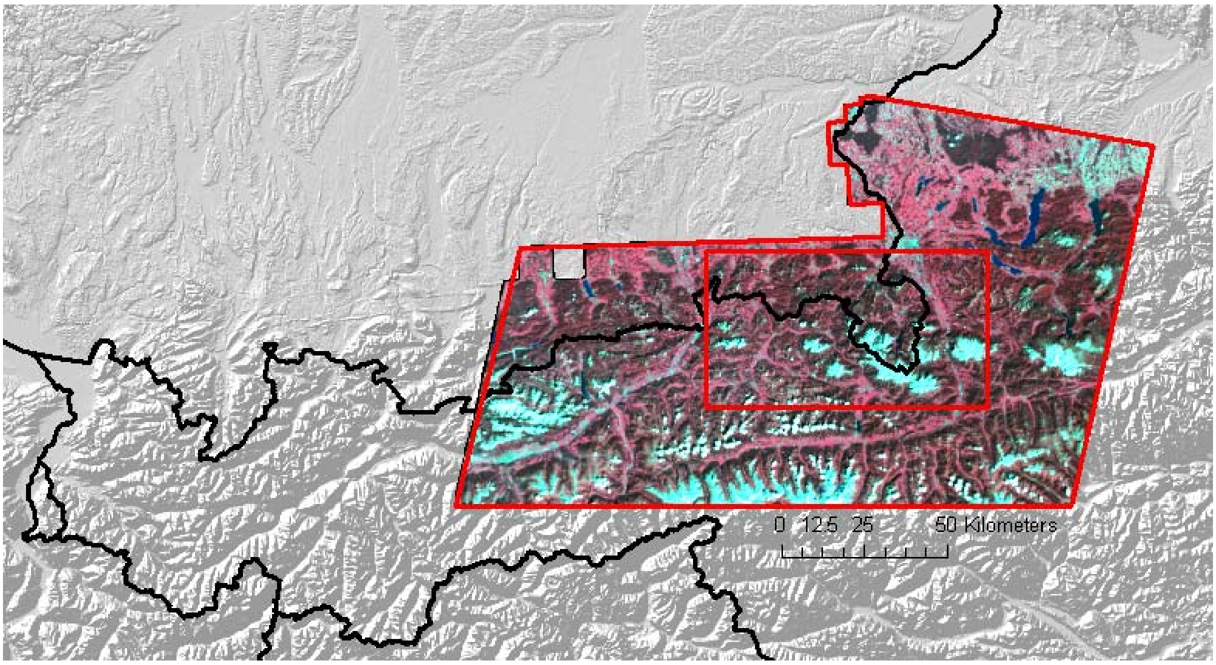

Figure 5-5: *Test sites C3 and C3-1 – Cross-border Austria – Bavaria.*

Location	Top:	2795000		
	Left:	4416000		
	Bottom:	2670000		
	Right:	4620000		
Coordinate Reference System:			ETRS_1989_LAEA	
Size		~17500 km^2		
RS Material	Landsat ETM 7+	192_027	26.8.2001	25m
Training data:		2'744 Plots (Austria)		
		548 Plots (Bavaria)		
DTM			25m	

Sub site C3-1:

Location	Top:	2747000		
	Left:	4487000		
	Bottom:	2700000		
	Right:	4572000		
Coordinate Reference System:			ETRS_1989_LAEA	
Size		4000 km^2		
RS Material	Landsat ETM 7+	192_027	26.8.2001	30m
DTM		25 m		

For the area chosen for cross-bordering forest mapping in Austria and Bavaria the Landsat scene 192_027 was used. In this case the resolution of the image was 25 meters. Besides the Austrian DTM parts of a Bavarian DTM were available. The DTMs had to be resampled to 25 meter resolution according to the Landsat image. It was possible to use data from 2'744 Austrian and 548 Bavarian inventory plots as training data.

C4: Cross-border Austria – Slovenia

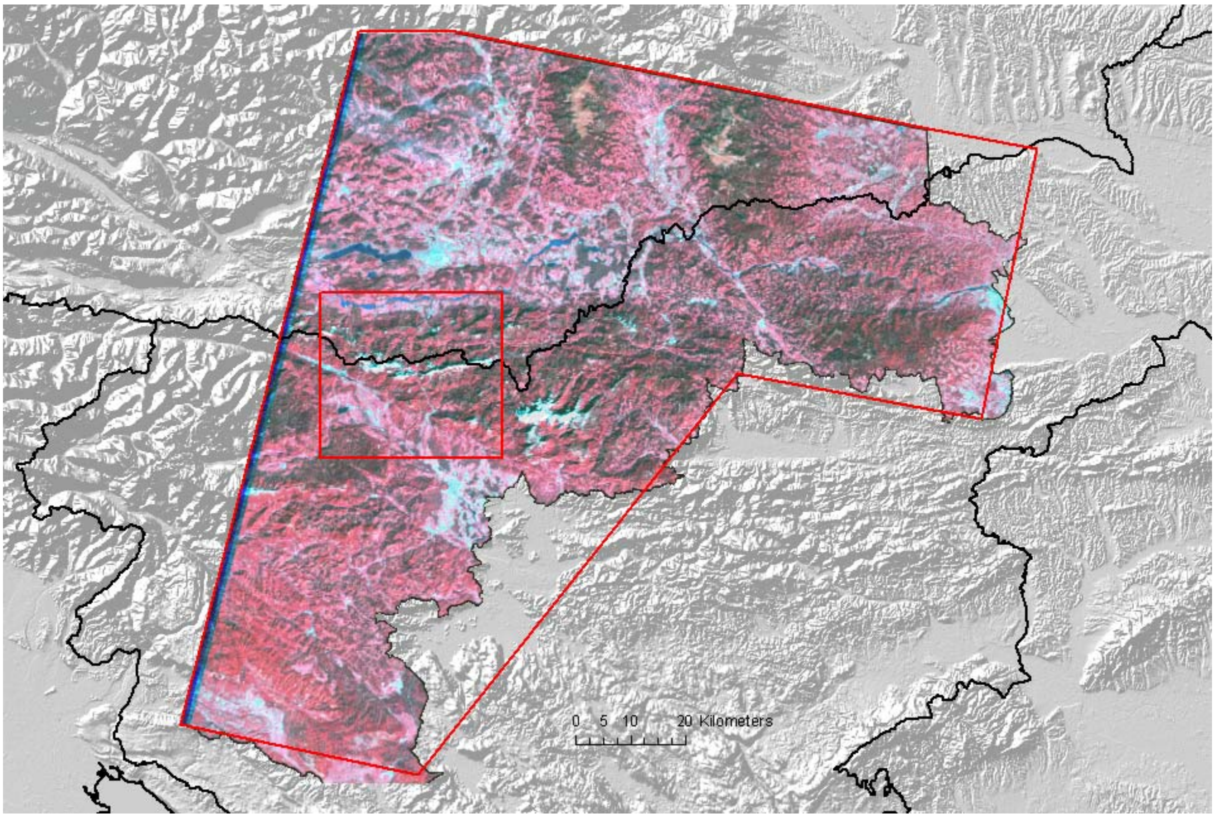

Figure 5-6: *Test sites C4 and C4-1 – Cross-border Austria.*

Location Top: 2660015
Left: 4599985
Bottom: 2524085
Right: 4765015

Coordinate Reference System: ETRS_1989_LAEA

Size: ~6630km²

RS Material Landsat ETM 7+ 190_028 10.9.2000 25 m

Training data: 750 Plots (Austria)

327 Plots (Slovenia)

DTM: 25 m

Sub site C4-1:

Location Top: 2613011
Left: 4635996
Bottom: 2583011
Right: 4668996

Coordinate Reference System: ETRS_1989_LAEA

Size ~ 900 km²

DTM: 25 m

5.1.2 Fine scale

F1: Paznauntal (Austria)

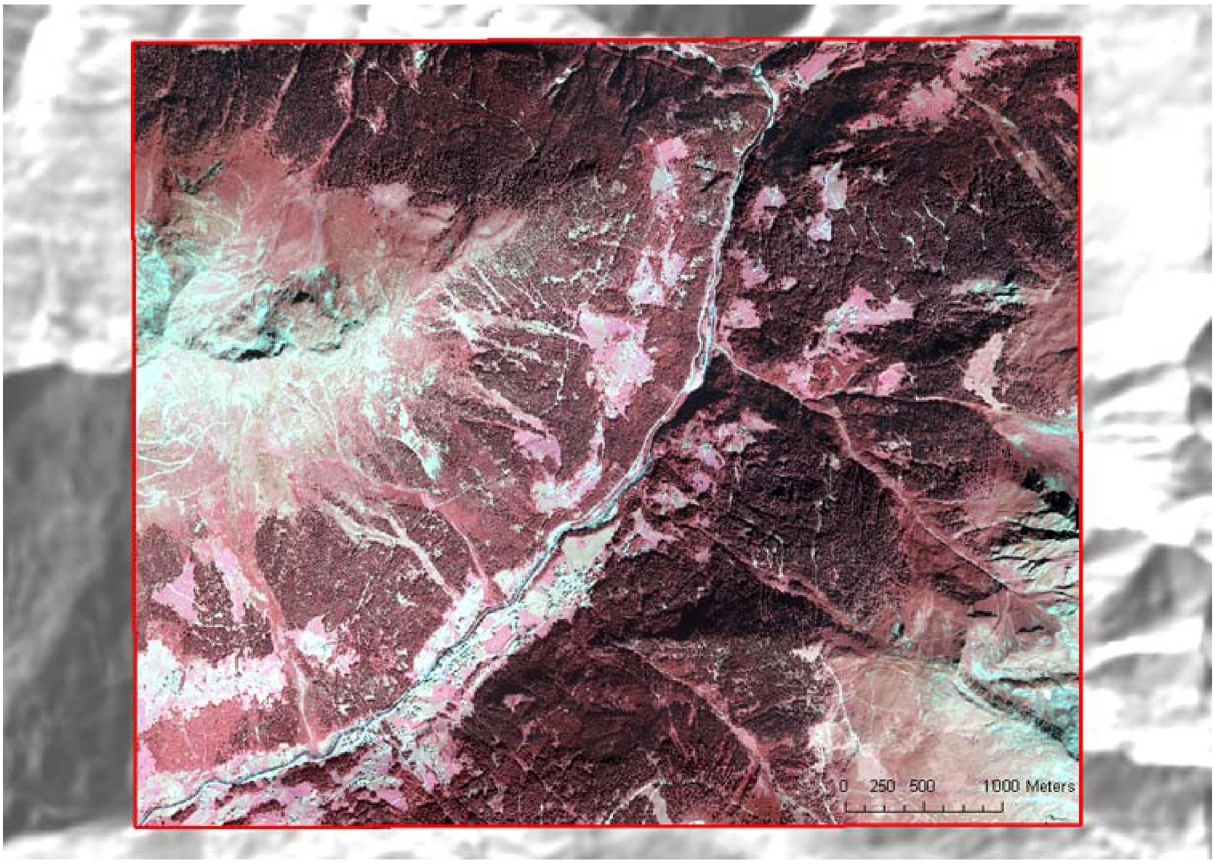

Figure 5-7: *Test site F1 – Paznauntal Austria.*

Location	Top:	2667387.49
	Left:	4354298.89
	Bottom:	2662362.49
	Right:	4360323.89

Coordinate Reference System: ETRS_1989_LAEA

Size ~ 30 km²

Aerial images

For the fine scale aerial digital photos (Ultracam Vexcel) with a ground resolution of 0.5 meters were used. The false-color-infrared photos were acquired during summer 2006.

LIDAR Data

The LIDAR data was acquired in summer 2006 by Swissphoto for the Tyrolean federal government. For this project no raw data points were available, only the derived Digital Terrain Model and the Digital Surface Model (1m x 1m). The CHM (canopy height model) is obtained by calculating the difference between DSM and DEM.

F2: Engadin (Switzerland)

Figure 5-8: *Test site F2 – Engadin (Switzerland).*

Location	Top:	2633469.91
	Left:	4319198.59
	Bottom:	2617944.91
	Right:	4339023.59

Coordinate Reference System: ETRS_1989_LAEA

Size 300 km^2

RS Material
ALS interpolated 2.5m x 2.5m (DSM + DEM)
DTM 25m x 25m
ADS40 1st Generation 0.5m x 0.5m (RGB)

5.2 Forest mapping

5.2.1 Methods

5.2.1.1 Coarse scale

As mentioned before some pre-processing work steps have to be accomplished before the kNN classification is put into execution.

Radiometric-topographic correction

Radiometric-topographic correction aims at recovering spectral signatures that are not disturbed by topographic effects. There is a big variety of methods for radiometric-topographic correction ranging from generating simple band ratios to employing complex models that additionally consider atmospheric conditions. Based on experiences from other studies, the Sun-Canopy-Sensor method (SCS) was selected to be applied in this project.

The SCS-method was developed to correct topographic effects in particular on forest surfaces (Gu and Gillespie 1998). Unlike other methods, such as cosine correction, this method pays attention to the geotropic nature of trees (vertical growth). Later, the method was enhanced by incorporating the diffuse sky radiation (Koukal et al. 2005) in order to avoid the well-known effect of overcorrection in areas that are poorly irradiated. The fractions of direct and diffuse sky radiation are estimated from the image itself with the help of linear regression. Due to this enhancement the method leads to satisfying results even in very rugged terrain.

The topographic information required for the SCS-correction (i.e. illumination and slope) was obtained from the SRTM (Shuttle Radar Terrain Model) with an original pixel size of 90 m.

In the following an example for using the radiometric – topographic correction is shown.

A Landsat 7 ETM+ scene (path 193, row 027, 19.9.1999) was used for forest mapping in the coarse scale. A major problem with this image is the low sun elevation in September, causing perturbing shadow and illumination differences between slopes of different expositions in mountainous regions. Therefore, a topographic normalisation procedure was applied to the image as a pre-processing step, consisting of dark objects subtraction and the SCS algorithm, extended for including diffuse sky radiation (Koukal et al., 2005). In the following figure the effects of the accomplished pre-processing steps are shown.

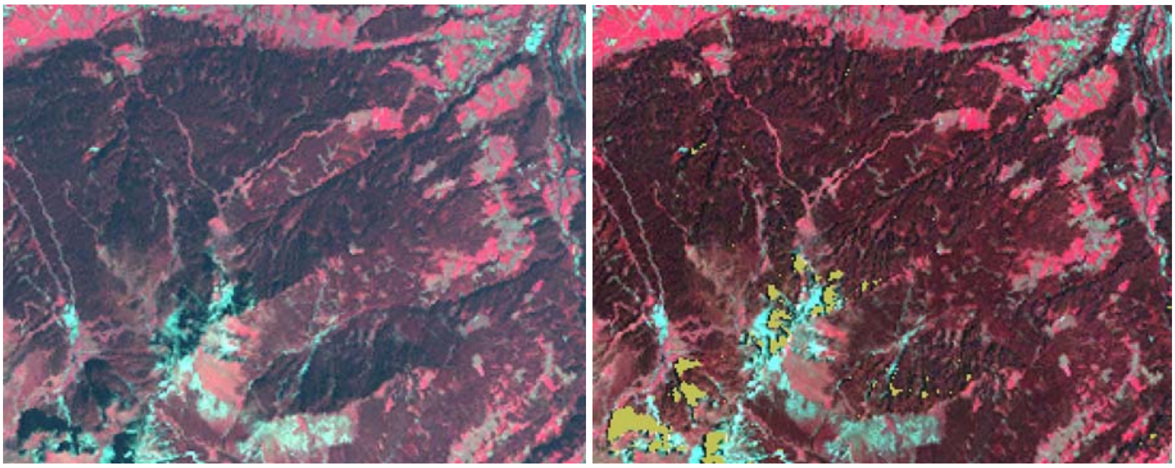

Figure 5-9: *Mountainous forest area in the south-west of Innsbruck, Landsat band-combination 4-3-2. Left side: original Landsat ETM+ image of 19. September 1999. Right side: Landsat image after topographic normalisation. Dark-yellow areas are shadow areas with pixel value null.*

Cross-validation

Cross-validation is a method to assess how well an algorithm will perform on future (i.e. as-yet-unseen) data. In this project, it is used

- for the selection of appropriate kNN-parameters (e.g. k, feature weights, neighbour weight function, parameters to spatially restrict the selection of plot pixels),
- for accuracy assessment, and
- for the detection of outliers in the reference data.

In cross-validation, the reference dataset of size N (i.e. the set of plot pixels) is randomly split into K disjoint subsets of approximately equal size. Each subset is used as a test set in turn, and the other K-1 subsets are put together to form the training set (K-fold cross-validation). The system is trained and tested K times. When K equals the number of observations N, the procedure is called leave-one-out (LOO) cross-validation. (Efron and Tibshirani 1993)

Cross-validation in general and LOO-cross-validation in particular is advantageous over more simple evaluation methods, such as the test-set method, because it uses the available reference data very efficiently. The higher efforts in terms of computation-time are negligible.

Cross-validation provides comprehensive information on the prediction process for each element of the reference dataset (i.e. for each plot pixel). This information can be aggregated to various measures of accuracy at pixel level both in regression and classification problems.

In regression problems, the Root Mean Square Error (RMSE) computed from the observed and predicted values as well as the Bias are used for parameter selection and accuracy assessment.

In classification problems, an error matrix is created and the performance of the algorithm is assessed by means of Overall Accuracy, Kappa, Producer's Accuracy and User's Accuracy.

Field plots that are close to each other (e.g. that belong to the same cluster) are very likely to be quite similar in terms of their forest characteristics. This may lead to over-optimistic estimates of prediction accuracy. Therefore, in cross-validation a plot pixel must not belong to the same cluster to be a valid neighbour.

Cross-validation can also be used to detect outliers in the reference data set. An outlier is an observation that lies outside the overall pattern of a distribution. An outlier may be a seldom event or an erroneous element of the reference dataset (e.g. due to a mistake during data collection), which is difficult to distinguish especially when the data is not normally distributed.

The kNN-algorithm is known to be very sensitive towards outliers leading to bad classification or estimation results especially when k is small. Therefore it may be desirable to detect and discard such elements from the dataset. In the context of the project, a plot pixel is regarded as erroneous if its spectral signature does not correspond to its forest attributes. Such errors may occur due to erroneous plot locations, land cover changes, mixed pixels etc.

The cross-validation procedure is an appropriate tool to trace the participation of each element of the reference data set (i.e. plot pixel) in the prediction process. You can see not only if a plot pixel is predicted correctly or not, but also how often it is identified as nearest neighbour and if it leads to right or wrong predictions. Based on this information, rules for the elimination of outliers can be defined, e.g. a plot pixel that is identified as nearest neighbour several times but never leads to a correct classification is probably an outlier and should be discarded.

The supervised non-parametric “kNN” algorithm was used for classification of this Landsat image (detailed information see section 4.2). The reference data was taken from NFI plots from Austria, Germany, Switzerland and Slovenia.

There are some problems that have to be considered. The fact that the date of the Landsat scene is different from the date of NFI field work brings along that certain land cover changes between the two acquisition dates may have happened. This land cover change cannot be exactly quantified in this work.

Another source of error is the difference between land use (represented by NFI) and land cover (shown in the Landsat scene) e.g., an NFI plot in an urban park is a non-forest plot irrespective of the trees located there. In the Landsat scene it is not possible to distinguish from spectral information if a stand of trees is a park or a forest according to the definition of the NFI.

To overcome this land use/land cover problem the resulting forest map should be enhanced and completed manually like it was done within the frame of the Austrian NFI in the year 2006 (see test site Northern Tyrol C1a): on the one hand information about the surface was missing because of clouds and shadows. On the other hand it was not possible to avoid misclassifications because of land use (forest/tree cover). Temporary unstocked sites or clear cuts and sites containing *Pinus mugo*, *Alnus viridis* and forest streets had to be digitized and classified as forest, on the other hand stocked areas like parks and gardens had to be digitized and classified as non-forest with the help of orthophotos.

Another problem is the localisation of NFI plot in the Landsat-scene. In both datasets there is a not quantifiable geolocation error. It can be assumed that this is the largest source of error in the forest mask generation.

Within ProAlp NFI data from different countries were available. One task was to investigate if different NFI data lead to different results concerning cross-national forest mapping. Another issue was the analysis if using different NFI data together lead to different results concerning cross-national forest mapping compared to results that were achieved by the use of NFI data from a single country. Several possibilities of using the different NFI data were accomplished which is described in chapter 5.2.2.

5.2.1.2 Fine scale

For the derivation of a forest mask using a moving window technique and a high resolution canopy height model were used (Figure 5-10).

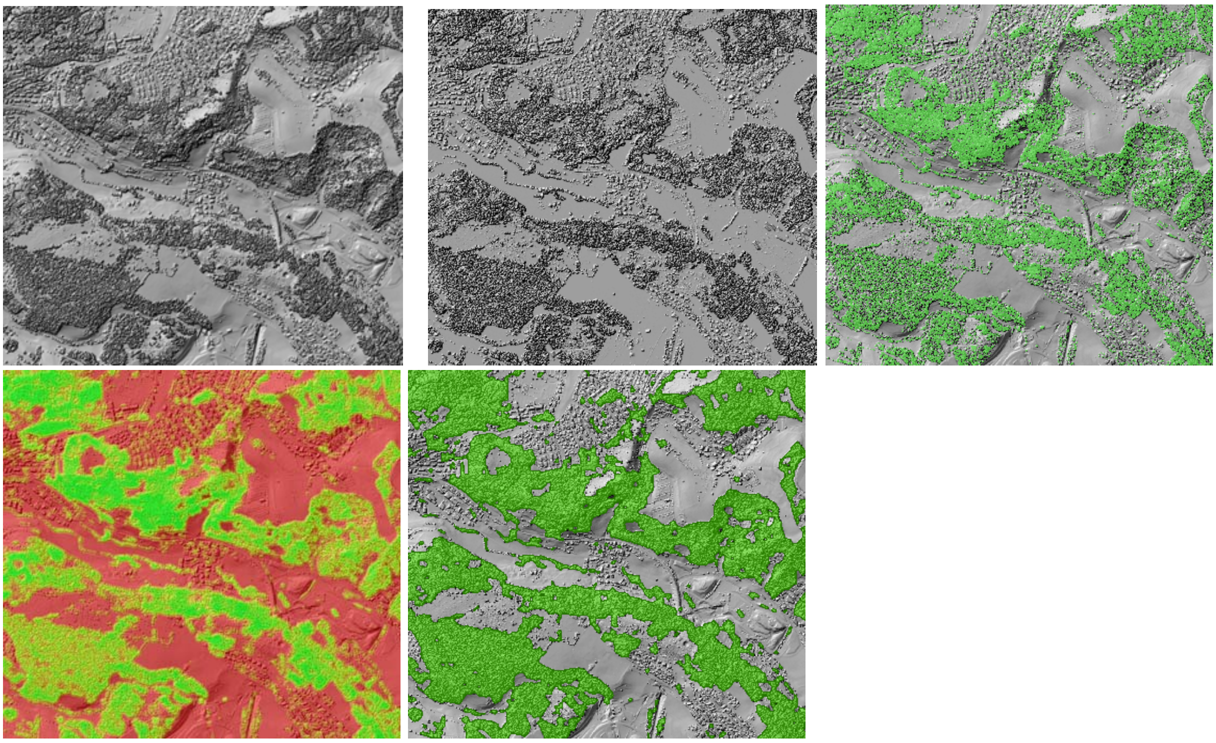

Figure 5-10: *Derivation of the forest mask: A: Shaded relief of the DSM. B: Shaded relief of the nDSM. C: Pixel ≥2m (green) filtered by buildings and artificial objects. D: Proportion of pixel ≥2m within a moving window (red=0%, green=100%). E: Forest mask (green) using a portion of e.g. 30%.*

For ProAlp project 'forest' is defined according to Table 3-1. The tree-threshold of 2 m was applied to the nDSM and within a moving window (the size of the window corresponds to the size of the interpretation window of 0.5 ha) the proportion of pixels ≥ 2 m was calculated. The result can be used as a crown coverage map (Figure 5-10, D) ranging from 0% (red) to 100% (green). Using the threshold of 30% crown coverage and removing areas smaller than 0.5 ha a fine scale forest mask is calculated.

<u>Substituting ALS (Airborne Laser Scanning) data by digital aerial photos:</u>

As a preliminary study within this project it was analysed how far digital aerial photos can substitute ALS data. Two different types of airborne digital photos (ADS40 and UltraCam) with two software packages (SocetSet, LPS) where tested in test sites F1 and F2.

For parts of the test site F2 in Switzerland digital images from the ADS40 sensor where available. The ground sample distance of the images is 50 cm. With techniques of stereo correlation it is possible to automatically derive digital surface models with very high sample distances (Figure 5-11). For the Swiss test site the NGATE module (Next Generation Automatic Terrain Extraction) of SocetSet5.4.1 (BAE System) was tested.

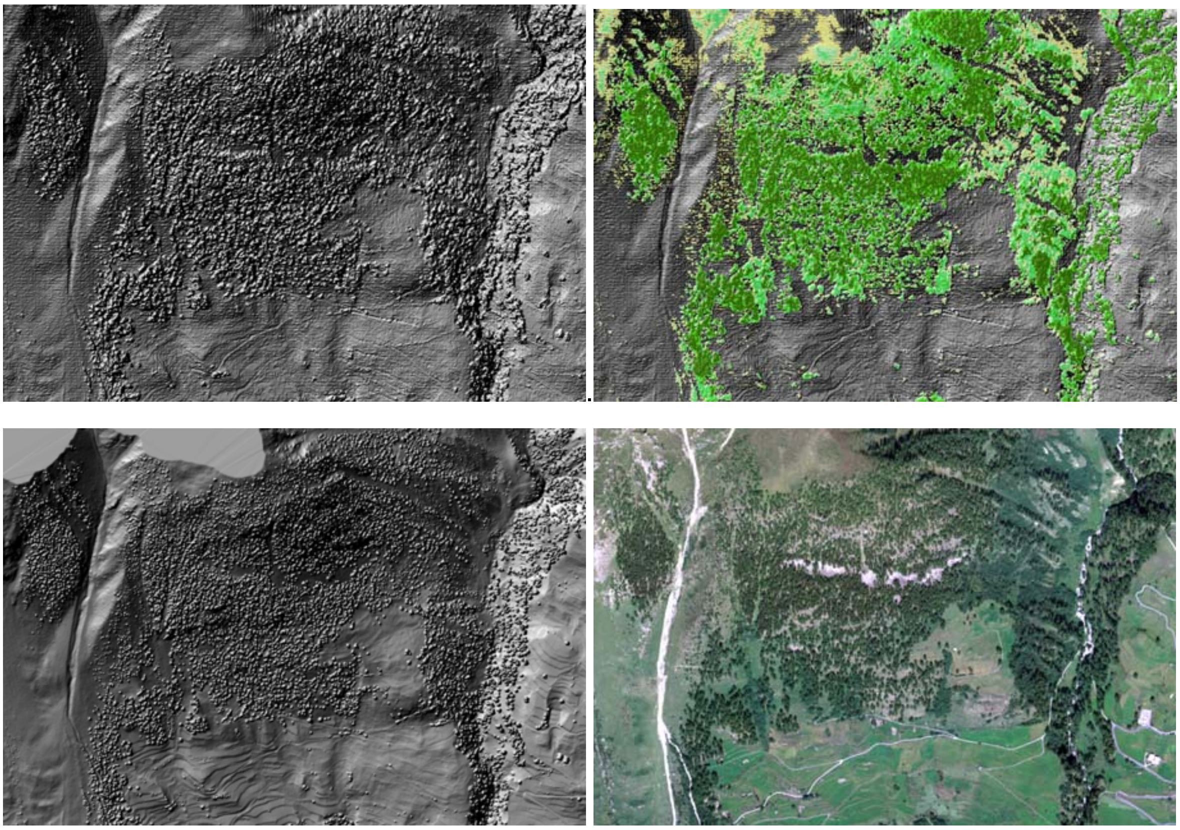

Figure 5-11: *Digital surface models by image stereo correlation methods. A: Hillshaded DSM from stereo correlation. B: nDSM (CHM) in three height classes. C: Hillshaded DSM from ALS. D: Orthophoto.*

The qualitative comparisons to the ALS results and the orthophoto are promising. Even small trees and wooded patches are extracted. The CHM gives reasonable results. Quantitative analysis and comparisons to the results from ALS data was not done within ProAlp.

For the triangulation of the aerial photos (UltraCam) and the DSM extraction the software LPS – Leica Photogrammetry Suite 9.2 was used. Appropriate parameters were determined for the DSM extraction such as the search window size, the correlation window size and different filtering modes. The results were compared to the ALS data and showed satisfying agreements (see Figure 5-12). Since a DTM could not be derived with image correlation methods, the DTM available from the ALS data was used for the calculation of a normalised DSM (nDSM). Using the nDSM as a crown canopy model it is possible to derive different forest parameters as described in the following chapters.

Figure 5-12: *Left: 3D-view of an Orthophoto where ALS data was used as height information. Right: 3D-view of an Orthophoto where the DEM derived from the Ultracam data was used as height information.*

Digital surface models can be derived by stereocorrelation of digital aerial images as well. The main advantage of using digital aerial photos instead of ALS data is that the acquisition of aerial photos is still cheaper than of ALS data. Additionally to the 3D information the spectral information of the digital images can be used. Aerial photos are more easily available and retrospective 3D information can be derived. ALS data often exist only for small areas.

5.2.2 Results and discussion

Test site C1: Parts of Northern Tyrol and Vorarlberg and Bavaria

In this case NFI data from Austria and Germany were available. As mentioned before it was analysed if the use of different NFI data leads to different results concerning forest mapping.

The first step was to perform a forest/non-forest classification with NFI plot data both from Austria and Germany. Here the problems explained in the section 5.2.1.1 are smaller than for the estimation of NFI parameters, mainly because only location problems in the forest/non-forest boundary areas affect the result. A location error in the forest/non-Forest boundary can make the difference that a forest plot falls on a non-forest Land-surface and vice versa.

There have been made different types of forest masks: using only NFI data from Austria, using only NFI data from Germany, combined both and all these combinations without NFI plots that are close to the boundary region between forest/non forest.

To evaluate the forest/non-forest mask the following confusion matrix was generated from all NFI plots (except NFI plots in Landsat shadow areas) in a kNN cross-validation procedure (Table 5-2). For the computation of the confidence intervals the observations were assumed to be binomially distributed. The confidence intervals for the accuracy estimates can be calculated with the help of the proportions of correctly and erroneously classified sample points. With p for the correctly an q for the erroneously classified points (in this case forest or non forest) the standard deviation of the proportional accuracy (SE) is $SE = \sqrt{(pq/n)}$ with n as number of samples used to calculate accuracy estimates. After calculating the 95% confidence interval the half-length of the confidence interval δ becomes $\delta_{0.5} = 1.96 \times SE/n$. The calculated proportional accuracies, their standard deviations and the half lenghts of the confidence intervals are shown in the following confusion matrices.

Table 5-2: *Confusion matrix with all Austrian and German NFI plots contained in the Landsat scene. Only NFI plots in shadow areas have been removed*

NFI Austria and Germany		NFI					
	k = 8	Non forest	Forest	Sum	User´s accuracy	SE	δ(%)
Classification	Non forest	1972	229	2201	89%	0.67	1.31
Result	Forest	300	1381	1681	82%	0.94	1.84
	Sum	2272	1610	3882			
	Producer´s accuracy	87%	86%				
	SE	0.71	0.86				
	δ(%)	1.38	1.69				
	Overall accuracy = 86%						
	Kappa = 0.72						

The result indicates a very modest quality (kappa value of 0.72). Therefore, it was tried to eliminate NFI plots with a high risk of error due to uncertainties of location. A forest/non-forest mask was produced with the NFI dataset still containing the problematic plots. This preliminary forest/non-forest mask was used to locate the problematic plots. It can be assumed that location errors mainly of the plots in the boundary regions between forest and non-forest will have an effect on forest mask quality. To define this problematic area, a shrink (width of 1 pixel) and a blow operation (width of 1 pixel) were applied to the preliminary forest mask. The resulting boundary areas (one boundary area inside the forest and one boundary area outside the forest) are areas with a high risk that a forest NFI plot is located on a non-forest pixel and vice versa. All NFI plots in these boundary areas were removed. The distribution of NFI plots in the defined areas is shown in Table 5-3.

Table 5-3: *Number of NFI plots in different areas based on the initial forest mask.*

NFI plots of Austria and Germany falling in the Landsat -scene	NFI in Landsat -scene	NFI not usable (shadow area)	NFI inside central forest area	NFI inside forest boundary area	NFI inside non-forest boundary area
Forest	1670	60	928	489	171
Non-forest	2394	122	35	236	551
Sum	4064	182	963	725	722

The confusion matrix obtained with the problematic NFI plots (40% of the initial data set) removed is shown in Table 5-4. The kappa value shows a rise of 0.22 compared to Table 5-2, and the overall accuracy of the forest/non-forest classification is 97%. The remaining error most probably is due to differences between land use and land cover, land cover changes between 1999 (Landsat) and 2002 (NFI).

Table 5-4: *NFI's in the areas close to forest/ non-forest boundary have been removed. Values to be compared with Table 5-2.*

NFI Austria and Germany boundary cleaned		NFI					
	k = 8	Non forest	Forest	Sum	User´s accuracy	SE	δ(%)
Classification	Non forest	1441	27	1468	98%	0.37	0.72
Result	Forest	44	923	967	95%	0.70	1.37
	Sum	1485	950	2435			
	Producer´s accuracy	97%	97%				
	SE	0.44	0.55				
	δ(%)	0.87	1.08				
	Overall accuracy = 97%						
	Kappa = 0.94						

Cross-national comparison

One of the efforts in the ProAlp project was to analyse the comparability of NFI data from different countries and to try to combine them for obtaining homogeneous and possibly better results in coarse scale mapping from Landsat by kNN classification. The tests to combine data from Austria and from Germany (Bavaria) for producing a forest/ non-forest mask gave the following results:

Table 5-5 to Table 5-10 show error matrices obtained in the cross-correlation analysis of the NFI pixel values. kNN results in general show a certain dependence on the value of k. The optimal value of k usually is different for every dataset. For the data shown here, the value k=8 was selected for which all datasets to be compared show near-optimal accuracy. Error matrices are shown for

- all Austrian NFI plots (except those in shadow areas), (←Table 5-5)
- all German NFI plots (except those in shadow areas), (←Table 5-6)
- Austrian NFI plots outside the forest/non-forest boundary area, (←Table 5-7)
- German NFI plots outside the forest/non-forest boundary area, (←Table 5-8)
- all Austrian and German NFI plots combined (except those in shadow areas), and (← Table 5-9)
- Austrian and German NFI plots outside the forest/non-forest boundary area combined. (← Table 5-10)

Table 5-5: *Confusion matrix with all Austrian NFI plots*

NFI Austria		NFI					
	k = 8	Non forest	Forest	Sum	User´s accuracy	SE	δ(%)
Classification	Non forest	1592	177	1769	90%	0.71	1.40
Result	Forest	196	732	928	79%	1.34	2.62
	Sum	1788	909	2697			
	Producer´s accuracy	89%	80%				
	SE	0.74	1.33				
	δ(%)	1.45	2.60				
	Overall accuracy = 86%						
	kappa = 0.69						

Table 5-6: *Confusion matrix with all German NFI plots*

NFI Germany		NFI					
	k = 8	non forest	forest	sum	user´s accuracy	SE	δ(%)
classification	non forest	400	58	458	87%	1.57	3.08
result	forest	84	643	727	88%	1.21	2.36
	sum	484	701	1185			
	producer´s accuracy	83%	92%				
	SE	1.71	1.02				
	δ(%)	3.35	2.01				
	overall accuracy = 88%						
	kappa = 0.75						

It can be concluded that

- the German data give better results (higher value of kappa)
- removing plots in the forest/non-forest boundary area has a positive effect both in Austria and in Germany
- combining the plot data from Austria and Germany gives a result in between the results for the individual countries.

The reason for the differing kappa values between Austrian and German data (both with and without the plots in the forest/non-forest boundary area) may lie in the different areal extent of the two datasets (see Figure 5-13). The German NFI plots cover just the foothills of the Alps. In addition, they are restricted to a quite homogeneous region. The results are homogeneous spectral characteristics of the forest data. The Austrian NFI plots lie in different regions from the central Alps to the northern foothills of the Alps. Here, the spectral characteristics of the forests are much more diverse than in Germany, thus the probability is higher that specific forest types of forest are spectrally underrepresented. In addition, the geomorphological variety on the Austrian side is much higher than in the German foothills of the Alps. The topographic normalisation cannot completely remove these effects.

Considering this situation, the two NFI datasets can be seen as comparable as far as forest/non-forest information is concerned. Other parameters of Austrian and German NFIs have not been compared yet.

It can be concluded that it is possible and advantageous to use both NFI datasets in combined form. The main benefit is that a wider range of characteristics of forest and non-forest pixels in the Landsat - scene is given.

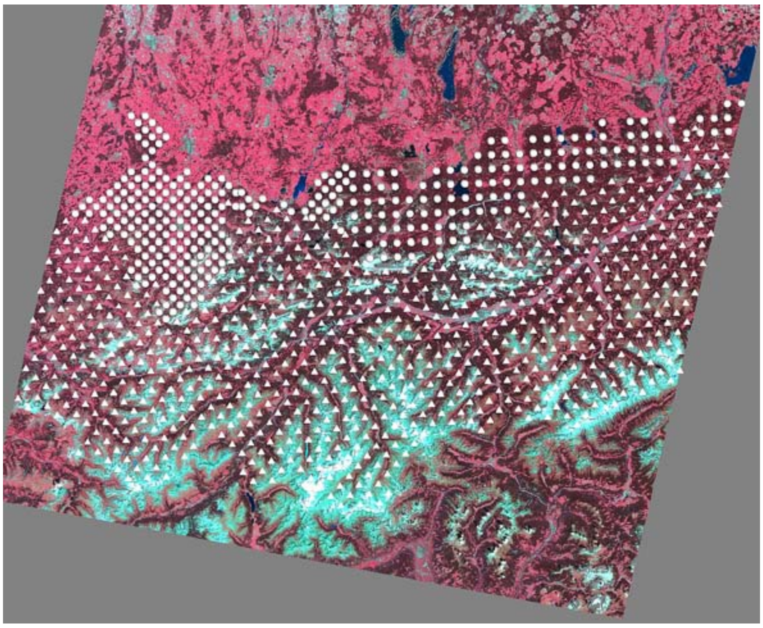

Figure 5-13: *NFI plots in Austria (triangular symbols) and in Germany (round symbols), Landsat band-combination 4-3-2*

Table 5-7: *Confusion matrix where NFI plots with high risk of failure are removed*

NFI Austria boundary cleaned		NFI					
	k = 8	non forest	forest	sum	user´s accuracy	SE	δ(%)
classification	non forest	1166	17	1183	99%	0.29	0.57
result	forest	34	496	530	93%	1.11	2.17
	sum	1200	513	1713			
	producer´s accuracy	97%	97%				
	SE	0.49	0.75				
	δ(%)	0.97	1.48				
	overall accuracy = 97%						
	kappa = 0.93						

Table 5-8: *Confusion matrix where NFI plots with high risk of failure are removed*

NFI Germany boundary cleaned		NFI					
	k = 8	non forest	forest	sum	user´s accuracy	SE	δ(%)
classification	non forest	274	7	281	97%	1.02	1.99
result	forest	11	430	441	97%	0.81	1.59
	sum	285	437	722			
	producer´s accuracy	96%	98%				
	SE	1.16	0.67				
	δ(%)	2.28	1.31				
	overall accuracy = 97%						
	kappa = 0.95						

Table 5-9: *Confusion matrix using all Austrian and German NFI's together*

NFI Austria and Germany		NFI					
	k = 8	non forest	forest	sum	user´s accuracy	SE	δ(%)
classification	non forest	1972	229	2201	89%	0.67	1.31
result	forest	300	1381	1681	82%	0.94	1.84
	sum	2272	1610	3882			
	producer´s accuracy	89%	89%				
	SE	0.66	0.78				
	δ(%)	1.29	1.53				
	overall accuracy = 86%						
	kappa = 0.72						

Table 5-10: *Confusion matrix where NFI plots with high risk of failure are removed*

NFI Austria and Germany boundary cleaned		NFI					
	k = 8	non forest	forest	sum	user´s accuracy	SE	δ(%)
classification	non forest	1441	27	1468	98%	0.37	0.72
result	forest	44	923	967	95%	0.70	1.37
	sum	1485	950	2435			
	producer´s accuracy	97%	97%				
	SE	0.44	0.55				
	δ(%)	0.87	1.08				
	overall accuracy = 97%						
	Kappa = 0.94						

Test site C1a: Northern Tyrol

When using Landsat data from the test side C1 only kNN estimation was accomplished (Figure 5-14). No further post-processing steps have been carried out to correct misclassifications that were mainly caused by hard shadows (pixel value = 0). With the use of further data those misclassifications can be corrected (see 5.2.1).

After enhancing the intital forest map (kNN algorithm) by digitizing manually orthophotos a forest map for Northern Tyrol could be established. This was elaborated within the frame of the Austrians National Forest Inventory during 2006.

A forest area of 4’182.9 km² was calculated for this test site (39.16% of the whole area of Northern Tyrol). This forest area was used as basis for hazard modelling mapping afterwards.

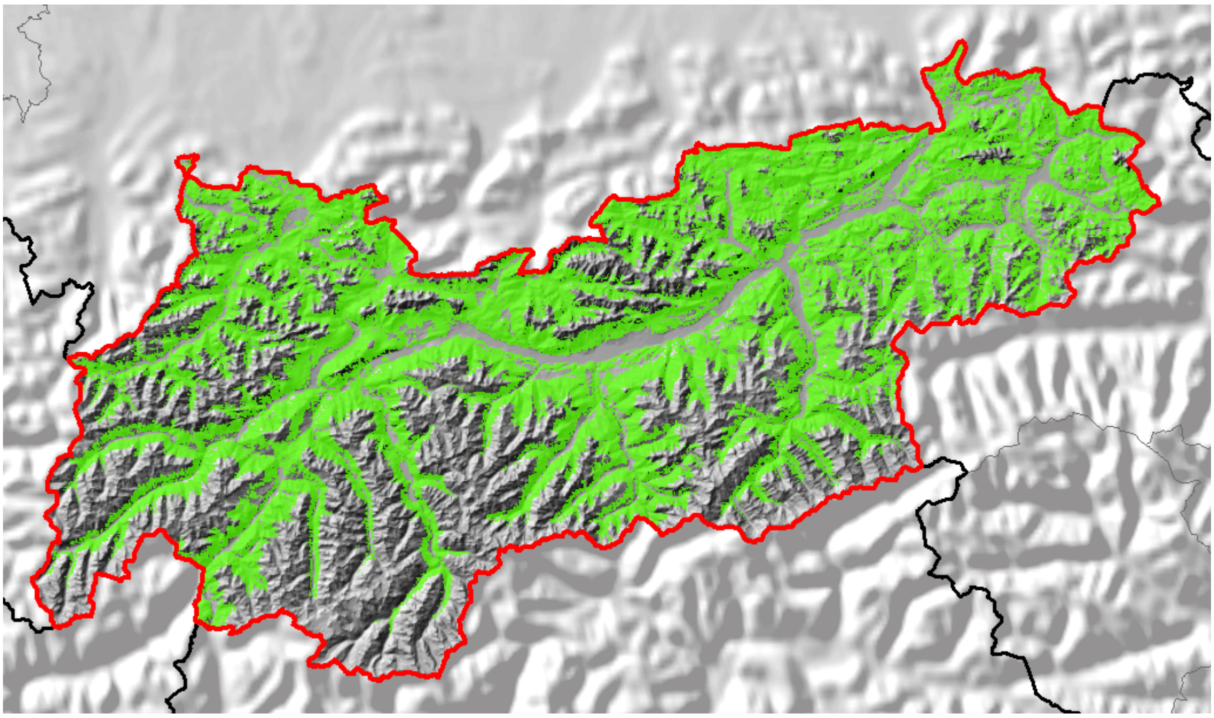

Figure 5-14: *kNN Forest map of Test site C1 – Northern Tyrol*

Test site C2: Austria-Bavaria-Switzerland

For the test site that was chosen for cross-bordering forest mapping concerning Austria, Bavaria and Switzerland the best results could be achieved with using Swiss NFI data (forest and non-forest). This evaluation was done visually. Furthermore the following confusion matrices were generated from the used NFI plots in a kNN cross-validation procedure again to evaluate the forest/non-forest masks (Table 5-11 to Table 5-17).

Table 5-11: *Confusion matrix with all Austrian NFI p*

NFI Austria		NFI					
all NFI plots	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ(%)
Classification	Non forest	660	102	762	87%	1.22	2.39
Result	Forest	96	162	258	63%	3.01	5.89
	Sum	756	264	1020			
	Producer´s accuracy	87%	61%				
	SE	1.22	3.00				
	δ (%)	2.40	5.88				
	Overall accuracy 81%						
	Kappa = 0.49						

Table 5-12: *Confusion matrix with Austrian NFI plots without eliminated outliers*

NFI Austria		NFI					
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	658	75	733	90%	1.11	2.17
Result	Forest	79	165	244	68%	2.99	5.85
	sum	737	240	977			
	Producer´s accuracy	89%	69%				
	SE	1.15	2.99				
	δ (%)	2.26	5.85				
	Overall accuracy 84%						
	Kappa = 0.58						

The quality is enhanced after outliers have been eliminated. Outliers are NFI plots that mainly lead to false kNN classification results and can be detected easily. They mainly are within the forest/non-forest boundary area.

Table 5-13: *Confusion matrix with all German NFI plots*

NFI Germany		NFI					
all NFI plots	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	294	68	362	81%	2.06	4.04
Result	Forest	87	221	308	72%	2.56	5.01
	sum	381	289	670			
	Producer´s accuracy	77%	76%				
	SE	2.16	2.51				
	δ (%)	4.23	4.92				
	Overall accuracy 77%						
	Kappa = 0.53						

Table 5-14: *Confusion matrix with German NFI plots without eliminated outliers*

NFI Germany		NFI					
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	295	61	356	82%	2.04	3.99
Result	Forest	71	214	285	75%	2.56	5.03
	sum	366	275	641			
	Producer´s accuracy	81%	78%				
	SE	2.05	2.50				
	δ (%)	4.02	4.90				
	Overall accuracy 79%						
	Kappa = 0.58						

Table 5-15: *Confusion matrix with all Swiss NFI plots*

NFI Switzerland		NFI					
all NFI plots	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	18866	2079	20945	90%	0.21	0.41
Result	Forest	2134	6922	9056	76%	0.45	0.88
	sum	21000	9001	30001			
	Producer´s accuracy	90%	77%				
	SE	0.21	0.44				

	δ (%)	0.41	0.87				
	Overall accuracy 86%						
	Kappa = 0.58						

Table 5-16: *Confusion matrix with Swiss NFI plots without eliminated outliers*

NFI Switzerland		NFI					
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	19021	1597	20618	92%	0.19	0.37
Result	Forest	1671	7068	8739	81%	0.42	0.82
	sum	20692	8665	29357			
	Producer´s accuracy	92%	82%				
	SE	0.19	0.41				
	δ (%)	0.37	0.81				
	Overall accuracy 89%						
	Kappa = 0.73						

Table 5-17: *Confusion matrix with German and Austrian NFI plots without outliers*

NFI Austria and Germany							
		NFI					
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	942	154	1096	86%	1.05	2.05
Result	Forest	161	361	522	69%	2.02	3.97
	sum	1103	515	1618			
	Producer´s accuracy	85%	70%				
	SE	1.08	2.02				
	δ (%)	2.11	3.96				
	Overall accuracy 81%						
	Kappa = 0.73						

When using data from all Austrian or Bavarian inventory data some serious misclassifications occurred. Especially lakes and other water bodies were classified as forest (Figure 5-15). Using only the data from forest inventory plots and applying a spectral search radius (maximal spectral distance) to them led to better results. When using Bavarian and Austrian data together and setting the maximal spectral distance to 40 an almost similar result could be achieved as with using only the Swiss data. In this case, data from 244 Austrian and 280 Bavarian inventory plots could be used as training data.

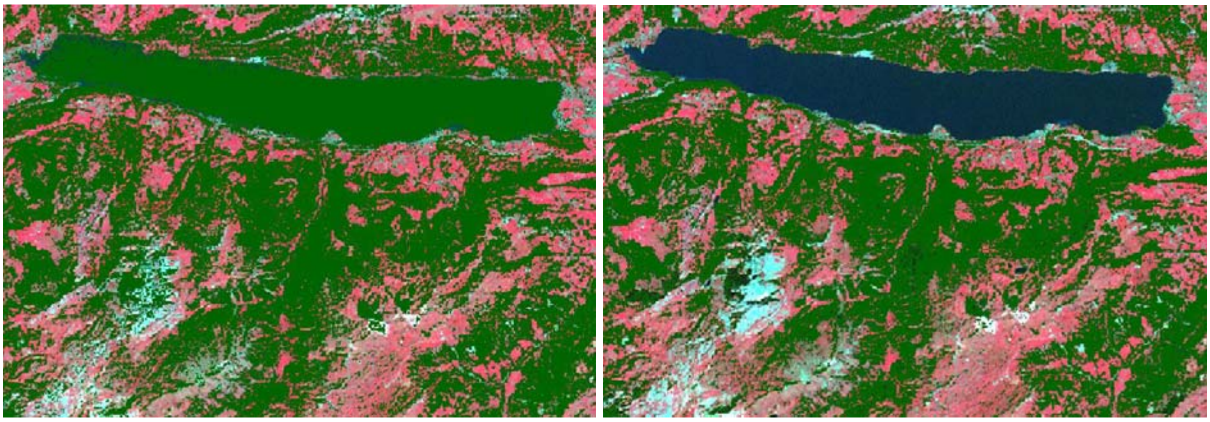

Figure 5-15: *example of the effect of using the spectral distance-parameter: kNN forest map around Walensee (CH) using German inventory data without (left) and with (right) using the spectral distance parameter*

It turned out that the high number of Swiss inventory data plots was the crucial factor for the better quality of the forest map.

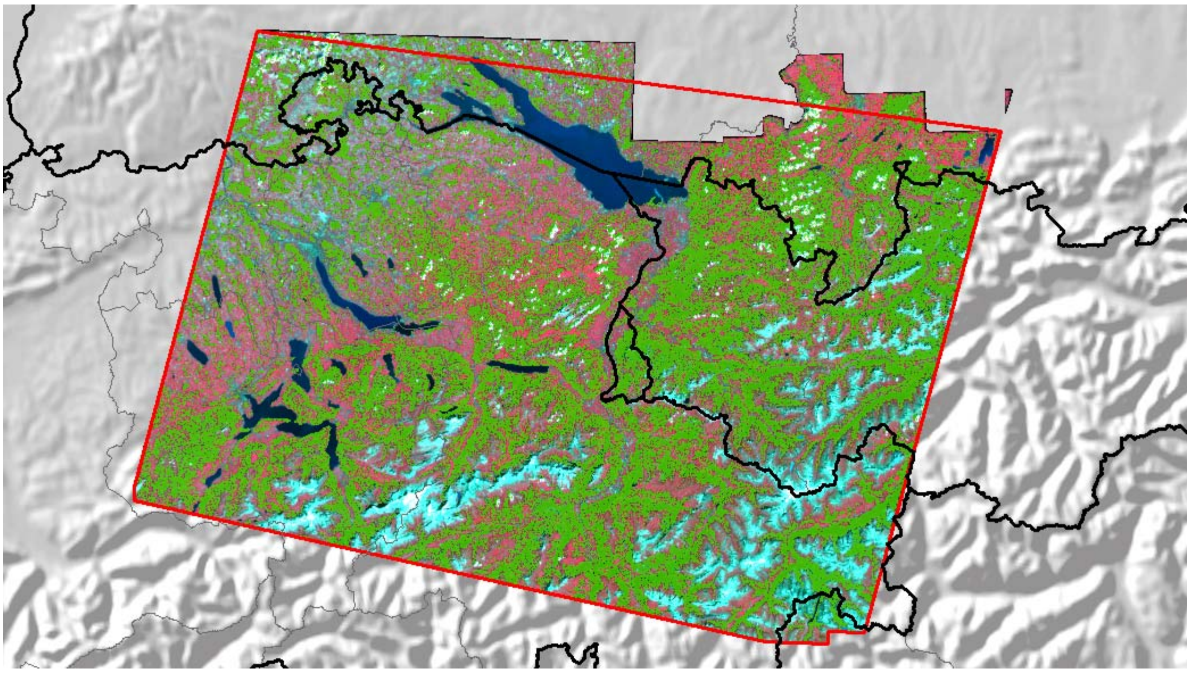

Figure 5-16: *kNN Forest map of Test site C2 – Austria-Bavaria-Switzerland*

Nevertheless some misclassifications always occurred irrespective of the training data used and independent of the use of the spectral distance parameter. Some parts of fields and reed were classified as forest. In the example below (Figure 5-17) the misclassification of fields is quite similar when using Swiss data or Austrian data. Here, the radiometry of the satellite image is much more crucial for the kNN results than the reference data used.

Figure 5-17: *Example of misclassified area: results using Swiss data only (left) and Austrian data only (right); parts of fields are always classified as forest*

The forest map that was calculated using Swiss NFI data was used for cross-bordering protective effect mapping afterwards.

Test site C3: Austria – Bavaria

For the test site C3 (Austria and Bavaria) the best result was achieved using data from all Austrian inventory plots (forest and non-forest) (Figure 5-18). When using data from Bavarian inventory plots only data from forest plots were used and the maximal spectral distance was applied again. In this case data from 432 forest plots was used for kNN classification. Furthermore data from Austrian and Bavarian forest plots were used together again. In this case data from 1009 forest plots was added.

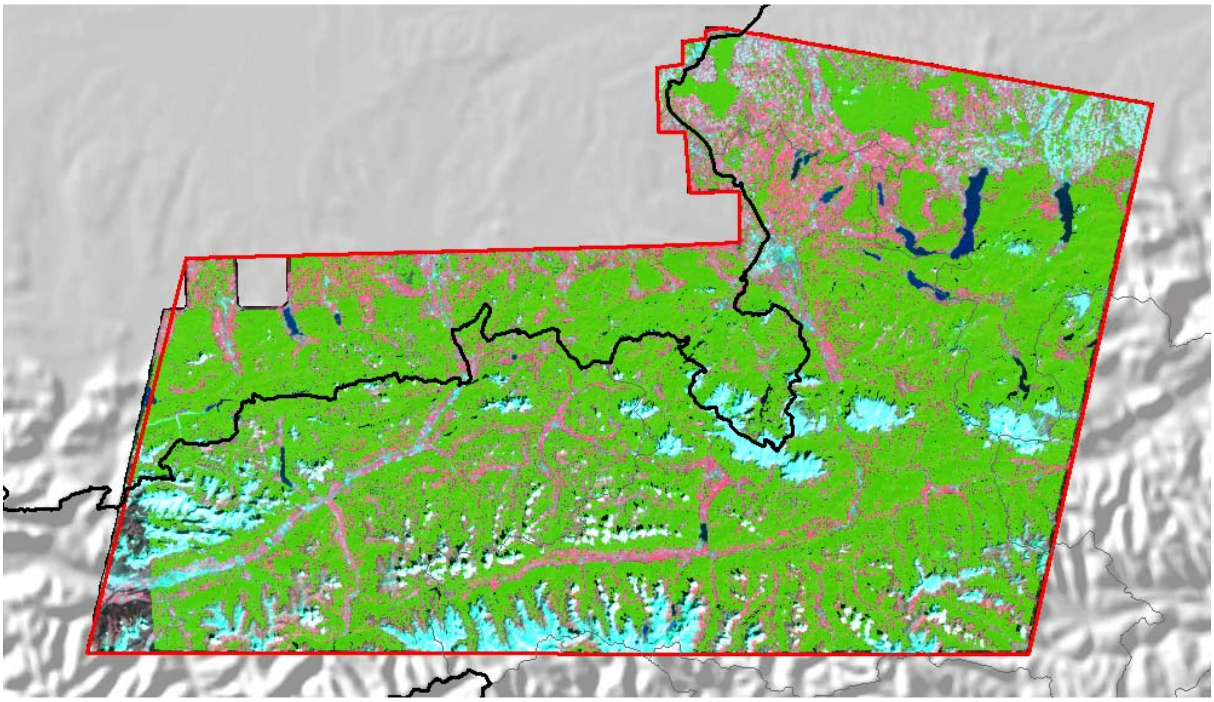

Figure 5-18: *kNN Forest map of Test site C3 – Austria-Bavaria*

The following confusion matrices were generated from the used NFI plots in a kNN cross-validation procedure again to evaluate the forest/non-forest masks (Table 5-18 to Table 5-22).

Table 5-18: *Confusion matrix with all German NFI plots*

NFI Germany		NFI					
all NFI plots	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	77	26	103	74%	4.32	8.47
Result	Forest	44	412	456	90%	1.40	2.75
	sum	121	438	559			
	Producer´s accuracy	64%	94%				
	SE	4.36	1.13				
	δ (%)	8.55	2.22				
	Overall accuracy 87%						
	Kappa = 0.61						

Table 5-19: *Confusion matrix with German NFI plots without eliminated outliers*

NFI Germany		NFI					
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	75	37	112	67%	4.44	8.71
Result	Forest	42	394	436	90%	1.44	2.82
	sum	117	431	548			
	Producer´s accuracy	64%	91%				
	SE	4.44	1.38				
	δ (%)	8.70	2.70				
	Overall accuracy 86%						
	Kappa = 0.56						

Table 5-20: *Confusion matrix with all Austrian NFI plots*

NFI Austria		NFI					
all NFI plots	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	1533	187	1720	89%	0.75	1.48
Result	Forest	228	856	1084	79%	1.24	2.42
	sum	1761	1043	2804			
	Producer´s accuracy	87%	82%				
	SE	0.80	1.19				
	δ (%)	1.57	2.33				
	Overall accuracy 85%						
	Kappa = 0.69						

Table 5-21: *Confusion matrix with Austrian NFI plots without outliers*

NFI Austria		NFI					
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	1543	162	1705	90%	0.73	1.42
Result	Forest	193	846	1039	81%	1.20	2.35
	sum	1736	1008	2744			
	Producer´s accuracy	87%	84%				
	SE	0.81	1.15				
	δ (%)	1.58	2.26				
	Overall accuracy 87%						
	Kappa = 0.72						

Table 5-22: *Confusion matrix with German and Austrian NFI plots without outliers*

NFI Austria		NFI					
and Germany							
without outliers	k = 3	Non forest	Forest	sum	User´s accuracy	SE	δ (%)
Classification	Non forest	1601	202	1803	89%	0.74	1.44
Result	Forest	252	1237	1489	83%	0.97	1.91
	sum	1853	1439	3292			
	Producer´s accuracy	86%	86%				
	SE	0.13	0.91				
	δ (%)	0.25	1.79				
	Overall accuracy 86%						
	Kappa = 0.72						

As can be seen the quality when using only German NFI data compared to the quality when using Austrian NFI data is rather poor (Figure 5-19). Again it was useful to use the parameter of spectral distance when using only German NFI data. When setting the spectral search radius to 40 quite good results could be achieved.

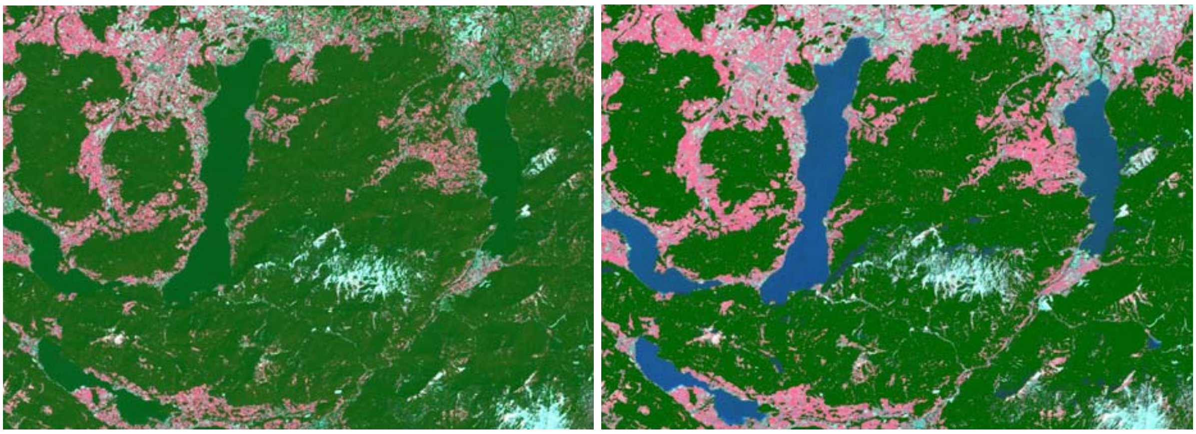

Figure 5-19: *Example of the effect of using the spectral distance-parameter: kNN forest map around Attersee and Traunsee (A) using German inventory data without (left) and with (right) using the parameter of spectral distance*

The forest map that was calculated using Austrian data was used for cross-national protective effect mapping afterwards.

Test site C4: Austria-Slovenia

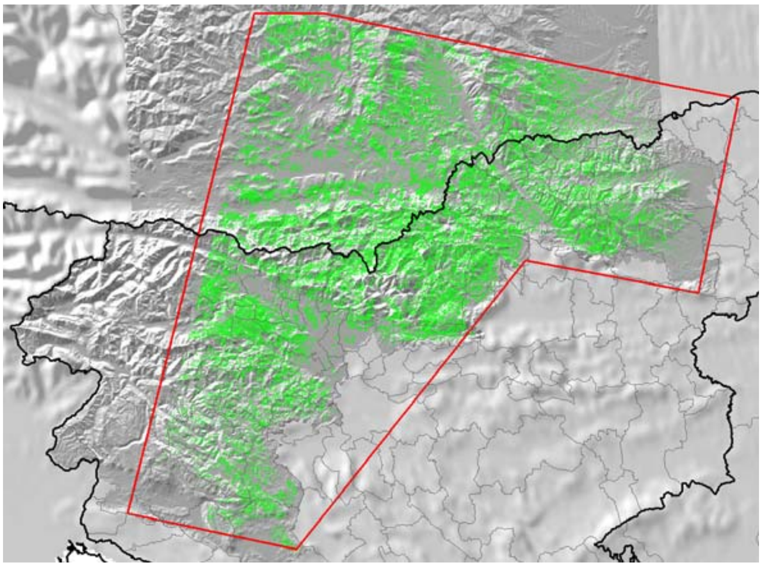

Figure 5-20: *kNN Forest map of Test site C4 – Austria - Slovenia*

A subset of the Landsat scene 190_028 was used for cross bordering forest mapping concerning Austria and Slovenia. In this case the resolution of the image was 25 meters. Besides the Austrian DTM, parts of a Slovenian DTM were available. The DTMs had to be resampled to 25 meter resolution of the Landsat image.

For the forest mapping it was possible to use data from 706 Austrian and 294 Slovenian inventory plots as training data (Figure 5-20). Due to the rather low number of inventory plots the kNN classification led to some misclassifications. On the one hand parts of fields were classified as forest, no the other hand parts of broadleaved forest were classified as non-forest.

Best results could be achieved when using only data from forested inventory plots and applying the maximal spectral distance when setting the spectral search radius to 30. In this case data from 402 Austrian and 129 Slovenian inventory plots was used.

It turned out that the use of a spectral search radius is useful when the number of inventory plots is rather small (e. g. German NFI data in test sites C2 and C3). If the number of inventory plots is rather big (e. g. Swiss NFI data in test site C2) it seems that the use of a spectral search radius does not have an impact on the quality of the classification at all.

<u>Test site F1: Paznauntal (Austria)</u>

The forest area in the test site Paznauntal is 1295 ha (43.7%) (Figure 5-21). The result of the automatic derived forest mask is satisfactory. When compared with the orthophoto only slight differences occur (Figure 5-22).

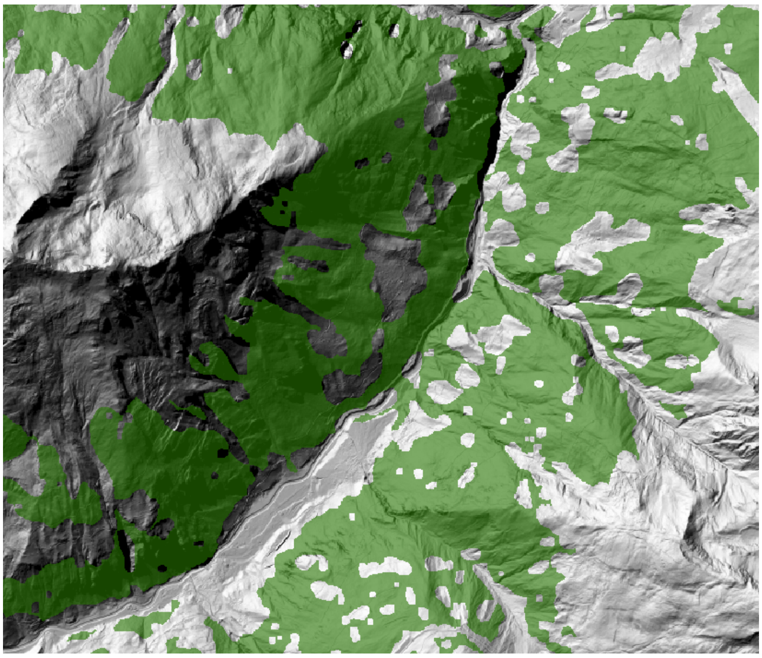

Figure 5-21: *Test site F1 - Paznauntal (Austria). Forest mask (green) derived from ALS data and moving window technique.*

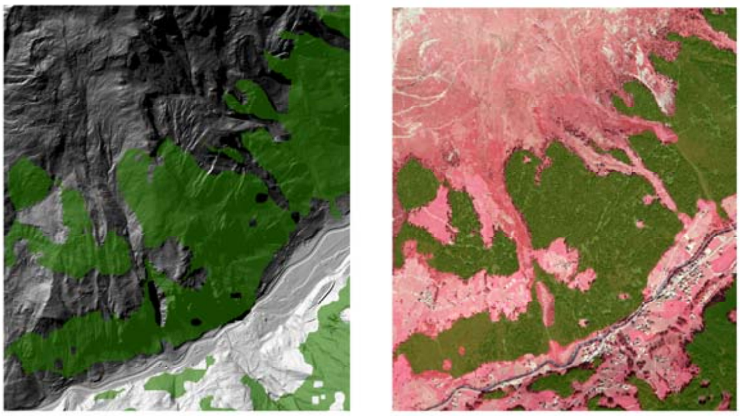

Figure 5-22: *Test site F1 - Paznauntal (Austria). Detail of the forest mask derived from ALS data and moving window technique. Left: Shaded relief of the DSM with forest mask. Right: Orthophoto with forest mask.*

This forest mask serves as the basis for the protective effect mapping (see chapter 1.1).

Test site F2: Engadin (Switzerland)

The forest area in the test site Engadin is 24.8% (7’342 ha) which is slightly smaller than the percent forest cover for the Canton Graubuenden with 27.0% according to the NFI2 (Figure 5-23). The difference can be explained by the different forest definitions of ProAlp and the Swiss NFI and the different methods. The forest area in the Swiss NFI2 is a result of forest/non-forest point decisions every 500m by aerial photo interpretation.

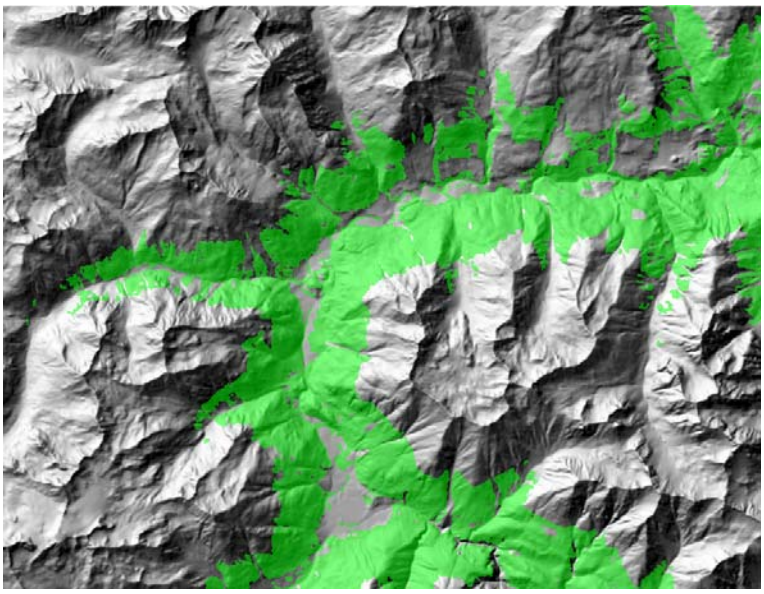

Figure 5-23: *Test site F2-Engadin (Switzerland). Forest mask (green) derived from ALS data and moving window technique.*

The result of the automatic derived forest mask is satisfactory. When compared with the orthophoto differences to the forest mask can be explained with missing data in the ALS data set (Figure 5-24).

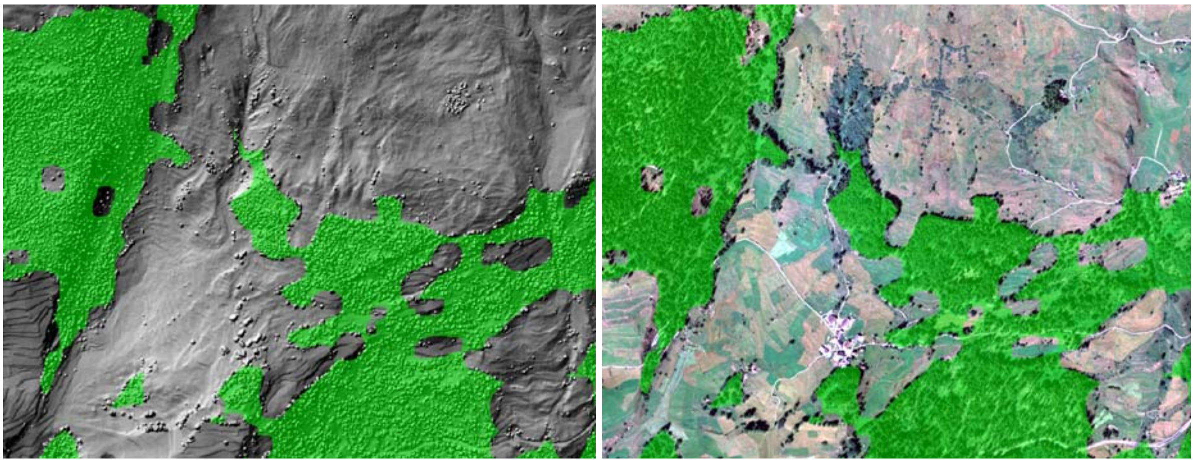

Figure 5-24: *Test site F2-Engadin (Switzerland). Detail of the forest mask derived from ALS data and moving window technique. A: Shaded relief of the DSM with forest mask. B: Orthophoto with forest mask.*

This forest mask serves as the basis for the protective effect mapping (see chapter 1.1).

5.3 Hazard modelling

5.3.1 Methods

5.3.1.1 Avalanche

The avalanche hazard potential (AHP) has to be subdivided into three hazard zones: the starting zone (release area), the transit zone and the run out zone of an avalanche (Figure 5-25).

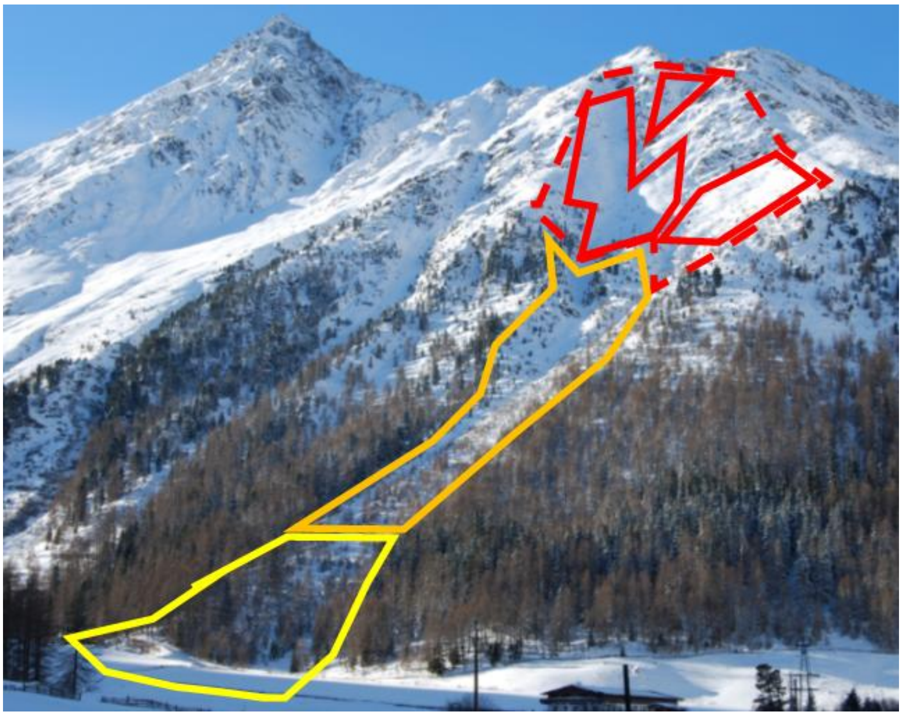

Figure 5-25: *Avalanche hazard zones: starting zone with potential release area (red), transit zone (orange) and run out and deposition zone (yellow).*

The ProAlp approach of avalanche hazard modelling is the determination of the hazard potential of forest areas only. Areas above the timberline are not taken into account.

The forest with protective function against avalanche (APF) is the forest use area with a basic susceptibility for an initiation of avalanches with a damage potential (AHP). Figure 5-26 shows an example.

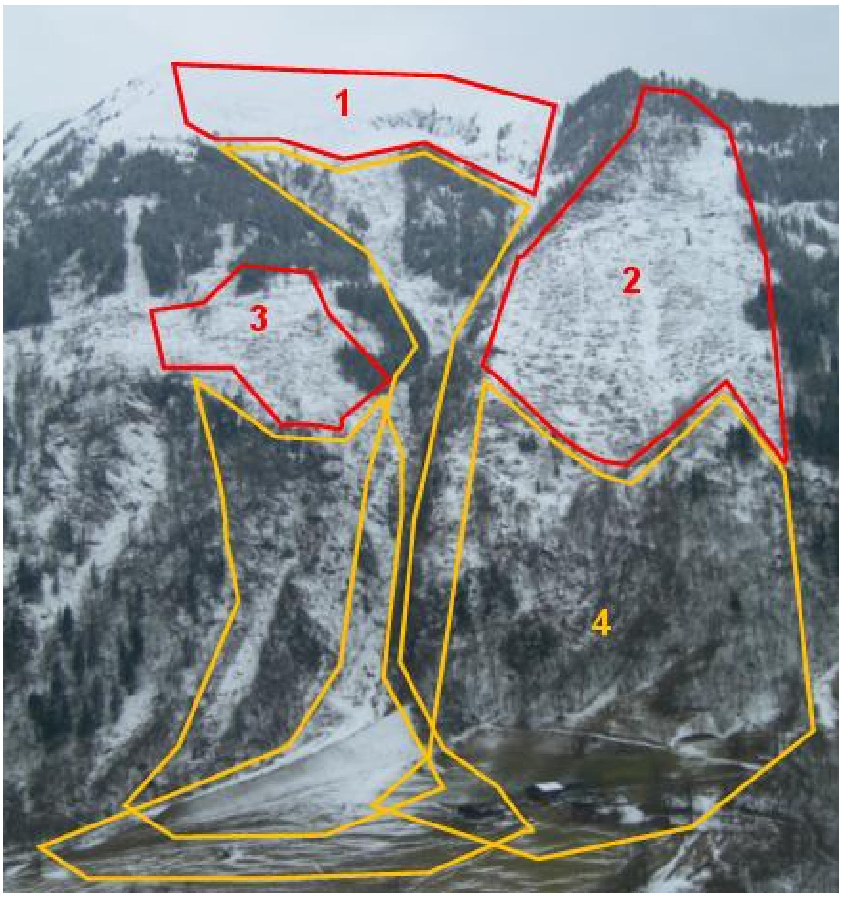

Figure 5-26: *Schematic drawing of AHP and APF within ProAlp: zone 1: no APF mapped for release area is above timberline; zone 2: APF is determined for release area is forest use area and damage potential below exists; zone 3: AHP without damage potential below so no APF is mapped; zone 4: transit zone*

Some information is needed in order to create maps of the AHP and the APF:

- size and position of potential avalanche release areas
- forest use area (forest map)
- characteristics of damage potential of potential avalanche release areas

In general the following operational steps are necessary for mapping the AHP and APF:

- mapping and characterizing areas of potential release areas
- intersection of the potential release areas with the forest use area
- Calculation of the avalanche tracks and intersection with infrastructure in order to detect the damage potential

The main indicators of the hazard potential used for mapping are the altitude, the slope gradient and the plan curvature.

The altitude is an indicator of the potential avalanche release frequency and magnitude. Different altitude thresholds within the Alpine space are used dependent on the climatic regions (Table 5-23).

The slope gradient is an indicator of the potential avalanche release frequency but there is no or only a weak correlation with the magnitude.

The plan curvature is an indicator of the avalanche release frequency and magnitude and has an effect on the snow depth, the release depth and the snow pack.

The data used for mapping the APF are a DTM and a forest mask with a resolution of 25 meters. The minimum forest area was set to 5000 m². Furthermore the snow cover regions are available as shape files.

In the following the practical work steps for calculating the APF should be described in detail. At first regions of altitude thresholds had to be created and depicted as grid files. In the climatic regions (snow cover regions) of the Alps the levels of hazard potential are different at the same altitude because of different climatic conditions. The indicator altitude includes several factors of avalanche prone site conditions – climatic conditions, mean and maximum snow depth and the kinetic head.

It is useful to define at least two altitudinal zones of avalanche hazard potential:

- Low zone: submontane regions with lower level of snow depth and snow cover durability; therefore mainly smaller avalanches and wet loose snow avalanches occur.
- Upper zone: montane and alpine regions with higher level of snow depth and snow cover durability as well as kinetic head.

The altitude thresholds of these altitude zones have been defined for climatic regions (snow cover regions) by experts (Table 5-23).

Table 5-23: *Snow cover regions and their altitude threshold values of avalanche hazard potential: Hazard potential level 1: low hazard potential – events are possible, but they are infrequent and small; hazard potential level 2: increased hazard potential*

Alpine Region		Altitudinal zone (hazard potential)	
Code	Region	1	2
	Austria		
A100	Vorarlberg	≥ 700 m	≥ 900 m
A210	Northern Alps – West Zone	≥ 800 m	≥ 1 000 m
A220	Northern Alps – Middle Zone	≥ 750 m	≥ 1 000 m
A230	Northern Alps – East Zone	≥ 700 m	≥ 900 m
A310	Western Central Alps – West Zone	≥ 900 m	≥ 1 100 m
A320	Western Central Alps – Middle Zone	≥ 1 250 m	≥ 1 700 m
A330	Western Central Alps – East Zone	≥ 900 m	≥ 1 400 m
A400	Eastern Central Alps	≥ 800 m	≥ 1 000 m
A500	Southern Subcontinental Alps	≥ 950 m	≥ 1 200 m
A600	Austrian Southern Alps	≥ 700 m	≥ 1 100 m
A700	Austrian Southeaster Alps	≥ 1 100 m	≥ 1 600 m
A810	Northern foothills – West Zone	≥ 900 m	≥ 1 100 m
A820	Northern foothills – East Zone	≥ 800 m	≥ 1 200 m
	Germany		
G110	Allgäu Alps	≥ 700 m	≥ 900 m
G120	Bavarian Alps – West Zone	≥ 800 m	≥ 1 000 m
G130	Bavarian Alps – East Zone	≥ 750 m	≥ 1 000 m
	Slovenia		
S100	Julian Alps	≥ 800 m	≥ 1 200 m
S200	Slovenian Southeastern Alps	≥ 1 200 m	≥ 1 600 m
	France – French Western Alps		
F100	French Jura	≥ 700 m	≥ 1 000 m
F210	French Northwestern Alps	≥ 800 m	≥ 1 000 m
F220	French Central Alps	≥ 1 000 m	≥ 1 250 m
F230	French Southern Alps	≥ 1 250 m	≥ 1 500 m
	Switzerland (and Liechtenstein)		
CH110	Swiss Northern Alps and Midland	≥ 700 m	≥ 900 m
CH120	Swiss Interior Alps	≥ 900 m	≥ 1 100 m
CH130	Swiss Southern Alps	≥ 900 m	≥ 1 200 m
CH200	Swiss Jura	≥ 700 m	≥ 1 000 m
	Italy		
IT110	Interior Alps (Alto Adige)	≥ 1 250 m	≥ 1 700 m
IT120	Dolomites – Carnic Alps	≥ 800 m	≥ 1 200 m
IT130	Insubric Alps	≥ 900 m	≥ 1 200 m
IT140	Maritim – Liguric Alps	≥ 1 250 m	≥ 1 500 m

Because of the breaks of the altitude thresholds between adjacent snow cover regions an interpolation is necessary. For this purpose the moving window technique (focal mean function, radius 50 cells, cell width 200 m) was used. The snow cover regions of the Alps are shown in figure 5-27.

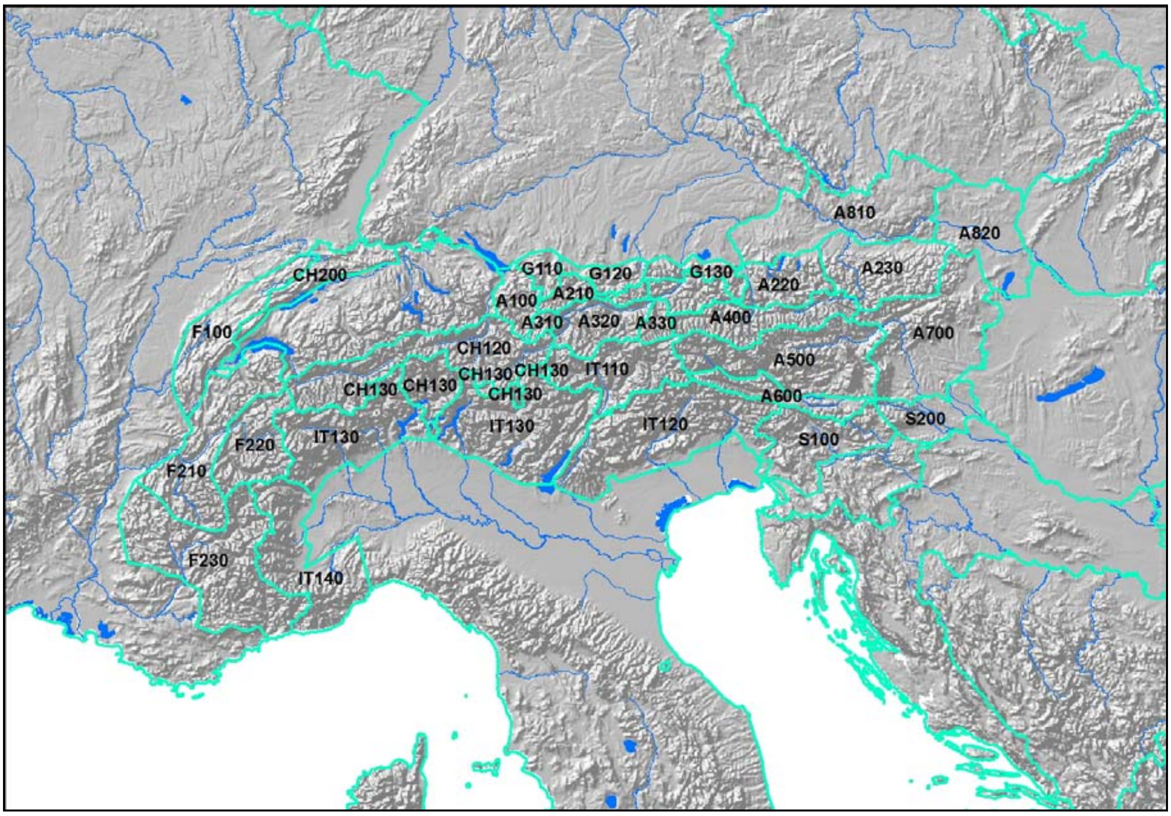

Figure 5-27: *Snow cover regions of the Alps*

The snow cover regions in Austria including the altitudal thresholds are shown in figure 5-28.

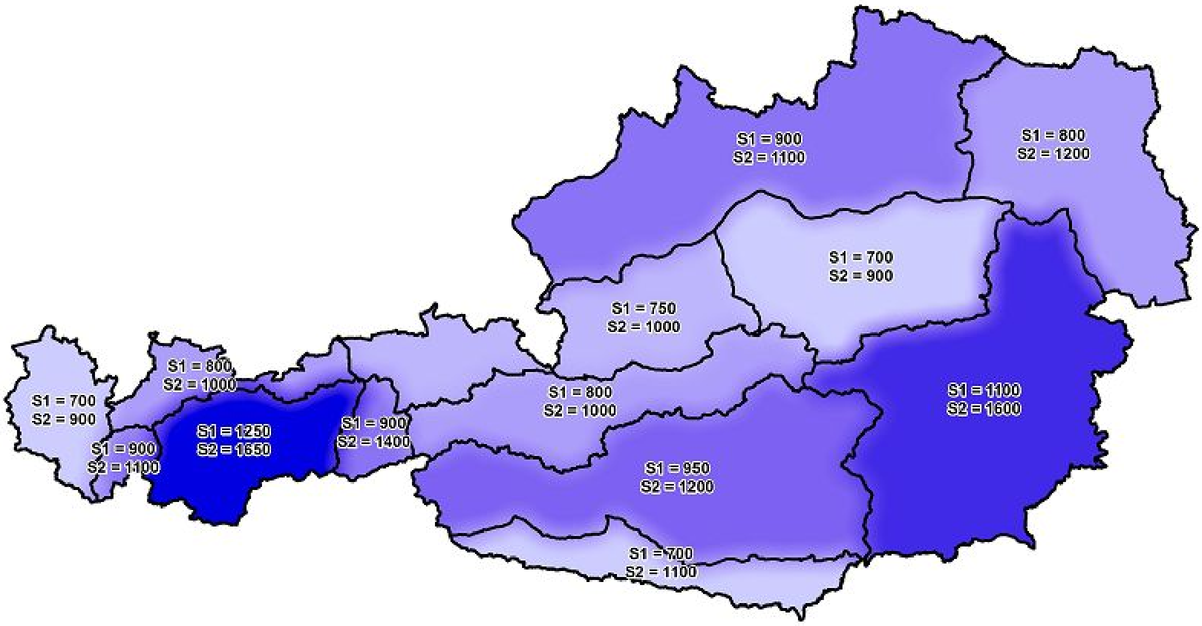

Figure 5-28: *Snow cover regions of Austria: S1 = altitude threshold 1 (minimal altitude of avalanche starting zones, if altitude >= S1, then avalanches are possible); S2 = altitude threshold 2 (if altitude >= 2, then avalanches are possible)*

Intersection of the zones of the altitude thresholds with the DTM provides the avalanche hazard potential zones because of climatic conditions. The results for Austria are shown in figure 5-29.

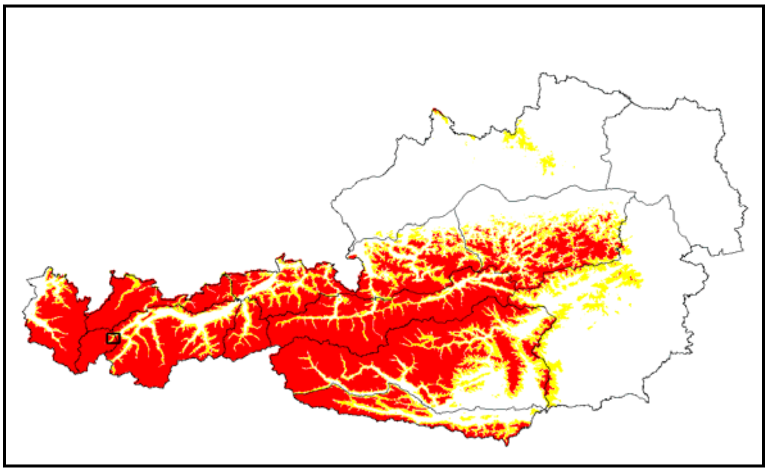

Figure 5-29: *Avalanche hazard potential of Austria because of climatic conditions (red - altitudinal zone 2, yellow – altitudinal zone 1).*

A detailed view (black rectangle in figure 5-29) of the altitudal zones is shown in figure 5-30.

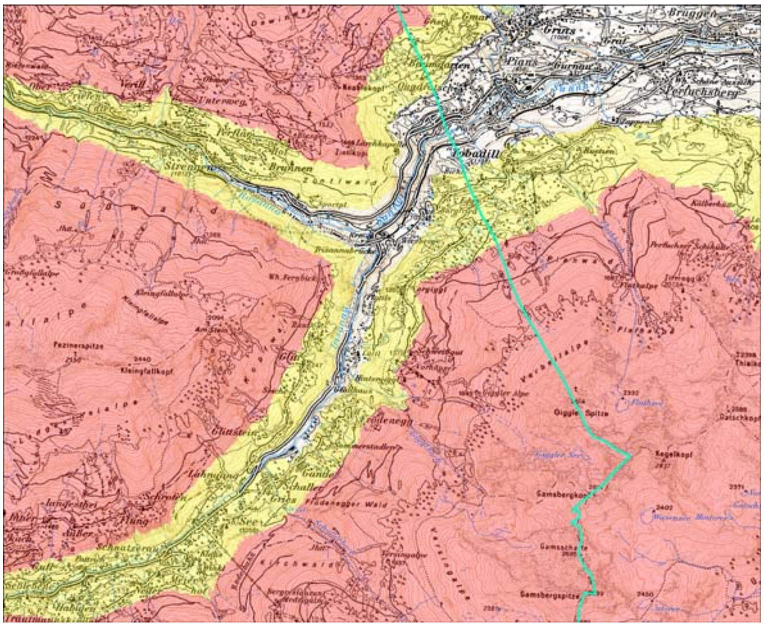

Figure 5-30: *Avalanche release potential because of climatic conditions. Example of the results for an Austrian valley: red - altitudinal zone 2, yellow – altitudinal zone 1; the blue line is the border between two cover regions.*

After calculating the AHP concerning the altitude the AHP concerning the slope gradient and the plan curvature had to be estimated. Table 5-24 shows the evaluation of the AHP relating to the slope gradient.

Table 5-24: *Evaluation of the hazard potential because of the slope gradient*

Slope gradient	Hazard potential (Slope_AHP)
- 28 °	0 – no hazard potential
> 28 – 34 °	1 – low hazard potential
> 34 – 39 °	2 (1-3) – medium hazard potential
> 39 – 55 °	3 – high hazard potential
> 55°	0 – no hazard potential

The estimation of the AHP concerning the slope gradient and the plan curvature delineates areas with AHP due to geomorphology. The slope layer and the layer of plan curvature were calculated by standard GIS tools.

The final step to estimate the overall AHP was to combine the AHP concerning altitude and the AHP concerning slope and curvature. The resulting grades of the AHP are shown in Table 5-25.

Table 5-25: *Combined matrix of indicators of avalanche hazard potential: 0 = no avalanche release potential - slopes are too steep, too flat or snow cover is not high enough for significant avalanches; 1 = low - steep slopes (> 34°) but low snow depth; snow sluffs are possible, significant avalanches occur very infrequent; 2 = medium - medium steepness and high snow depth; significant avalanche release is possible more frequently; also big avalanches may occur, but they are infrequent; 3 = high - steep slopes and high snow depth, common avalanche release terrain (small and big releases, frequently).*

Climatic avalanche hazard potential (Altitude_AHP)	Slope gradient				
	- 28°	>28 – 34°	>34 – 39°	>39 – 55°	> 55°
	Avalanche hazard potential of slope gradient and curvature (Slpcur_AHP)				
	0	1	2	3	0
	Avalanche hazard potential (AHP)				
0	0	0	0	0	0
1	0	0	1	1	0
2	0	2	3	3	0

An extract of the map containing the AHP for a region in Tyrol is shown in figure 5-31.

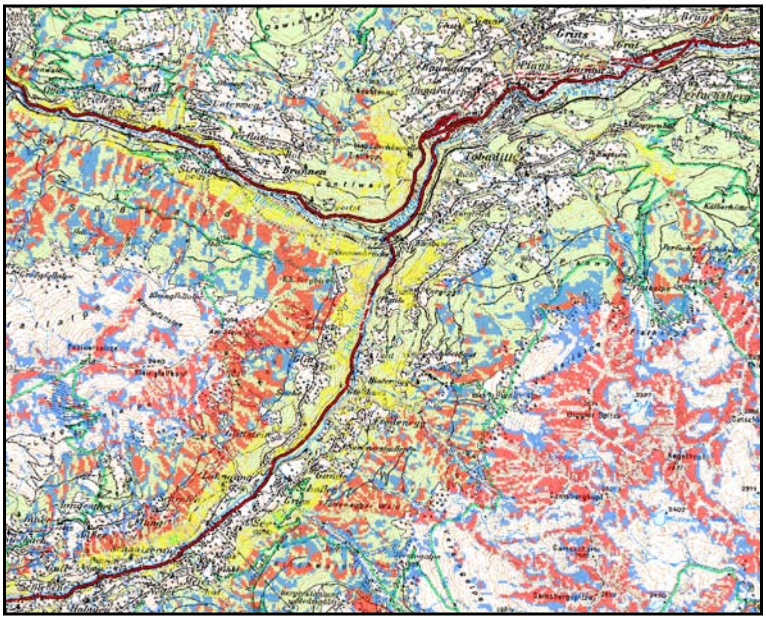

Figure 5-31: *Avalanche hazard potential of a region in Tyrol, Austria: red: high AHP, blue: medium AHP, yellow: low AHP.*

After the AHP had been estimated_a layer including forest with AHP (FAHP) was created by intersecting the calculated AHP with the forest map. The forest map including the FAHP for the region in Tyrol mentioned before is shown in figure 5-32.

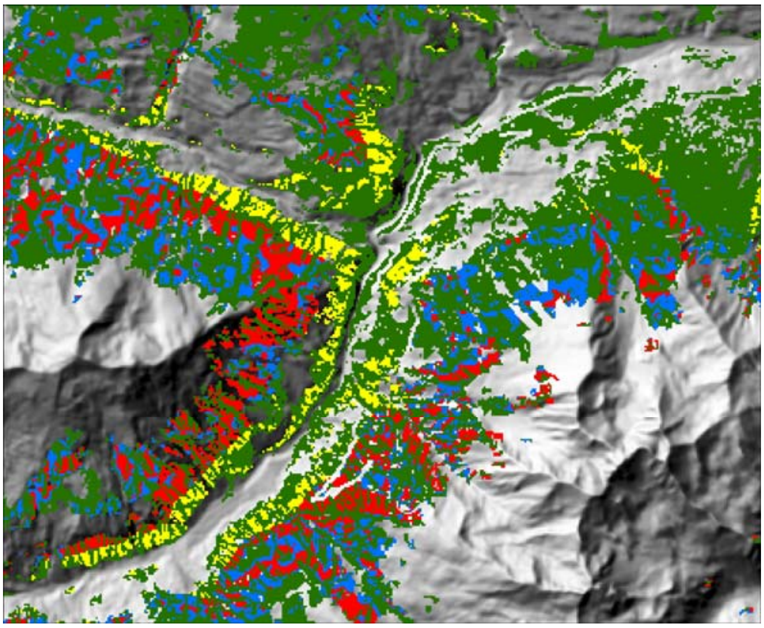

Figure 5-32: *FAHP of a region in Tyrol, Austria. Green – forest without AHP, yellow – forest with low AHP, blue – forest with medium AHP, red – forest with high AHP*

The area of forest with protective function (APF) had to be extracted from the area of the forest with potential protective function (pAPF) which was similar to the FAHP within ProAlp. In case of an existing damage potential – that means that infrastructure might be endangered by avalanches – the pAPF lying above this infrastructure has a protective function. In order to determine damage potential and the APF the potential avalanche tracks (transit and runout zones) have to be calculated. Within ProAlp the energy line concept using the geometric angle α_g was used for calculating potential avalanche tracks.

Within ProAlp a geometric angle of 28 *degrees* has been used for calculation. This value is derived from the mean angle of terrain types where 80 avalanches occurred in Austria during a period of one year. This mean angle is 27 degrees, 1 degree was added to guarantee safety (Lied et al. (1995)). It turned out that the use of a geometric angel lower than 28 degrees is only adequate if avalanches are modelled that start from above the timberline. This case was not examined within ProAlp.

The calculation of the avalanche tracks from the FAHP - zones was executed with the 8 D Model grid calculation program Alphamodel_2 (Klebinder, Fromm & Perzl 2006, unpublished). The program executes the following steps:

- Calculation of the flow path from each start pixel. All pixels within the FAHP (with low, medium and high AHP) are used.
- Calculation of the energy cone with the angle α_g.
- Calculation of the avalanche run-out length through intersection of the cone with the flow path.
- Intersection of the avalanche tracks with the infrastructure and selection of tracks and starting zones which endanger infrastructure
- Recalculation of starting zones.

The damage potential zone was calculated by intersecting the detected avalanche tracks with the infrastructure. The avalanche tracks were recalculated back up to the avalanche starting zones using the damage potential zones as starting zones. The recalculated area only covered parts of the pAPF (FAHP). These parts were detected as forest with protective function (APF) by intersecting the recalculated area with the FAHP. The forest map including the FAHP and the APF for the region in Tyrol mentioned before is shown in figure 5-33.

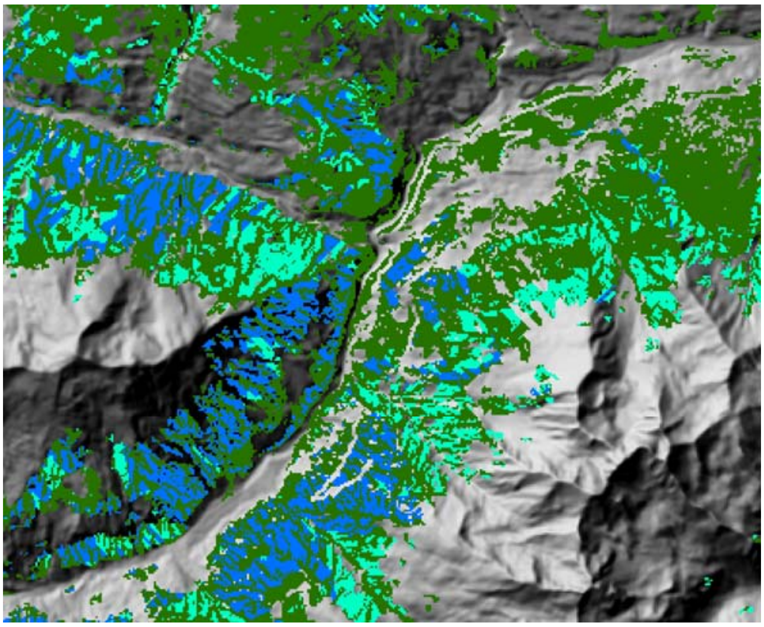

Figure 5-33: *The area of the APF compared to the area of the FAHP; green: forest area, turquoise: FAHP, blue; APF*

The results after several work steps have been executed are shown in figure 5-34:

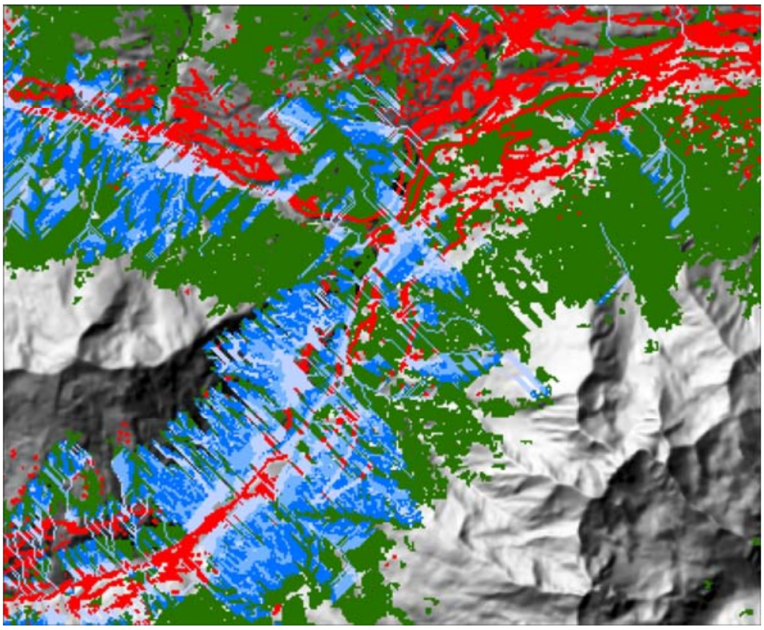

Figure 5-34: *APF of a region in Tyrol, Austria, example: green: forest: dark blue - APF (starting zones in forests endangering assets); medium to light blue– avalanche tracks in and out of forest; red – settlements and infrastructure.*

The method gives only a rough idea of the run out length of avalanches without consideration of lateral spreading of the track. Dynamic aspects of avalanche motion are disregarded. But for the application of dynamic models at a national or alpine scale the necessary data listed below are not yet existent:

- maps of expectation values (dependent from selected average return period) of the 3 or 5 day new snow depth for estimation of fracture depth and release mass

- maps of snow density dependent from climatic region and altitude for estimation of release mass
- additional spatial separation of the potential avalanche release areas on basis of topographic parameters for estimation of release mass (because usually only on smaller portions of the PRA the snow cover breaks off)
- estimation of coulomb friction coefficient μ for each avalanche path (or at least regional calibration on basis of test areas with well documented avalanche tracks)
- estimation of turbulent friction coefficient ξ for each avalanche path (or at least regional calibration on basis of test areas with well documented avalanche tracks)
- mapping of snow entrainment areas

5.3.1.2 Rockfall

Input data

The primary input data for the calculation of the rockfall active area by rockfall are a rock mask, a forest mask and a slope layer.

The availability of rock masks differs between countries. In Switzerland the digital landscape model Vector25 can be used. From the thematic layer ‘Primary Surfaces’ the class ‘Rock’ is selected. The selected polygons were converted to raster datasets. In Austria the rock mask was extracted from the digital map OEK50 by colour threshold techniques (figure 5-35).

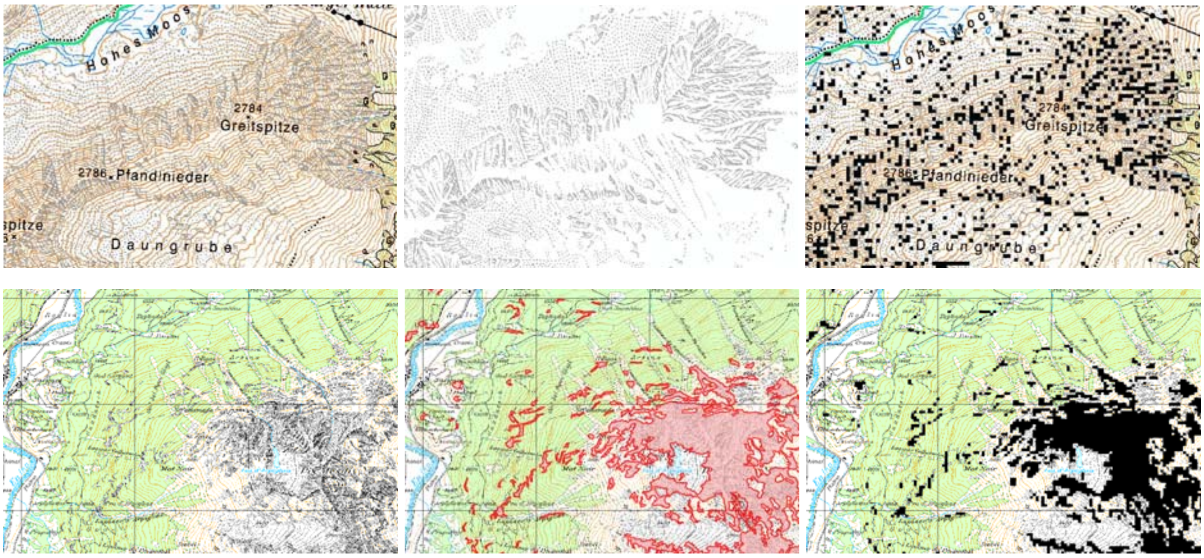

Figure 5-35: *Top: Austria - Example of OEK50 – extracted rock layer – final rock mask. Bottom: Switzerland - Example of Vektor25 – selected rock polygon – final rock mask.*

The forest mask is the result of the different forest mapping procedures (see Chapter 5.2).

The slope layer is calculated by standard GIS techniques (ArcMap 9.2).

Energy line principle

In the rockfall model used for this project, energy loss during rebounds is not taken into account, because we decided not to include rock size and energy in our analyses. The most important information needed is the rockfall runout zone for each potential rockfall start cell. This has been calculated using the energy line angle principle as described by Heim (1932), Toppe, (1987), Gerber (1998), and Meißl (1998). The energy line is a virtual line, with a certain angle that represents the friction energy that connects the rockfall start cell with its stopping point (figure 5-36). The angle of the line is assumed being representative for larger regions. The energy line angle used in this study is 32° .

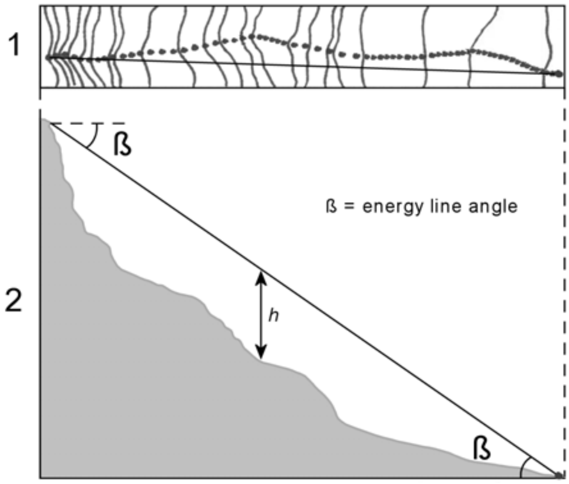

Figure 5-36: *Explanation of the energy line principle. Scheme 1 gives a helicopter view of a slope with the rebound positions of a rockfall event; Scheme 2 shows a cross- section of the slope with the energy line of the rockfall event.*

For this study, we calculated the energy line angle in 2D, meaning that from each starting cell, we calculated an "energy cone" following Jaboyedoff (200x). For multiple adjacent start cells, the overlaying cones eventually result in a continuous rockfall active zone (figure 5-37). The software program that was available for the ProAlp team to calculate the rockfall hazard potential was written in C++ and called ELModel.exe.

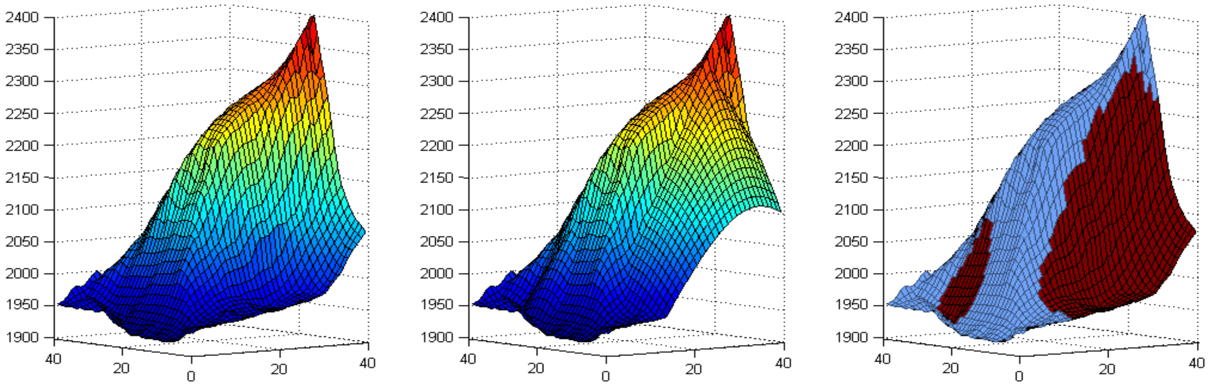

Figure 5-37: *Visulations of the energy cones. Left: the digital terrain model. Middle: the digital terrain model with calculated cones from 2 startzones. Right: The modelled rockfall active areas.*

5.3.2 Results and discussion

5.3.2.1 Avalanche

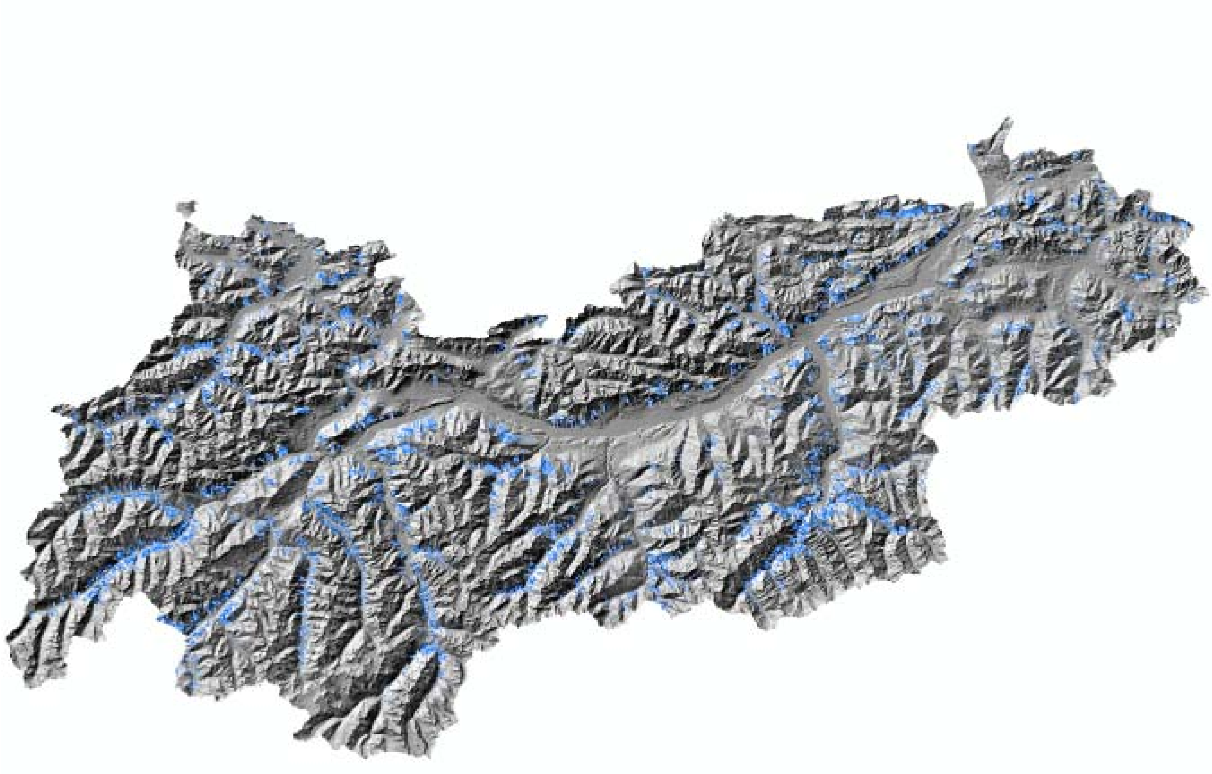

Figure 5-38: *Test site C1a: Avalanche hazard potential: Forest with protective effect against avalanches and forest avalanche tracks calculated using Alphamodel_2*

We evaluated the results for the two steps:

1. Modeling of the AHPs.
2. Calculation of avalanche tracks with the energy line concept.

In Austria no sufficient database about historical forest avalanche events exists. Furthermore the protective effect of the existing forest distorts perception of the avalanche hazard potential of forest sites. Hence, the evaluation of the results of modeling AHPs could occur only through a comparison with known avalanche release zones mainly above the upper timberline.

The results of modelling AHPs are surprisingly well, taking into account the regional scale. Almost all well known and dangerous avalanche release areas in Tyrol were mapped, three of them are shown in the following (figure 5-40 to figure 5-43).

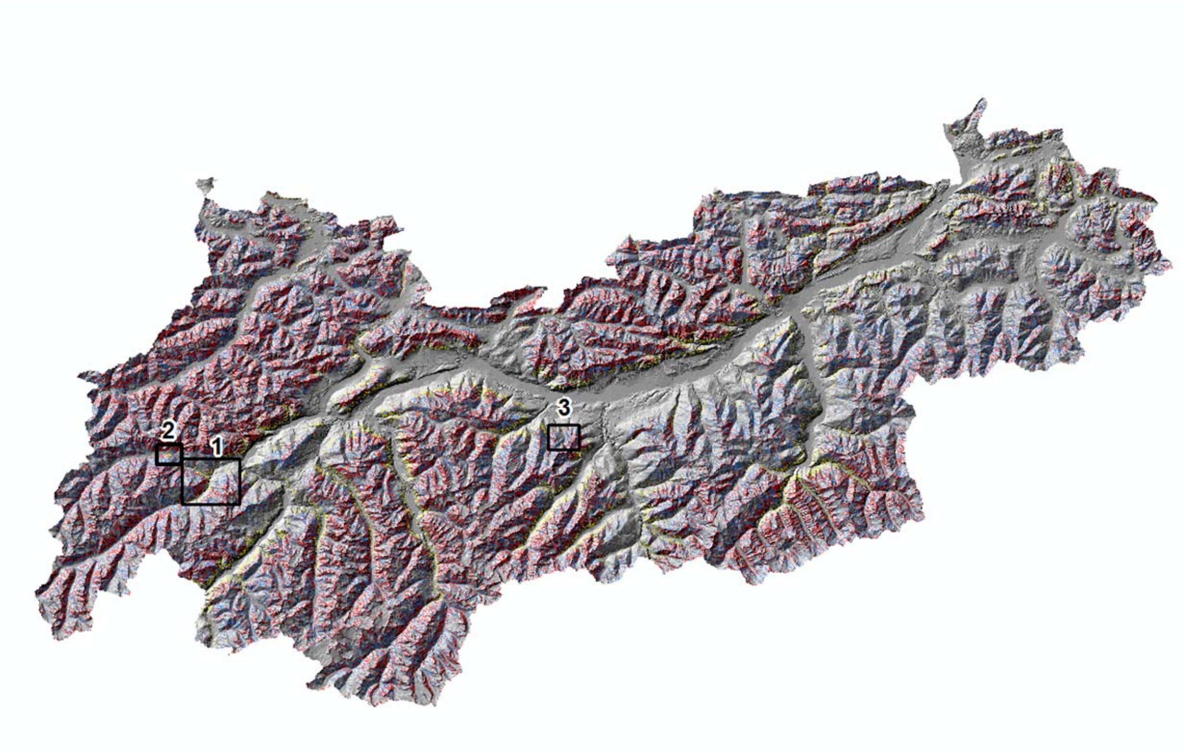

Figure 5-39: *Test site C1a: Three examples: modelled and real avalanche release areas.*

Example 1 is the Paznauntal valley (figure 5-40), numerous hazardous events occurred from this avalanche release areas, and construction of avalanche defence structures is ongoing:

1) Flungbach avalanche

2) Langesthei avalanche

3) Moosbach avalanche

4) Lahnegg avalanche

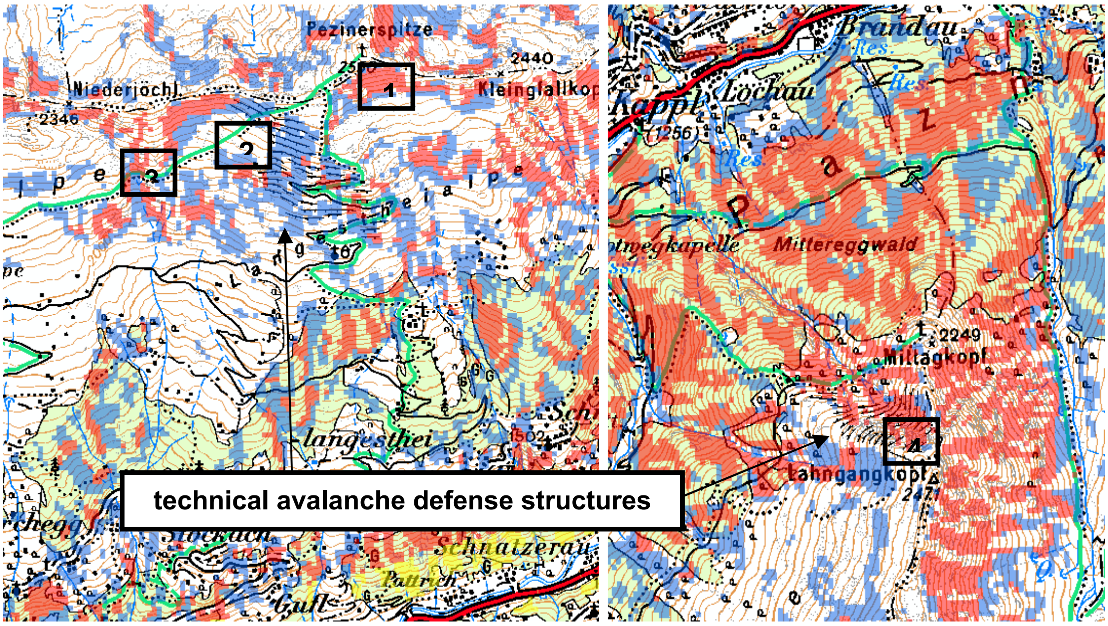

Figure 5-40: *Modelled AHPs and real avalanche release areas (here: technical avalanche defense structures). The release areas of these avalanches (blue and red areas) contain true avalanche release areas.*

Example 2 is a forest avalanche which occurred for the first time on 24th of March 2006 in the Stanzertal valley and interrupted the railway (figure 5-41).

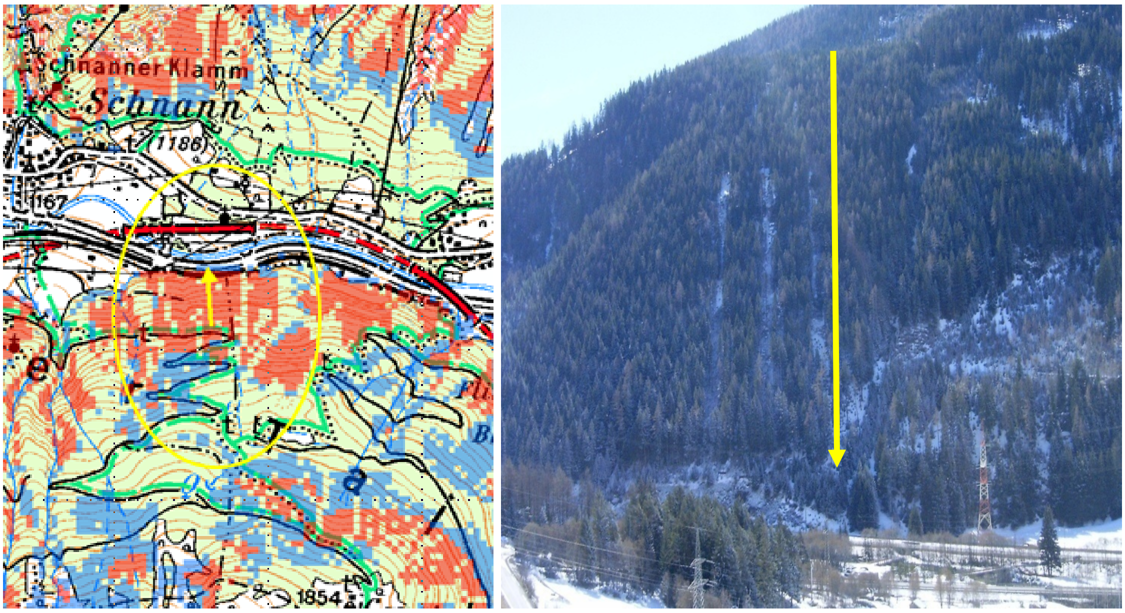

Figure 5-41: *Modelled PRAs and real avalanche release areas (yellow arrow).*

Example 3 is the Axamer Lizum valley (figure 5-42): on 9Th of February 1984 a hazardous avalanche occurred from the modelled AHP. The avalanche damaged a building at a cable car station. Four people were killed, 12 people injured and 8 cars destroyed. Afterwards technical defence structures have been constructed.

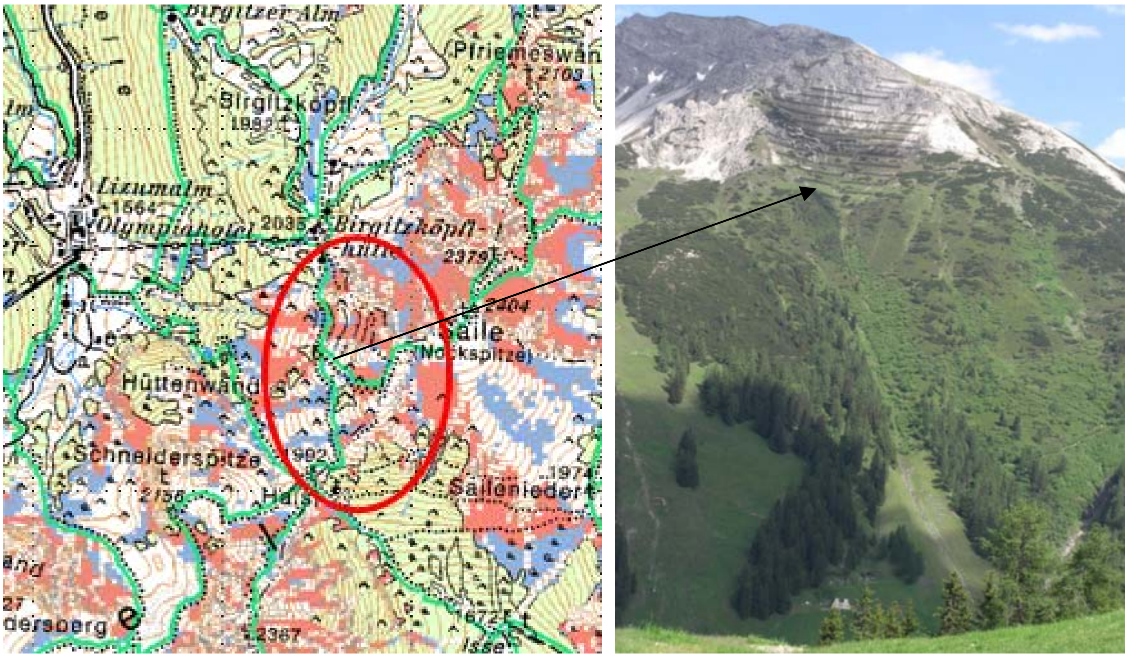

Figure 5-42: *Modelled AHPs and real avalanche release areas.*

Some uncertainties remain in the selection of the thresholds of slope gradient, the plan curvature and in the quality of the DTM. Furthermore medium scale topography and the surface roughness have not been taken into account. Nevertheless plausible AHPs could be achieved.

Figure 5-43 shows the FAHP and the modelled potential avalanche tracks simulating the so called Kienberg avalanches on a slope between Stans and Jenbach in Tyrol. It is documented that these avalanches reached and buried the roads between the settlements.

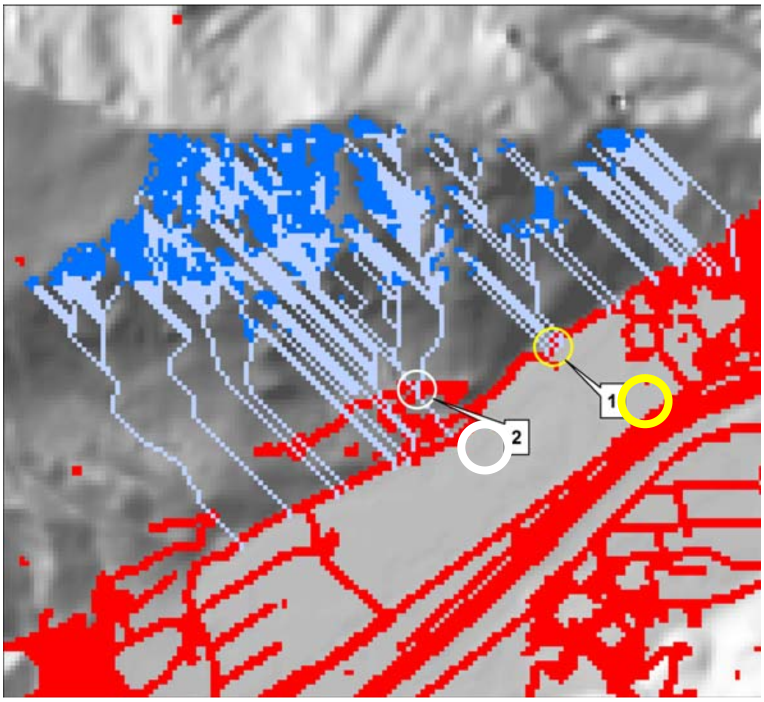

Figure 5-43: *Modelled FAHP (dark blue) and avalanche tracks (light blue) near Kienbach. Yellow circle in the map: 1981/02/04, an avalanche buried the street (red) on a length of about 50 meters (reference: BFW damage avalanche database). White circle in the map: 2000/01/31, an avalanche buried the street to the inhabited castle of Tratzberg (reference: BFW Damage Avalanche Database).*

The quality of the calculation of the avalanche tracks is more difficult to judge. Due to the forest cover, no avalanches released from most of the AHPs. Also, only for large avalanches which initiated above the upper timberline reference data of runout lengths are available. However, within ProAlp the method is only addressed for avalanches released inside the forest. A comparison with physical methods is not suitable and the database of historical events is not sufficient (often inaccurate mapping of release zones and outer edges of run out zones).

In spite of the fact that necessary data for modelling avalanches are still not existent and could not be used most of the avalanches calculated within ProAlp show plausible results. Important factors of avalanche dynamics like the snow mass were not considered and the method is also strongly influenced from the chosen geometric angle and from the quality of the DTM. The energy line concept is only suitable for smaller avalanches like forest avalanches and a more or less regular terrain.

The calculated areas of the FAHP are shown in Table 5-26.

Table 5-26: *Area of FAHP (Avalanche hazard potential within forests).*

Testside	Hazard potential area (ha)	% of total area
C1a	98356	9.19
C2-1	6433	10.29
C1-2	2766	1.84
C3-1	36732	9.18
C4-1	9290	1.40
F1	652	21.73
F2	9850	32.83

5.3.2.2 Rockfall

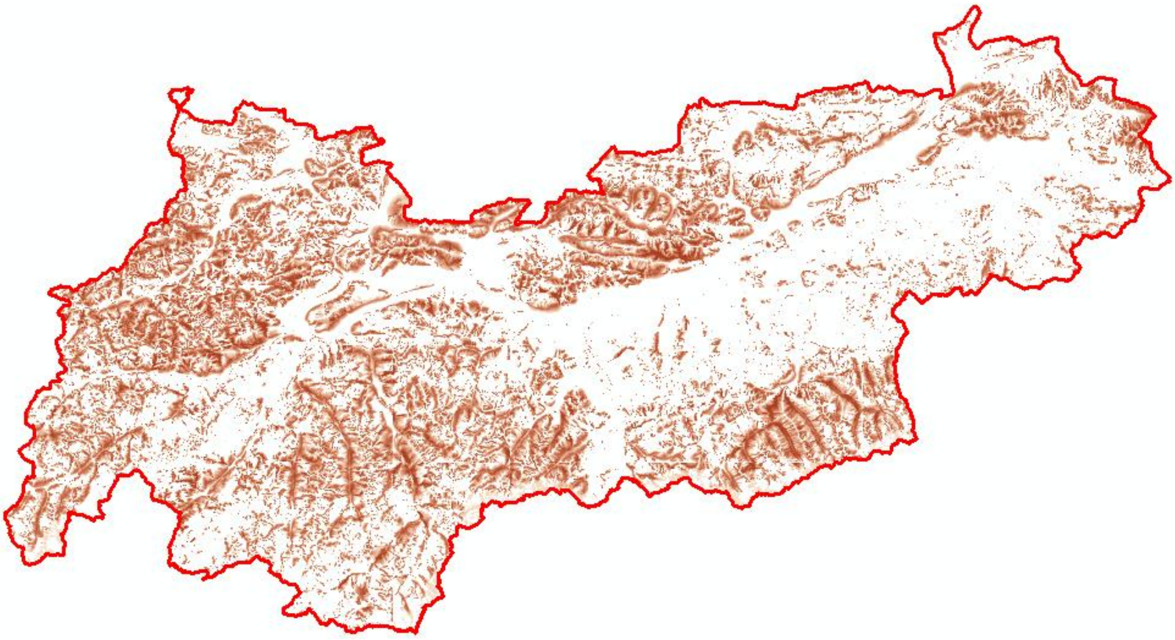

Figure 5-44: *Test site C1a: Hazard potential for Northern Tyrol calculated with ELmodel.exe.*

Mainly two factors are influencing the modeled rockfall active areas. The defined starting zones or cells and the used energy line principle. Regarding the rockfall starting cells, there remains uncertainty on the identified rockfall start zones on forested slopes and especially on those where no rock faces are depicted on the topographical maps. As explained before, we decreased the slope threshold value used in forests as compared to the one used for rock face, to account for the smoothing effect of the forest cover on the terrain as represented by the DEM. Small rock faces that do exist on forested slopes in the Alps, disappear in the DEM due to the smoothing effect. As many of the forested slopes, where such rockfall active faces exists, cover slope of 35 – 38°, it can be expected that on slopes having a steeper gradient than 39°, such faces occur. But, as already mentioned, by using that threshold, also slope without rock faces will be selected.

Regarding the used energy line method, two arguments have to be discussed. The first one is the method itself, which is not sensitive for local conditions other than the topography. The slope characteristics such as form and slope surface roughness and damping are not taken into account. This can result in underestimated or overestimated rockfall runout zones. With a more physically-based rockfall model, these mentioned terrain factors can be represented better. For a regional study that is carried out at a national-or alpine scale, such a model is too detailed. The second factor is the choice of the energy line angle. Normally, this angle should be chosen on the basis of historical rockfall events that have occurred in a region. Retro-calculation of the angle between the actual stopping and release point gives a good indication of the value of this angle and the variations within. Not having a historical rockfall event database for the test regions, we chose an “average” angle value of 32º. This of course, locally leads to underestimated or overestimated rockfall runout zones.

The calculated areas of the RHP are shown in Table 5-27.

Table 5-27: *Area of RHP (Rockfall hazard potential)*

Testside	Hazard potential area (ha)	% of total area
C1a	439039	41.03
C2-1	28300	45.28
C4-1	10500	11.67
C1-2	30265	77.60
F1	1186	39.53
F2	15800	52.67

5.4 Damage potential mapping

Roads, railroads and buildings were selected from two different types of datasets: On the one hand only international data with rather poor information was available (TELEATLAS, EuregionalMap), on the other hand national datasets which are by far more detailed could be used. Within ProAlp we applied a buffer of 25m around the infrastructure (figure 5-45). The value of 25 meters was adjusted to the resolution of the data that had been used for hazard potential mapping.

Figure 5-45: *Infrastructure with 25m buffer.*

The buffered polygons where converted into raster datasets with a resolution of 25 m. After intersecting the enhanced infrastructure layer with the created hazard potential zone the finally damage potential zone was created (figure 5-46).

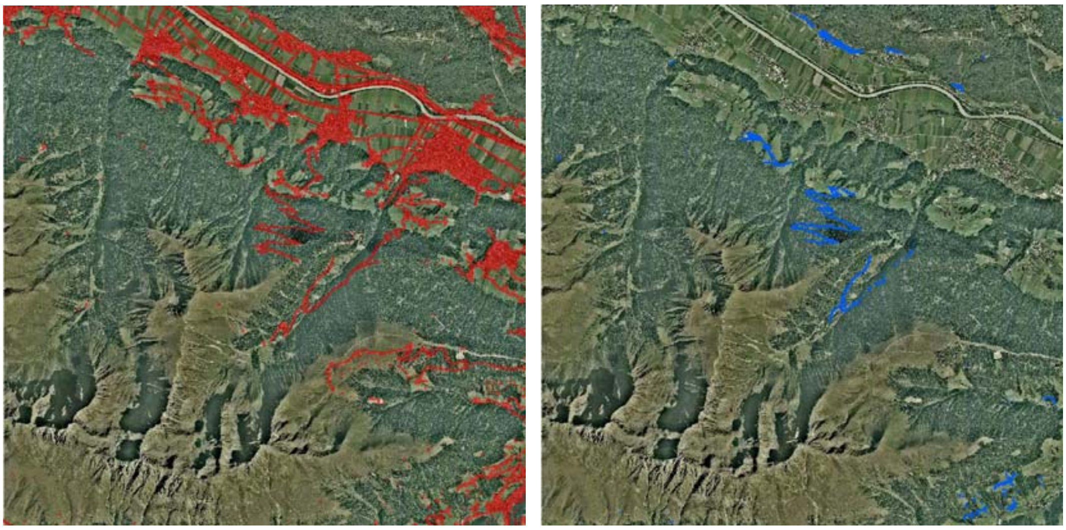

Figure 5-46: *Site in Northern Tyrol with buffered infrastructure (red) and damage potential zone (blue).*

The availability of the different data types for the cross border test sites is summarized in Table 5-28.

Table 5-28: *Different types of infrastructure data for the cross border test sites.*

Test site	C1-2	C2-1	C3-1	C4-2	C4-1
National data		x			
International data	x		x	x	x

For non-cross border test sites C1a, F1 and F2 national data were available. For the test site C1 (Northern Tyrol) manual corrections were carried out. At first, the layers containing streets and buildings had to be corrected and filtered. Forest streets were eliminated and also streets below tunnels had to be excluded. Railway lines were digitized and added. Objects and infrastructure concerning tourism like hiking trails or fixed rope routes were not taken into account.

For the test sites in Switzerland the vector data of the landscape model VECTOR25 was used (buildings and streets of class 1 and class 2).

For other countries only infrastructure data from TELEATLAS and/or EuregionalMap were available. The classification of infrastructure as potential damage zones was different when using different data within this study. It was not possible to harmonise these datasets. Therefore only examples for methods are provided within ProAlp. It was not possible to establish an unambiguous model for natural hazard mapping or risk zone planning. Obviously the expected area of forest with protective function depends on the quality and availability of the infrastructure.

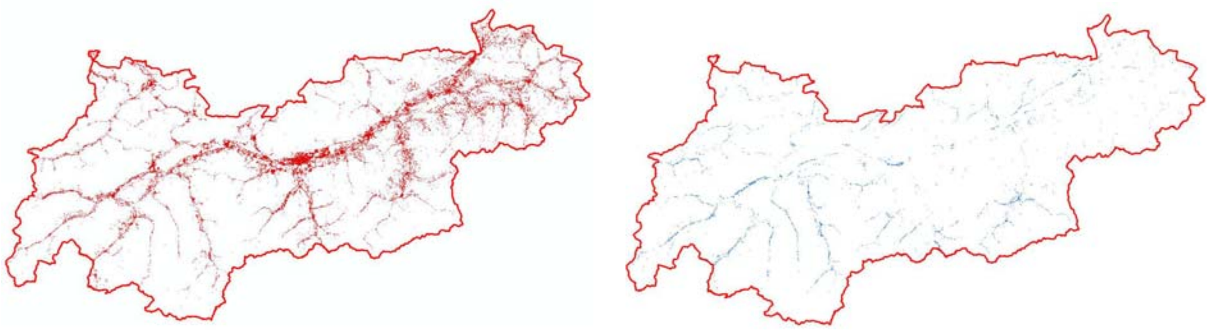

Figure 5-47: *Infrastructure and damage potential zones for the Test site C1a Northern Tyrol.*

5.5 Protective effect mapping

5.5.1 Methods

For both natural hazards (avalanche and rockfall) the following procedure was done:

First step:	derivation and mapping of forests with protective functions
Second step:	derivation and mapping of the protective effect of these forests using respective indicators and thresholds

Table 5-29: *Summary of used indicators with remote sensing for the protective effect of forests.*

Hazard	RS Coarse scale	RS Fine scale
Avalanche	Crown cover conifer	Crown cover conifer
	Total crown cover	Total crown cover
		Gap length
Rockfall		Fraction of gaps (<25%)
	Forest slope length (>200m)	Forest slope length (>200m)
	Basal area	Stem density
		DBH

5.5.1.1 Avalanche

Mapping of forests with protective function

Forests with protective function against avalanches are forests that can prevent the release of avalanches. The mapping of the forest was done before the modelling process.

Indicators for protective effect from coarse scale RS data

For each forest Landsat - pixel, a certain number of forest parameters surveyed in the field at the NFI plots was estimated. The basic assumption is that spectrally very similar pixels should have similar forest composition and similar forest parameters. This is an effort of a highly detailed classification. The requirements for exact location of NFI plots in the Landsat image are much higher here than for the forest mask generation, where only location errors close to forest/non-forest boundaries have negative effects.

The following NFI parameters were estimated with kNN:

- Volume fraction of coniferous trees (%)
- The mean tree height (m)

The kNN-method provides satisfying results for the volume fraction of coniferous trees.

To derive the protective effect, total crown cover had to be estimated. Due to the relative good quality of kNN volume estimates the crown cover estimate was based on the volume estimate using an empiric function developed by Austrian NFI data. Within ProAlp NFI data from Northern Tyrol were used. Total crown cover (TCC), mean tree height (H_m), sea level (H) and the logarithm of volume per hectare (m^2/ha) were used as input data:

$$TCC = 0.236 - 0.1461 * H_{DTM} - 0.1227 * H_m + 4.0624 * \log(V)$$

TCC = total crown cover
H_m = Mean tree height (m)
$HDTM$ = height from the DTM (hectometres)
V = Volume/ha (m^2/ha)

The coniferous crown cover (CCC) is then estimated by multiplying TCC with the volume fraction of coniferous trees.

Indicators for protective effect from fine scale RS data

For the fine scale there are three indicators relevant for the protective effect: the tree height, the crown coverage (crown cover of coniferous trees and total crown cover) and gaps. Depending on the avalanche hazard potential (AHP) there are two different thresholds of tree heights (2 m and 5 m) used. These forest areas can be derived from the nDSM (Figure 5-48).

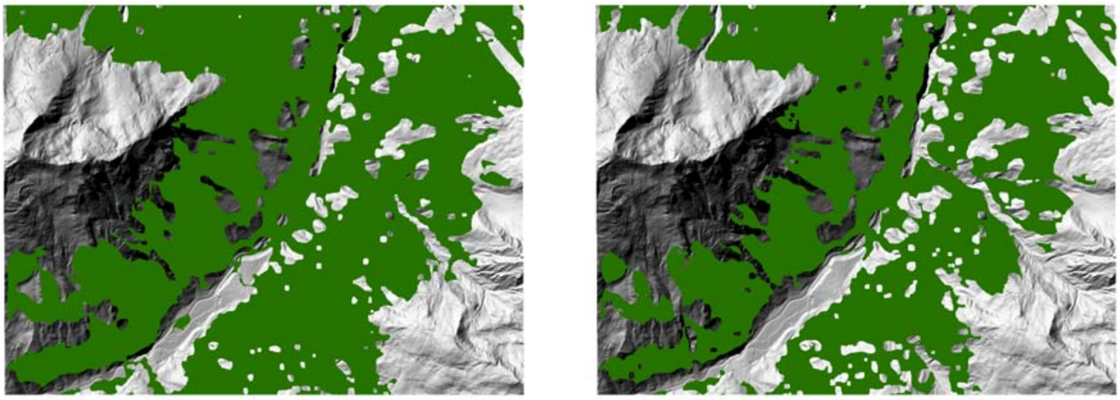

Figure 5-48: *Testside F2, Paznauntal: Indicators for protective effect: (a) forest with tree heights above 2m, (b) forest with tree heights above 5 m.*

The thresholds are the same as for the coarse scale (see Table 5-25).

Critical gaps:

As a first step gaps had to be identified. A gap is defined as an open area within the forest with maximal crown coverage of 10% and a minimum size of 10x10 meters. For the extraction of gaps the same moving window technique as for the forest mask was used (see chapter 5.2.1.2). The size of the moving window for gap extraction corresponds to the minimum size of gaps (10 m x 10 m).

The procedure is similar to the extraction of the forest mask. Because the size the moving window is reduced, smaller areas within the forest mask are now detected as ‘Non – forest’. These ‘Non – forest’ areas, if they are larger than 10x10 meters, are used as gaps in the forest mask.

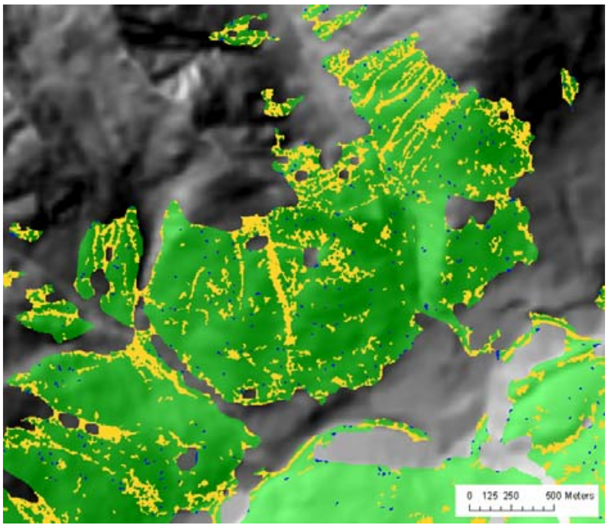

Figure 5-49: *Test site F1 Engadin, extracted gaps: green – forest mask; orange – extracted gaps by using a threshold of 5 m of tree height and a length ≥ 20 m. blue – gaps shorter than 20 m.*

The critical gap length is determined mainly by the slope. According to Frehner et al. (2005) there is a linear relationship between slope and the critical gap length (Table 5-30).

Table 5-30: *Dependency of critical gap length on slope (Frehner et al. 2005).*

Slope (°)	Critical gap length (m)
30	60
35	50
40	40
45	30

The critical gap length was calculated using the formula:

$$\text{Critical Gap Length [m]} = -2 \times (\text{Slope [°]}) + 120$$

Using standard GIS functions the gap length and the critical gaps where identified.

Crown cover:

For test site F1- Paznauntal it was not possible to distinguish between evergreen and non-evergreen trees. Especially larches are relevant for the protective effect. In the test site F1 only few larches occur and they all stand free as single trees – bad conditions for a classification of digital aerial photos where homogenous stands of a certain size are necessary as input data for a good classification. Another possibility to be able to distinguish between evergreen and non-evergreen trees is the analysis of ALS data which were acquired under leaf-off canopy conditions during fall, conditions that were not fulfilled from the available ALS data (acquisition period during summer), thus only the total crown cover was used for the evaluation of the protective function.

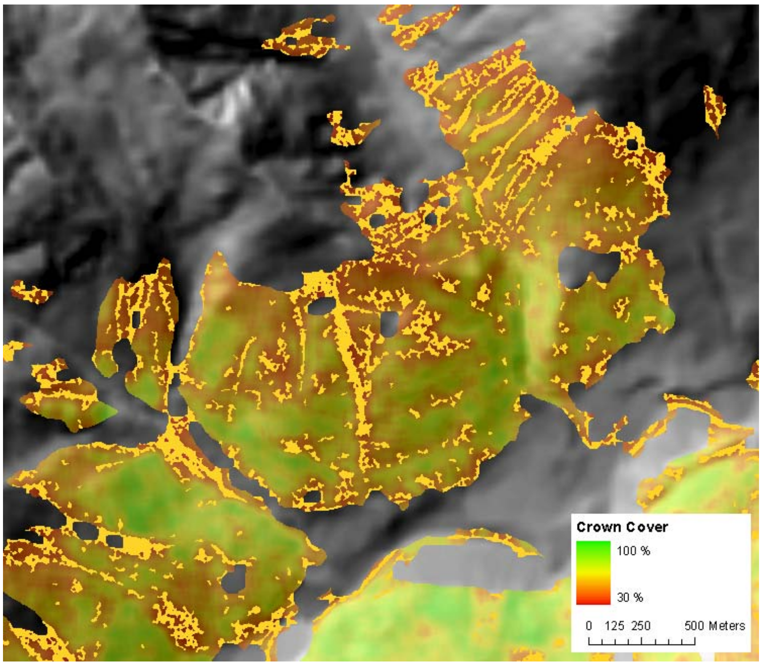

Figure 5-50: *Test site F1, Engadin: Total crown cover with gaps.*

5.5.1.2 Rockfall

Mapping of forests with protective function

Forest with protective function (RPF) was defined as forest with potential protective function (pRPF) that is actually up hill of existing damage potential. To detect areas above existing damage potential the standard watershed function inside the hazard potential zones was applied using the damage potential as pour data. This simple approach of flow direction was used to simulate falling rocks onto the areas of damage potential.

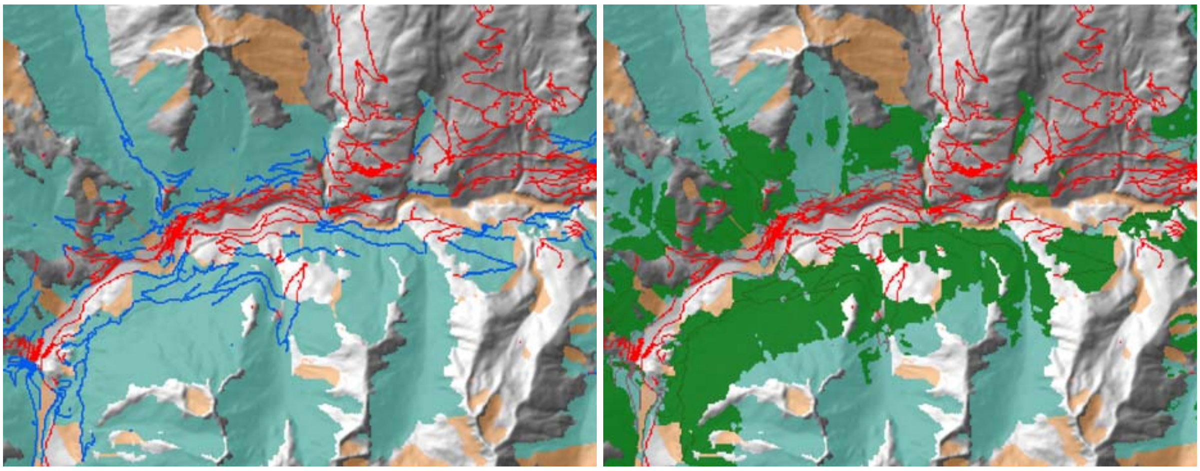

Figure 5-51: *Mapping of forests with protective function. Left: Areas (light-blue) of the hazard potential zones above damage potential areas (dark-blue). Orange areas of the hazard potential zones do not affect any damage potential areas. Right: Forest with potential protective function (green) - derived by intersection of the forest mask and the areas of the hazard potential zones above damage potential areas.*

A layer including forest with potential protective function was created by intersecting the calculated hazard potential area (light-blue areas in Figure 5-51) with the forest.

The areas of forest with potential protective function serve as input masks for the analysis of the actual protective effect of these forests (dark-green areas in Figure 5-51). The indicators for the protective effect are derived from coarse scale and fine scale remote sensing data.

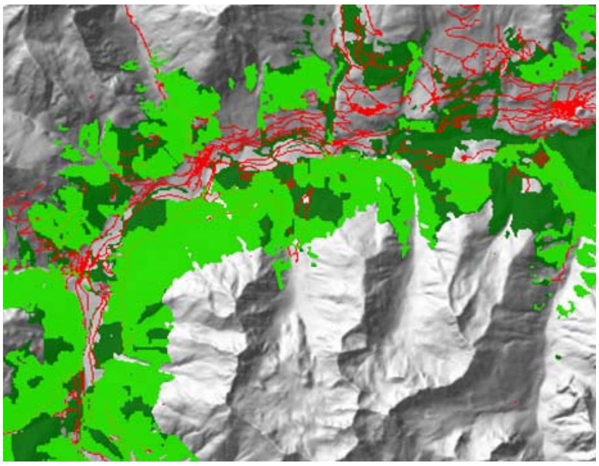

Figure 5-52: *Detail of Test site Engadin: Forest mask (green); Forest with potential protective function (light-green).*

Indicators for protective effect from coarse scale RS data

For the coarse scale the protective effect is depending on the forested slope length in horizontal projection which should be not shorter than 200m and the basal area.

Forested slope length:

Based on the inverse DEM basins were calculated with the hydrology tool. The Basin tool analyzes the flow direction raster to find all sets of connected cells that belong to the same drainage basin. These basins represent the single slopes that are relevant for the evaluation. They were used as mask to clip the DTM. Inside these zones the flow direction and the flow length were calculated. Furthermore the slope was calculated and the mean slope (zonal mean) and the cosines of the mean slope were calculated for each basin. The cosines times the before calculated flow length represents the slope length in horizontal projection. Slopes that are shorter than 200 meters have no protective effect.

Basal area:

The basal area was not derived directly from remote sensed data, but from a stochastic relationship between Volume and basal area, which was established using NFI data from Austria:

$$G/ha = 0.7819 * V^{0.6719}$$

G/ha = basal area,
V = volume/ha

The volume/ ha was downscaled with the kNN method. The basal area was only calculated for areas with slopes longer than 200 meters.

Indicators for protective effect from fine scale RS data

For the fine scale there are four indicators relevant for the protective effect: the forested slope length in horizontal projection (not shorter than 200 meters), the gap lengths in slope direction in relation to the forested slope length (the fraction of gap lengths should not be larger than 25 percent of the forested slope length), the stem density (stems per hectare) and the breast height diameter.

Forested slope length:

The forested slope length in horizontal projection was calculated as described for the coarse scale.

Gaps:

The gaps were derived from the ALS data as described before (see chapter 5.5.1.1).

The gap length was calculated with the zonal statistics tool. The gaps were used as mask to clip the DTM; afterwards the flow direction and the flow length were calculated inside the gap, whereas the zonal maximum of the gap length is the relevant gap length in slope direction, whereas the critical gap length lies above 20 meters. Based on these gaps a layer containing forests with protective function was produced where the gaps were weighted with 2 and the remaining forest with 1. The hydrology tool was used to calculate the flow accumulation – once with and once without weighted layer. Afterwards basins were derived from the DTM – inside these zones the zonal maxima of the two different flow accumulation layer were calculated. The fraction of the gap lengths in relation to the forested slope length is the difference of the zonal maximum of the weighted flow accumulation layer and the zonal maximum of the non-weighted flow accumulation layer divided by the zonal maximum of the non-weighted flow accumulation layer. If the fraction of the gap lengths is larger than 25 percent of the forested slope length this slope has no protective effect.

Stem density:

From ALS data it is not possible to derive directly the stems per hectare (because of the crown closure) but it is possible to calculate the crowns per hectare. Based on the crown height model (the difference between DSM and DTM) the local maxima representing single crowns were calculated (RAINER 2005).

The local maximum and the local minimum were calculated within a moving window (size 5 x 5 m). If the difference between the maximum and minimum was larger than one meter the maximum was identified as local maximum. These local maxima are the relevant crowns for the calculation of the stem density. To be able to extrapolate the crowns per hectare to stems per hectare field data were necessary. Based on the comparison between field data and the data derived from the ALS data in a test site in Switzerland a factor of 4.25 was calculated. The stem density was only calculated for forested slopes longer than 200 meters and slopes where the summed gap lengths represent less than 25 percent of the forested slope length.

Breast height diameter:

The breast height diameter cannot be derived from remote sensed data. As it is possible to calculate the correlation of the tree height and the breast height diameter (derived from Austrian NFI data), this parameter was calculated based on the crown height model which contains the relevant tree heights with the formula:

$$BHD = -129.574 + 1.7114 * H_{nDSM} + 8.8813 * H_{DTM}$$

BHD = Breast Height Diameter in cm
HnDSM = height from the nDSM in decimetres
HDTM = height from the DTM in hectometres

The breast height diameter was only calculated for forested slopes longer than 200 meters and slopes where the summed gap lengths that represent less than 25 percent of the forested slope length.

5.5.2 Results and discussion

5.5.2.1 Avalanche

Example coarse scale of test site C1 (25 m resolution):

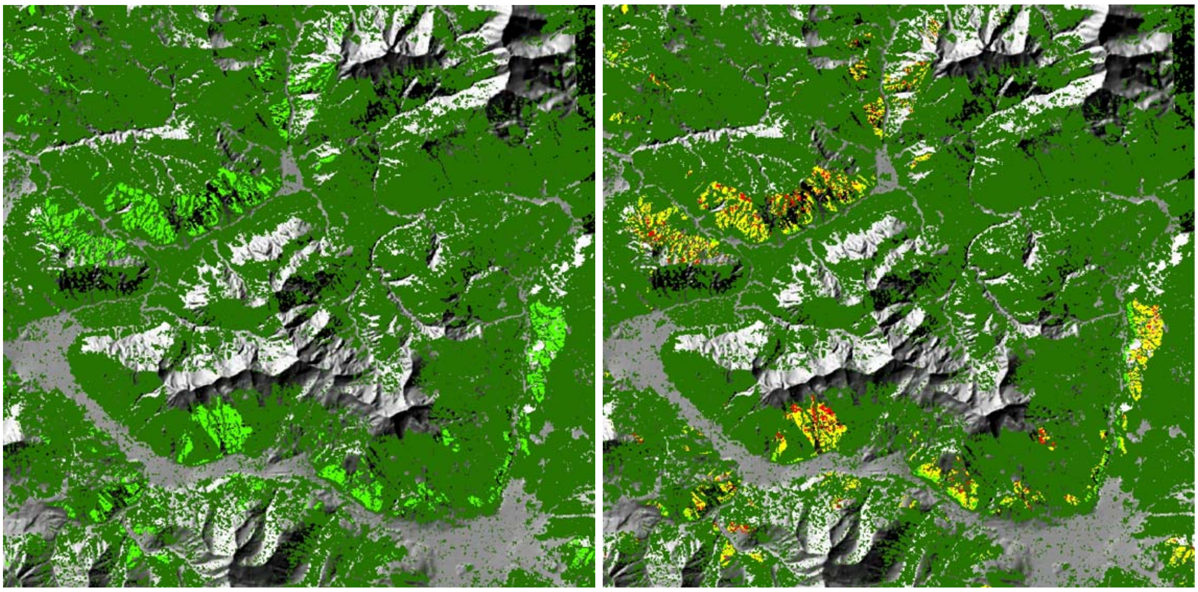

Figure 5-53: *Test site C1 (example): left: forest area (dark green) and forest with protective function (light green); right: sufficient protective effect (light green), no sufficient protective effect (yellow) and very little protective effect (red).*

Only a small fraction of the total forest area was assigned to be a forest with direct protective function against avalanche release (2.15%). This small fraction is also due to the problems discussed with forest mapping in test site C1. Large areas were covered by hard shadows due to the late flight date of the Landsat scene. For the test site C1a, where the shadowed parts were manually digitised by using orthophotos the fraction of forest with protective function is more than doubled. Nevertheless the derivation of the protective effect by kNN is restricted to areas without hard shadows. The following tables contain the results of the achieved area for forest, forest with potential protective function, forest with protective function and the protective effect.

Table 5-31: *Results concerning avalanche in the test site C1.*

	whole area	forest area	pAPF	APF
km²	9822	4162	3090.57	173.23
%	100	42.37	31.47	1.76
% of forest		100	74.26	4.16
% of pAPF			100	5.61

Table 5-32 gives the figures for the protective effect for test site C1.

Table 5-32: *Test site C1: Protective effect*

	Fraction of the APF
Sufficient protective effect	25 %
Very little protective effect	52 %
Not sufficient protective effect	23 %

Example coarse scale cross border test site C2-1 Austria – Switzerland:

29.7% of the test site was classified as forest. 13.9% of the forest is modelled as forest with protective function against avalanche release.

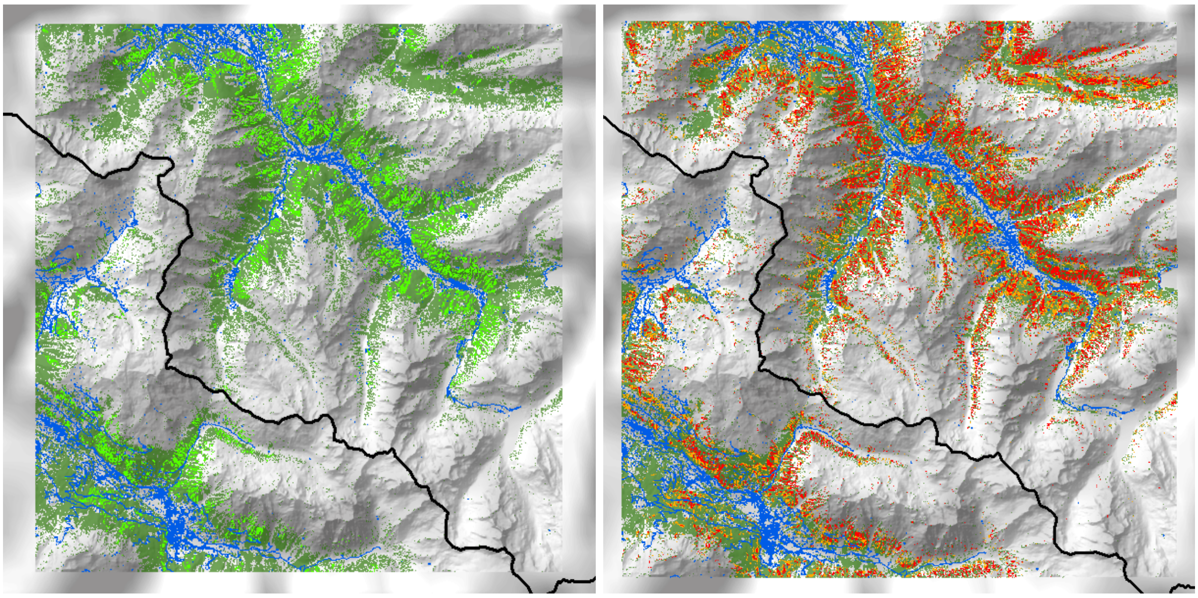

Figure 5-54: *Cross border test site C2-1 Austria - Switzerland. Left: Dark green – Forest mapped by kNN method; Light green - forest with protective function against avalanches; Blue – infrastructure used for modelling of the forest with protective function. Right: Forest avalanche hazard potential. Light blue – little hazard potential, orange – medium hazard potential, red – high hazard potential.*

Example coarse scale cross border test site C3-1 Austria – Bavaria (25 m resolution):

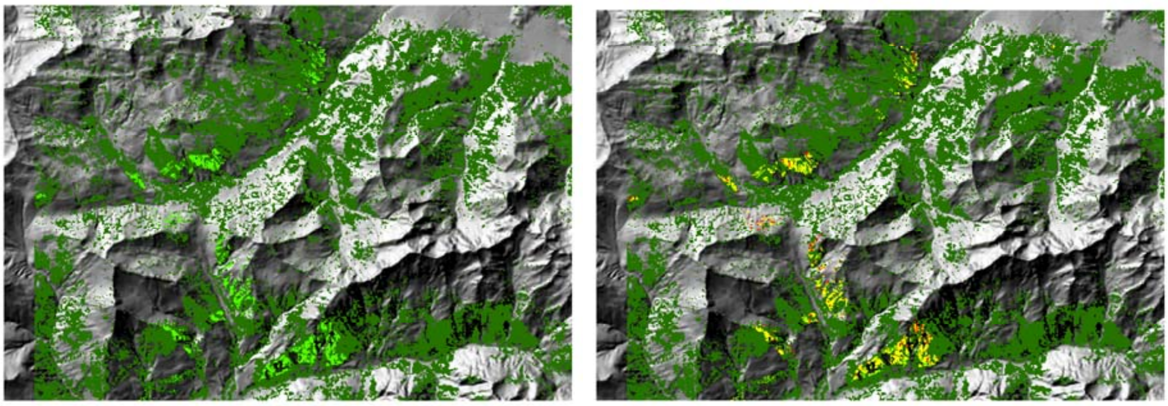

Figure 5-55: *Extract of cross border test site C3-1 Austria - Bavaria. Left: forest area (dark green) and forest with protective function (light green); right: sufficient protective effect (light green), no sufficient protective effect (yellow) and very little protective effect (red).*

The very low fraction of the forest with protective function is mainly caused by the use of Teleatlas for damage potential mapping where only small parts of the infrastructure are available. The following tables contain the results of the achieved area for forest, forest with potential protective function, forest with protective function and the protective effect.

Table 5-33: *Results concerning avalanche in the test site C3-1*

	whole area	forest area	pAPF	APF
km²	1492	556	15.43	6.61
%	100	37.27	1.03	0.44
% of forest		100	2.78	1.19
% of pAPF			100	42.84

Table 5-34: *Test site C3-1 Austria – Bavaria: Effectiveness of forests with protective function*

Sufficient protective effect	12 %
Very little protective effect	72 %
Not sufficient protective effect	16 %

Example coarse scale cross border test site C4-1 Austria – Slovenia:

Only 0.3% of the forest is mapped as forest with protective effect against avalanches. This small percentage is also due to the selection of the potential damage zones. Data from TELEATLAS (street-type 0-4) and railway data from EuroregionalMap was used. As shown in Figure 5-55 (left) there is very little infrastructure in Slovenia, especially in the areas with forest avalanche hazard potential (right). Therefore the area of forest with protective function is highly underestimated.

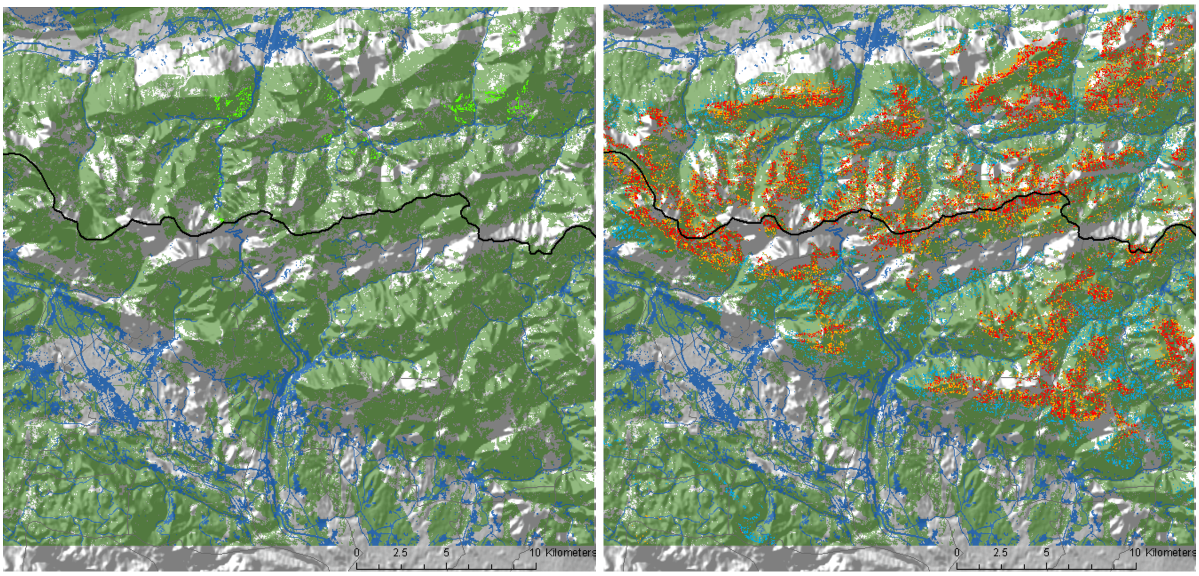

Figure 5-56: *Cross border test site C4-1 Austria - Slovenia. Left: Dark green – Forest map; Light green – APF; Blue – Infrastructure. Right: Forest avalanche hazard potential. Light blue – little hazard potential, orange – medium hazard potential, red – high hazard potential.*

Example fine scale test site F1 - Paznauntal:

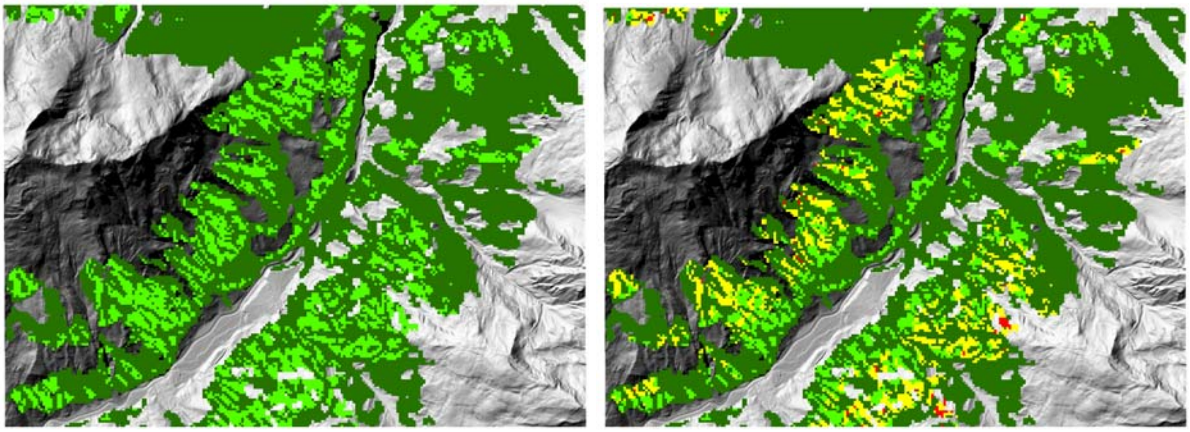

Figure 5-57: *Test site F1 – Paznauntal (Austria); left: forest area (dark green) and forest with protective function (light green); right: sufficient protective effect (light green), no sufficient protective effect (yellow) and very little protective effect (red).*

The following tables contain the results of the achieved area for forest, forest with potential protective function, forest with protective function and the protective effect.

Table 5-35: *Results concerning avalanche in the test site F1*

	whole area	forest area	pAPF	APF
km²	30	13.86	5.39	3.35
%	100	46.2	17.97	11.17
% of forest		100	38.88	24.17
% of pAPF			100	62.15

Table 5-36: *Test site F1 - Paznauntal: Effectiveness of the forests with protective function*

Sufficient protective effect	53 %
Very little protective effect	45 %
Not sufficient protective effect	2 %

Example fine scale test site F2 – Engadin:

For test site Engadin 20% of the forest was classified as forest with protective effect (starting zones for avalanches, Figure 5-58 - left).

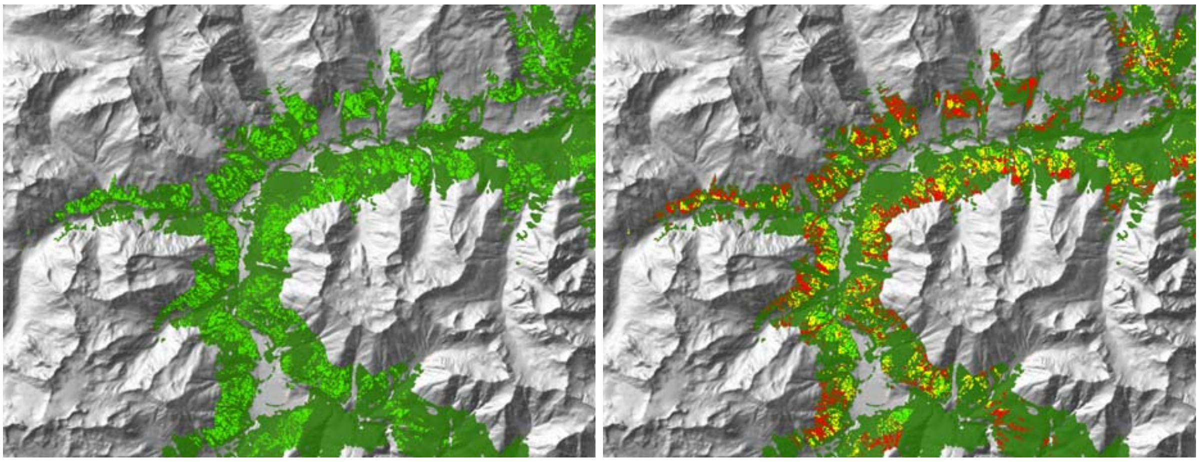

Figure 5-58: *Test site F2 – Engadin (Switzerland); left: forest area (dark green) and forest with protective function (light green); right: sufficient protective effect (light green), no sufficient protective effect (yellow) and not sufficient protective effect (red).*

The protective effect of the forest with protective function is illustrated in Figure 5-58. Quite a high portion has very little protective effect (51%). The rest has minimal to sufficient protective effect (Table 5-37).

Table 5-37: *Protective effect against avalanches according to crown coverage and gaps longer than critical length*

	Fraction of the APF
Sufficient protective effect	13 %
Very little protective effect	51 %
Not sufficient protective effect	36 %

The differences in the protective effect between the fine scale test sites in Austria and Switzerland could be explained by different ALS data quality. For both test sites ALS data was used to calculate the crown coverage. In Austria the raster size of the DTM was 1m x 1m whereas in Switzerland the raster size was 2.5m x 2.5m. From the Austrian ALS data no meta information was available. In Switzerland the average point density of the first pulse dataset was 0.5 points/m^2. Recent studies have shown that the point datasets across Switzerland are a combination of at least two flights (in some places up to 4). So it can happen that in a certain area too many points in the first pulse dataset are actually ground hits (when acquired in leaf off times). After interpolation to a regular raster (triangulation was used) the height of raster cells could be underestimated. This could result in underestimated crown coverage in the Swiss test site and in a high fraction of forest with protective effect with very little protective effect against avalanches.

5.5.2.2 Rockfall

Example coarse scale of test site C1 (25 m resolution):

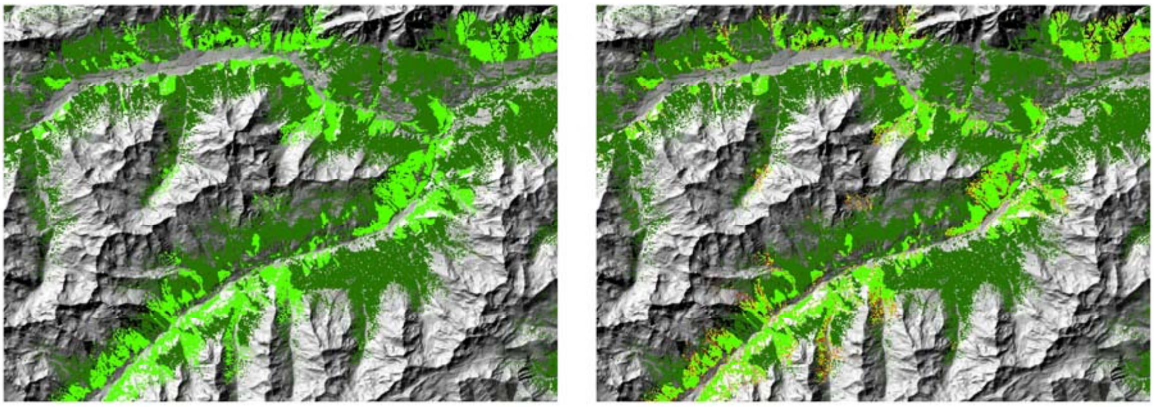

Figure 5-59: *Test site C1 (example): left: forest area (dark green) and forest with protective function (light green); right: sufficient protective effect (light green), no sufficient protective effect (yellow) and very little protective effect (red).*

The following tables contain the results of the achieved area for forest, forest with potential protective function, forest with protective function and the protective effect.

Table 5-38: *Results concerning rockfall in the test site C1.*

	whole area	forest area	pRPF	RPF
km²	9822	4162	1631.78	706.08
%	100	42.37	16.61	7.19
% of forest		100	39.21	16.96
% of pRPF			100	43.27

Table 5-39: *Test site C1: Effectiveness of the RPF.*

Sufficient protective effect	77 %
Very little protective effect	8 %
Not sufficient protective effect	15 %

The forest area and the area of forest with protective function in Northern Tyrol are shown in Figure 5-60.

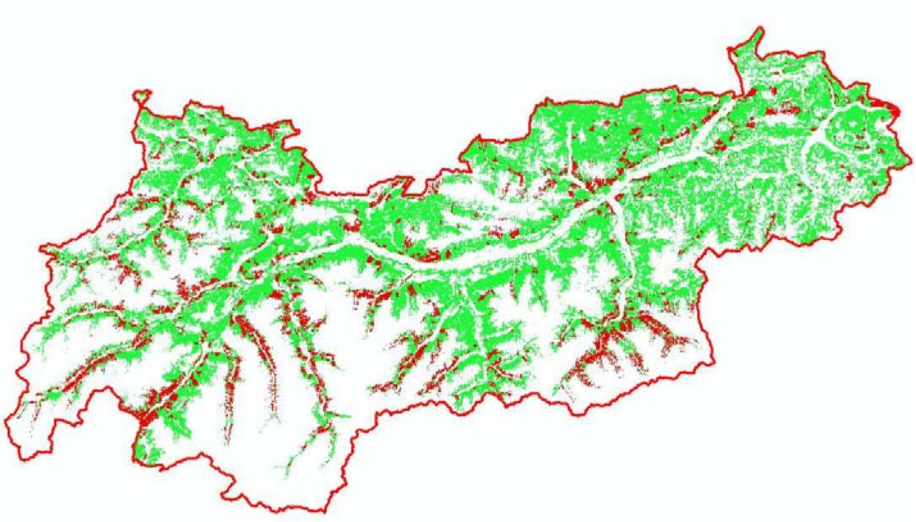

Figure 5-60: *Test site C1a. Forest (green) and forest with protective function concerning rockfall (red) for the whole test area of Northern Tyrol.*

The following table contains the results of the achieved area for forest, forest with potential protective function and forest with protective function concerning rockfall for Northern Tyrol.

Table 5-40: *Results concerning rockfall in the test site Northern Tyrol*

Northern Tyrol	whole area	forest area	pRPF	RPF
km²	10682	4182.91	1806.76	730.82
%	100	39.16	16.91	6.84
% of forest		100	43.19	17.47
% of pRPF			100	40.45

Examples coarse scale cross border C1-2: Austria - Bavaria:

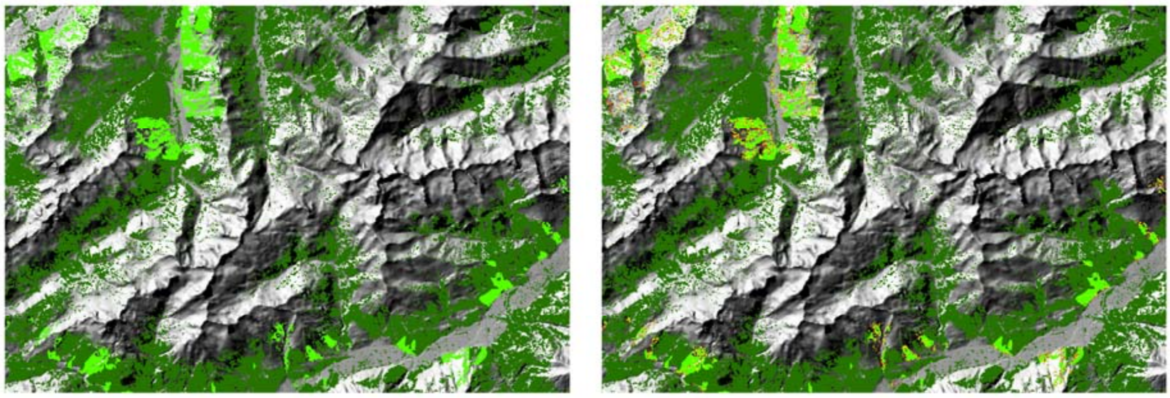

Figure 5-61: *Extract of cross border test site C1-2 Austria – Bavaria: left: forest area (dark green) and forest with protective function (light green); right: sufficient protective effect (light green), no sufficient protective effect (yellow) and very little protective effect (red).*

The following tables contain the results of the achieved area for forest, forest with potential protective function, forest with protective function and the protective effect.

Table 5-41: *Results concerning rockfall in the test site C1-2.*

	whole area	forest area	pRPF	RPF
km²	609	159	83.24	11.74
%	100	26.11	13.76	1.93
% of forest		100	52.36	7.38
% of pRPF			100	14.1

Table 5-42: *Test site C1-2: Effectiveness of the RPF.*

Sufficient protective effect	71 %
Very little protective effect	11 %
Not sufficient protective effect	18 %

Examples coarse scale cross border C2-1: Cross-border Austria – Switzerland

33.5% of the forest in test site C2 is modelled as pRPF. 29.6% of the potential protective forest has a width smaller than 200m and is therefore not effective against rockfall according to the thresholds used in this study.

Table 5-43: *Test site C2-1: FAHP.*

Avalanche Hazard Potential	Fraction of AHP of forest (FAHP)	Fraction of AHP of forests protecting infrastructures (APF)
0 – no hazard potential	63.7 %	- - -
1 – low hazard potential	0.5 %	1.9 %
2 – medium hazard potential	14.6 %	35.8 %
3 – high hazard potential	21.2 %	62.3 %

Table 5-43 shows the avalanche hazard potential and the avalanche protective forest. The forest area is 17743ha and the APF 14.5%.

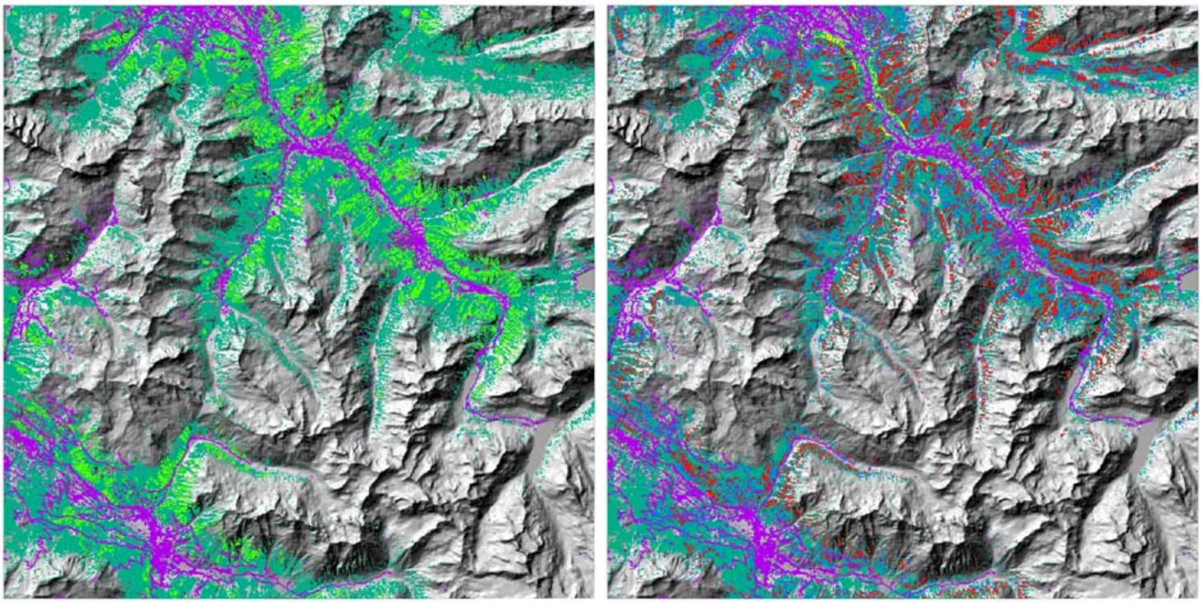

Figure 5-62: *Cross border Test site Austria – Switzerland. Left: Dark green – forest mapped by kNN method; Light green – APF; Violet – infrastructure used for modelling of the forest with protective effect. Right: Forest avalanche hazard potential (all forests sites with a avalanche release potential). Yellow – little hazard potential, blue – medium hazard potential, red – high hazard potential.*

Examples coarse scale cross border C4-1: Austria - Slovenia

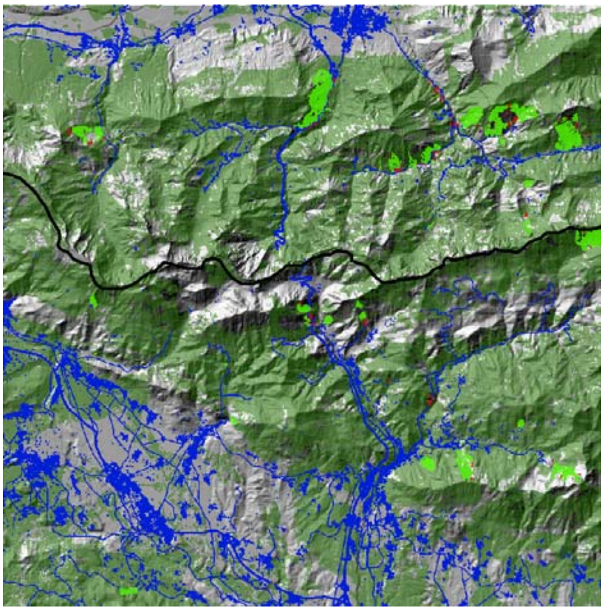

Figure 5-63: *Cross border test site C4-1 Austria – Slovenia. Dark green – Forest map; light green – RPF; red – RPF with width < 200m; blue – Infrastructure in parts of the test site C4 – Slovenia.*

62% of the area of the test site is forested. From the forest 2.3% are classified as forest with protective effect against for rockfall for the selected infrastructure. 92% of the classified RPF fulfil the protective effect regarding the minimum length of 200m. The land use mask from the Ministry of Agriculture, Forestry and Food form 2007 was used. For infrastructure the data came from the Ministry of the Environment and Spatial Planning (roads and railways and the cadastre of buildings from 25.5.2007). No further analysis on indicators of effectiveness for coarse scale remote sensing data was carried out in this test site.

Example fine scale test site F1: Paznauntal

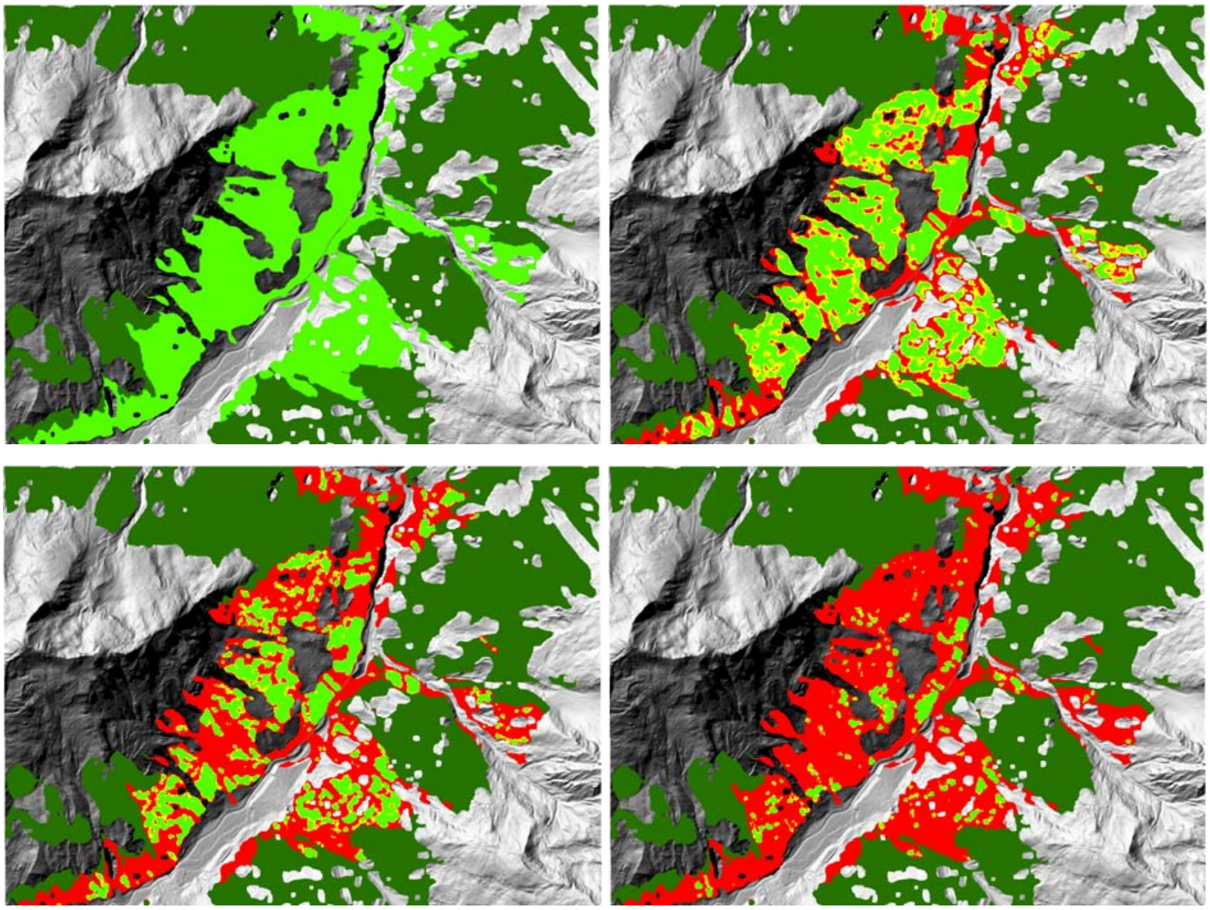

Figure 5-64: *Test site F1 Paznauntal (Austria). Top left: forest area (dark green) and RPF (light green). Top right: sufficient protective effect (light green), no sufficient protective effect (yellow) and very little protective effect (red) for small rocks Down left: same for medium rocks. Down right: same for large rocks.*

The following tables contain the results of the achieved area for forest, forest with potential protective function, forest with protective function and the protective effect.

Table 5-44: *Results concerning rockfall in the test site F1.*

	whole area	forest area	pRPF	RPF
km²	30	13.86	5.97	5.35
%	100	46.2	19.9	17.83
% of forest		100	43.07	38.6
% of pRPF			100	89.61

Table 5-45: *Test site C1: Effectiveness of the RPF.*

		Fraction of the RPF
Small rocks	Not sufficient protective effect	37.1 %
	Very little protective effect	22.8 %
	Sufficient protective effect	40.1 %
Medium rocks	Not sufficient protective effect	63.5 %
	Very little protective effect	11.5 %
	Sufficient protective effect	25.1 %
Large rocks	Not sufficient protective effect	89.4 %
	Very little protective effect	4.5 %
	Sufficient protective effect	6.1 %

The results clearly indicate that the derivation of the protective effect is very sensible to the rock size. This can be seen as a first positive plausibility check. But this procedure was only possible for the fine scale approach.

Example fine scale test site F2 – Engadin:

For the test site Engadin the protective effect of the forest with protective effect against rockfall was mapped. The results are illustrated in Figure 5-59. Very few areas do not have sufficient protective effect because of a slope length of less than 200 m (4%) 21% of the pRPF have a gap fraction of more than 25 % and therefore very little protective effect (Table 5-46). For those parts of the pRPF with a sufficient slope length and a small gap fraction the stem density was analysed. According to the stem density (results of the local maxima calculations) there is not sufficient protective effect for small and medium rocks (up to 60 cm diameter). For large rocks (diameter 60 cm – 80 cm) 21 % have minimal protective effect and only 5 % have sufficient protective effect (Table 5-47).

Table 5-46: *Protective effect according to forest width and gap fraction.*

	Forest Width	Gap fraction	Forest Width & Gap fraction
Sufficient protective effect	96 %	81 %	79 %
Not sufficient protective effect	4 %	19 %	21 %

Table 5-47: *Protective effect according to forest width, gap fraction and stem density for large rocks (60 -180cm).*

	Stem Density	Gaps & Forest width	All
Sufficient protective effect	5 %		5 %
Very little protective effect	21 %		21 %
Not sufficient protective effect	53 %	21 %	74 %

The reason for these small numbers is most probably the underestimation of the stem density by the local maximum algorithm. The nDSM with 2.5 m cell size is too coarse and in dense forests tops of trees standing close together can not be separated. To achieve better results the density of the ALS point clouds (when using ALS data) should be higher. Other studies suggest a point density of at least four points per square meter (e.g. Maier & Hollaus 2006).

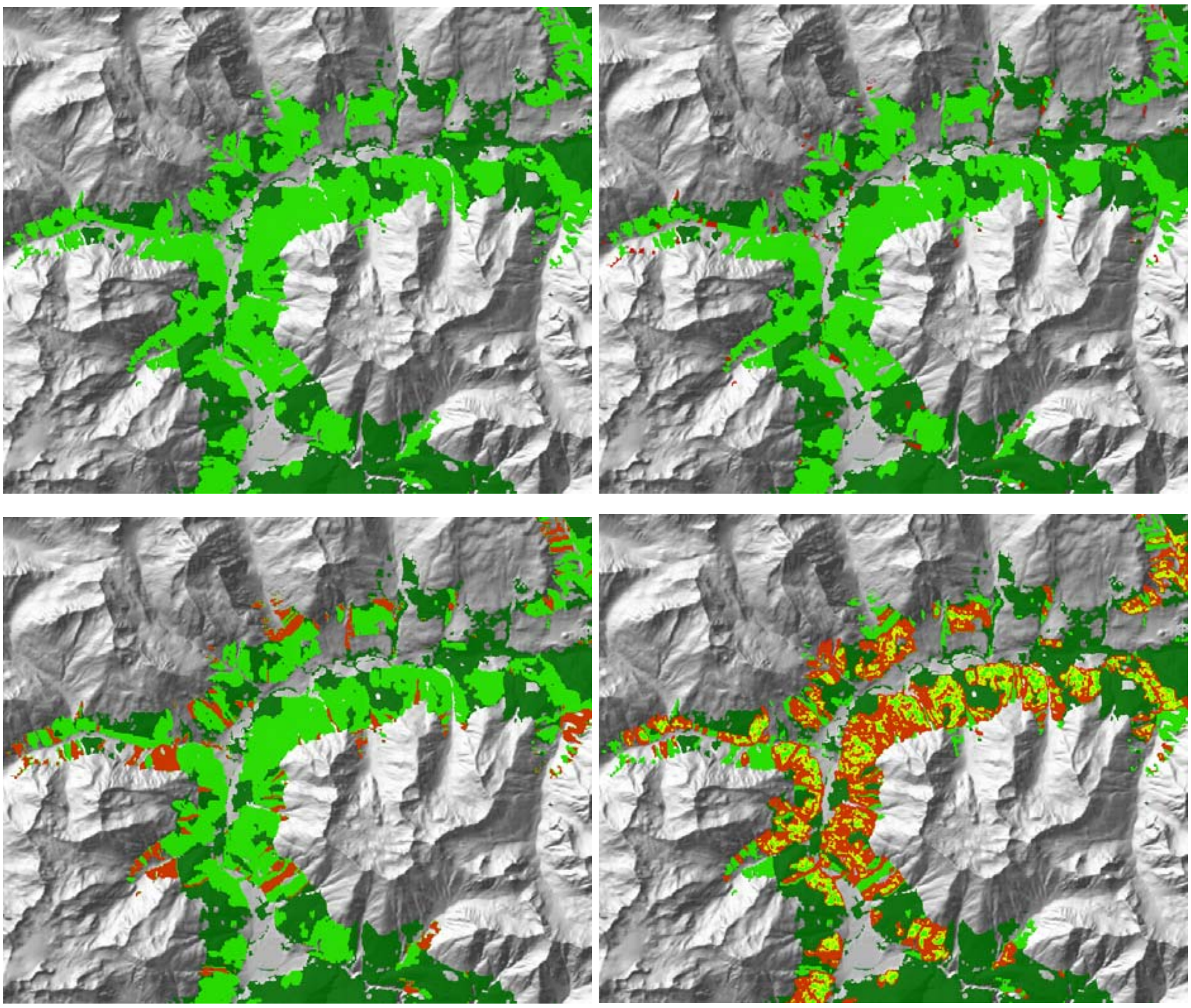

Figure 5-65: *Test site Engadin (Switzerland). Top left – forest (light green) and pRPF (dark green). Top right: Parts of the forest with a slope length < 200m (red). Low left: Parts of the forest with a gap fraction > 25% (red). Low right: Classification of the forest according to stem density (red – no protection, yellow – minimal protection, dark green – optimal protection) for protection of rocks with a diameter between 60 to 180 cm (according to NaiS).*

5.5.2.3 Comparison of results from fine and coarse scale approach

For the test side F1 Paznauntal the results gained from the coarse scale approach were compared to those gained from the fine scale approach. Figure 5-66 shows the two forest maps and the area of the APF.

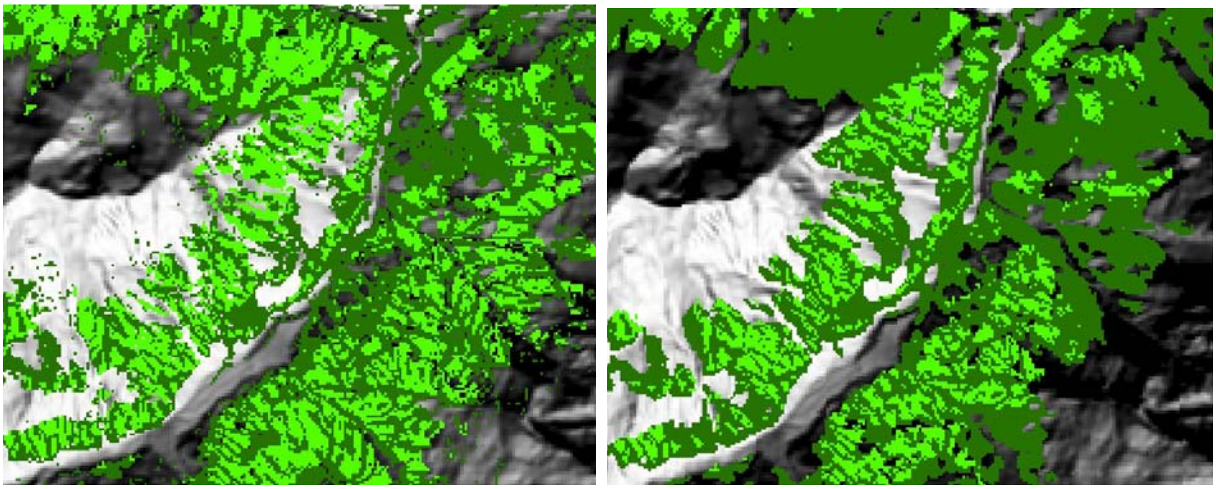

Figure 5-66: *Test site F1 Paznauntal, left: forest map (dark green) and APF (light green) from coarse scale approach; right forest map (dark green) and APF (light green) from fine scale approach*

.Figure 5-67 shows the two forest maps and the area of the RPF.

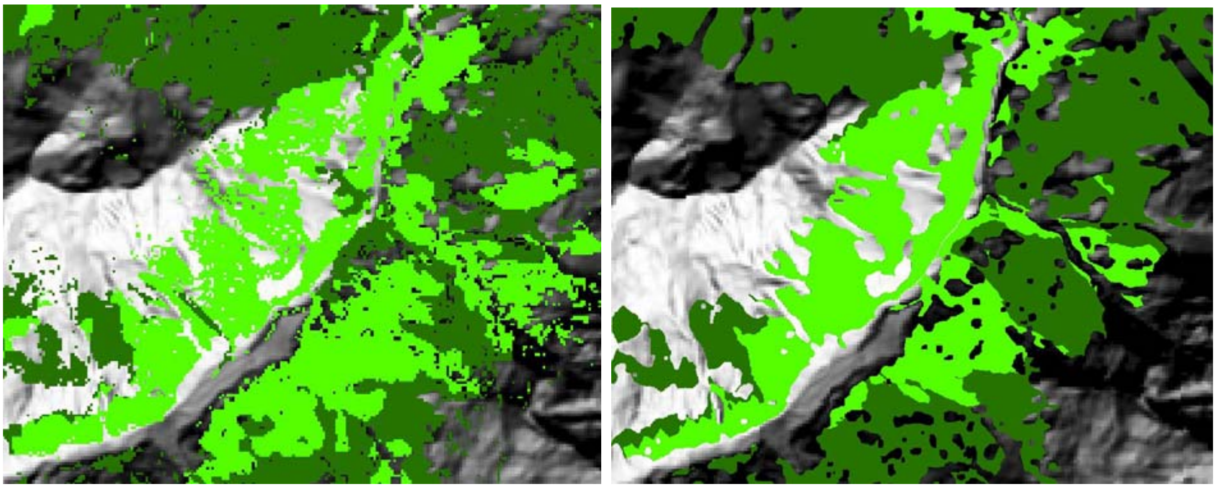

Figure 5-67: *Test site F1 Paznauntal, left: forest map (dark green) and RPF (light green) from coarse scale approach; right forest map (dark green) and RPF (light green) from fine scale approach*

The forest area achieved within the coarse scale approach is slightly bigger (figure 5-68). This difference occurs because of the use of different methods which includes different resolutions and the threshold of 2 meters of minimum height within the fine scale approach. Therefore differences occur especially at the upper timber line.

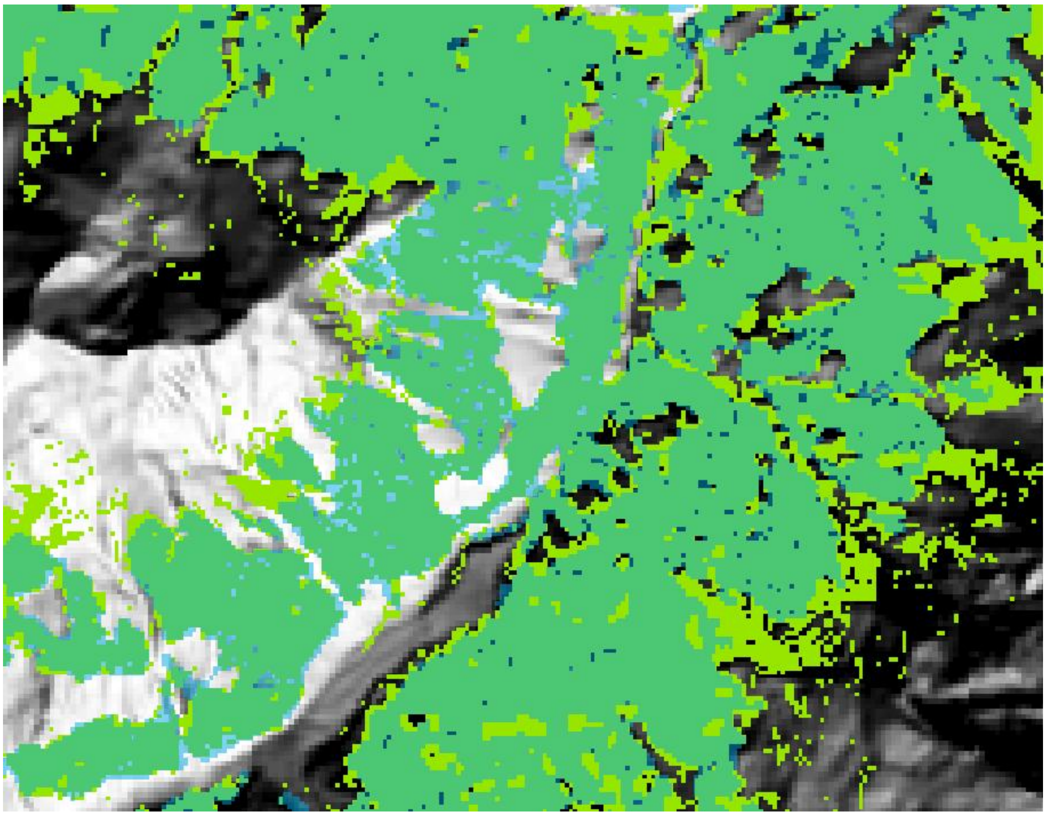

Figure 5-68: *Test site F1 Paznauntal, forest map from fine scale approach (blue) laid over forest map from coarse scale approach (light green); overlapping zones are shown in turquoise;*

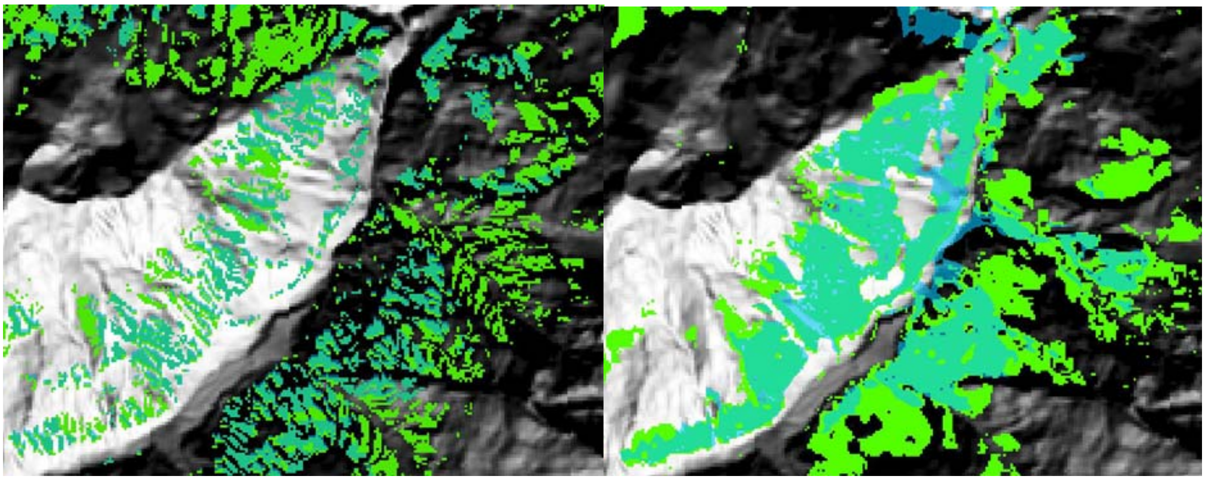

Figure 5-69: *Test site F1 Paznauntal,left: AFP map from fine scale approach (blue) laid over AFP map from coarse scale approach (light green); right: RFP map from fine scale approach (blue) laid over RFP map from coarse scale approach (light green); overlapping zones are shown in turquoise;*

In figure 5-69 the two maps of the APF and RPF are each overlaid. The area gained within the coarse scale approach is bigger at any one time. On the one hand this difference is due to the bigger forest area gained within the coarse scale approach. On the other hand the much finer resolution that was used when calculating the area for APF and RPF within the fine scale approach seems to be decisive. The used techniques for calculating the hazard potential zones are sensitive to the resolution of the DTM. The area of starting zones and especially transit zones is getting bigger when using a smoothed DTM (coarse scale).

6 Conclusions

According to the aims of ProAlp the project succeeded in developing harmonized indicators and estimation procedures for forests with protective functions against natural hazards. The project was also successful in modelling the hazard potential for avalanche and rockfall for different infrastructure like buildings, roads or railroads. Additionally the attempts to use NFI field data together with remote sense data for up-scaling NFI point information and producing maps of the different system components and hazard types were successful.

Nevertheless results and maps concerning the three system parts, hazard potential, damage potential and protective effect, which were developed within ProAlp, must not be interpreted as concrete natural hazard indication mapping or risk zone planning. The intention of ProAlp was a science based development of indicators and procedures to derive the area of forest with protective function and to evaluate their protective effect. Delivered maps and figures are examples for the capability of the developed methods.

Harmonised indicators and their respective thresholds are the outcome of intensive literature studies and guidelines used in different Alpine countries. For reasons of practical derivation of the system components hazard potential and protective effect with NFI data and remote sensing techniques they were adapted to the assessment possibilities of terrestrial NFIs and the restrictions of RS up-scaling procedures.

Hazard Potential:

Based on the harmonised indicators and procedures, the hazard potentials for avalanche and rockfall could be modelled within ProAlp for several test sites. In general the used modelling approaches were simple in relation to highly sophisticated models which can only be used on a local scale with very elaborative input data. It is not likely that such data will be available for larger regions within the next future.

The result of modelling avalanche hazard potential is surprisingly good and the avalanche release zones within the forest could be covered spatially very well. At least in a rough framework the results seem to be plausible and suitable as a basis for assessing the area of forest with protective function and its protective effect for a wide overview of the alpine space.

It is difficult to evaluate the results of modelling the transit zone for avalanches. Due to the restricted availability of data, the use of the energy line principle was the only possible solution. Actually this method is appropriate for small flow avalanches in regular relief. The model cannot evaluate the lateral spread of avalanches. At least the results do not appear implausible, but in any case they are not suitable as a basis for local risk management.

The evaluation for rockfall hazard potential is hardly possible. In relation to the availability of avalanche event data, which existent at least in some cases, there are no event data available for rockfall to be compared with the hazard modelling.

Mapping of forests with protective functions depends on the accuracy of the forest and infrastructure layers, on the validity of the modelled release areas and the transit zone model. All related errors and uncertainties in the characterization of the potential of the release zones and the evaluation of the protective effect add up in the evaluation of the avalanche or rockfall protection of the forest. The overall results of hazard modelling can not be verified, because appropriate data are missing. Nevertheless on average over the entire surface the results are plausible.

Damage potential:

Digital infrastructure data are necessary for risk analysis. For disposition and exposure analysis and a following bottom-up analysis like mapping of forests with protective function and evaluation appropriate digital data with location and type of subjects of protection are required. The geometry data should include attributes on the nature of the construction, the importance of the spatial function and the current use and frequency of use. Such data are currently not available for the alpine region. European data sets do not include enough details and the existing national data are not comparable. The harmonization of existing data sets is not possible. Therefore the data used for the derivation of areas of forests with protective function at least for cross border test sites did not satisfy our requirements. Nevertheless it could be shown also for cross border evaluations that the developed procedures work properly. The plausibility of the results can be enhanced as soon as harmonized datasets for infrastructure will be available in future.

Forest mapping:

In Tyrol two approaches were applied. On the one hand a forest map was calculated using the kNN estimator only. On the other hand the resulting forest map was enhanced manually afterwards with the help of orthophotos. This step was accomplished because of the problems mentioned in chapter 5.2.1 that occur when using the kNN estimation for forest mapping.

On the one hand forest areas beneath clouds and shadows could be complemented by digitizing in orthophotos. The images were recorded in September which leads to long shadows. So the date and time of day of acquisition is very important. On the other hand some forest areas near the upper timber line are underestimated by kNN and can be added by digitizing as well. Therefore the forest area in Tyrol is smaller when applying only the kNN estimation without digitizing afterwards.

In general the main reason for achieved kNN - results is the radiometric quality of the images. These radiometric attributes have much more impact than forest definition differences of different alpine countries. Thereby, for the use of radiometric information, the sampling density is an important issue as well.

When applying kNN the parameter of the spectral distance can be used. In this case only data from forest plots are used (i.e. without non forest data) and only pixels that are within a certain spectral distance to the reference pixels are classified.

Using this parameter of the spectral distance has a big impact on the results when the number of inventory plots is low. The quality of the results was best when using a spectral distance between 30 and 40 when calculating with for example Slovenian or Bavarian inventory data only. It seemed to have no big impact on the results when the number of inventory plots is high. There seemed to be almost no differences in the results when using for example Swiss inventory data. The results achieved using all data and the results using data from forest plots and in addition the spectral distance parameters were almost the same. The misclassifications mentioned in chapter 5.2.2 (Figure 5-15) could not be corrected by using the spectral distance parameter.

Forest with protective function and its protective effect:

The derivation of the areas of forest with protective function with direct protective effect is highly influenced by the quality of infrastructure data. Due to the described shortcomings the areas mapped within ProAlp can only be interpreted with respect to infrastructure data used.

The estimation of the protective effect of forests is still open to scientific research. Even if very intensive field assessments which are not possible within the framework of NFIs were available, solutions for the exact derivation of the protective effect are still lacking. Nevertheless the approaches in some alpine countries like the silvicultural guidelines in NAIS (Switzerland), ISDW (Austria) and GSM (France) are promising. Within ProAlp it was possible to harmonise these approaches by finding a common set of indicators and respective thresholds. It was also possible to fit the indicators to the possibilities of remote sensing techniques for up-scaling procedures.

Nevertheless it is challenging to evaluate the results of the estimation of the protective effect. For the coarse scale approach for avalanches the results from the statistical approach can be compared to the results from the up-scaling approach with the use of Landsat imagery. Although the results are not identical they proof that the up-scaling procedure with kNN leads to comparable results for the indicators used for the protective effect against avalanche release.

For the fine scale approach it turned out clearly that the quality of the laser scanning data has a high impact on the results. This means that for the Swiss test site with a lower resolution and not well defined meta information the results are not plausible. For harmonised results on the fine scale level it would be necessary either to use laser data with comparable resolution and quality or to apply different estimation procedures which take into account the differences in data quality.

A pixel-wise comparison between LiDAR and kNN classification of the protective effect which was applied for one Austrian test site leads to low correlations mainly due to the different modelling of the indicators. A comparison for larger areas seams to lead to better results. One weakness of the comparison is also caused by differences in indicators and thresholds, which have to be applied for different RS techniques. For future activities also local expert knowledge would have to be included in such an evaluation process. Finally it could be possible to use the coarse scale classification of the protective effect to evaluate the need of a successive fine scale analysis.

Outlook:

The harmonised procedures for estimating the forest areas with protective function and their protective effect developed within ProAlp can provide a rough picture of the situation within the Alpine Space. These procedures are a valuable contribution to existing scattered local knowledge of the protective effect of forests. Due to the high sensibility of mapping forests with protective function it would be important to take this local information into account and to include also local decision makers into further developments.

During the next years it will be likely that many parts of Alps will be covered with ALS data thus providing a valuable basis for further investigation of forests with protective functions against natural hazards.

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Appendix I: Terminology

The following definitions should be seen as proposals. They will be further developed within ProAlp.

Alpine space (Alpenraum, espace alpin, Alpski prostor)

The alpine space defined by Bätzing for the „alpine convention“ encloses very well those regions, which would commonly be designated as alpine space and in which most of the concerned natural hazard processes take place (see also: http://www.conventionalpine.org/page1_en.htm)

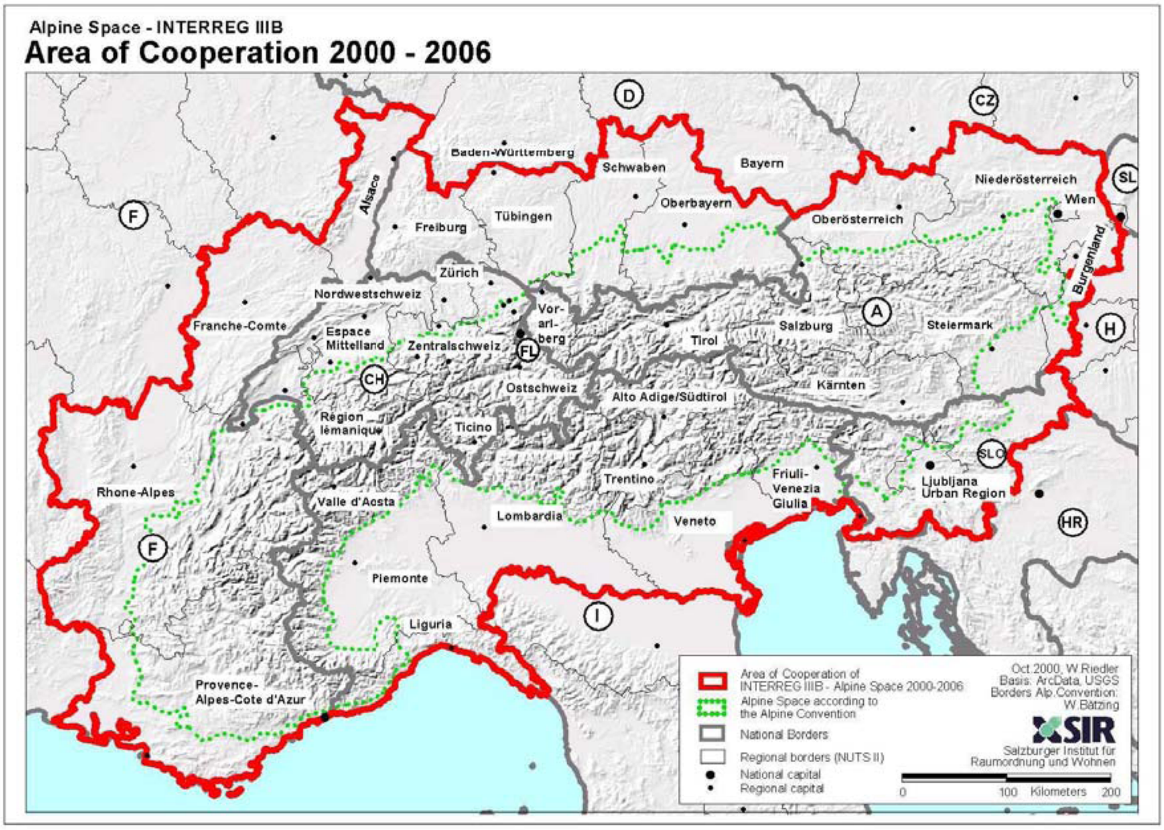

Figure I-1: Map of the area of Cooperation of INTERREG IIB – Alpine Space 2000 – 2006 and Alpine space according to the Alpine Convention (SIR, Salzburger Institut für Raumordnung und Wohnen).

A Shape of the Convention Space is under construction.

Forest with protective function (Schutzwald, forêt protectrice, varovalni gozd)

Forest with protective function:

Forest with protective function in common is a forest which protects people or asset against the negative impact of environmental influences (natural hazards and civilization dangers).

A specific type of the forest with protective function is the *natural hazard forest with protective function*. The primary management objective of such forests is to maintain the protective function as their most important spatial function, timber production comes second.

The protective function of forests can be necessary on woodless areas too. Hence, the protective function can also be a spatial function (the main function) of forest on a temporarily unstocked but potentially forest covered area.

> The protective function implies that there is (1) a natural hazard potential, (2) a damage potential, and (3) a wooded or potentially forest covered area in between that is able to provide effective protection (a potential contribution to protect) against the natural hazard at the site (see Brang et al., 2001; cf. Fig. 1), (cited from Wehrli et al., 2007, submitted). The term forest with protective effect refers exclusively to wooded areas with protective function.

Forest with protective function may be classified into forests offering **direct and indirect** protection (cf. Brang et al. 2006).

Forests with **direct** protective function can be assigned directly and definitely at local level to certain external assets (cf. Perzl 2007). A given forest provides direct protection if the protective function depends on the presence of the forest at a particular location, e.g. in case of a forest that protects a village against snow avalanches.

The protective function of forests with **indirect** protective function cannot be assigned to certain external assets clearly. Indirect protection depends on the presence of a certain proportion of forest at the landscape level as well as on the presence of forests at special (sensitive) sites of landscape (catchments) respectively on spatial distribution of forests within landscapes and on average forest health. This makes it difficult to relate such forests to a certain damage potential. Examples include forests in catchment areas that potentially reduce soil erosion or peak flows (Hamilton, 1992).

Forest (Wald, forêt, gozd):

Area belonging to the land cover/use class “forest” according to national forest law definition (main input criteria: size, canopy coverage, minimal width, tree species etc.).

Asset (Schutzgut, -, dobrina):

Spatial unit that has to be protected against dangerous external processes on account of the importance of its spatial function for human existence purposes (residential, social and economic purposes). Besides that, not only material values but human resources are linked directly to these spatial units.

<u>Natural hazard (Naturgefahr, danger naturel, naravne nevarnosti):</u>

<u>Natural hazard (Kienholz et al. 1998):</u>

Natural hazards are a form a dangerous process in the nature objectively menacing evil. That includes all processes and influence in the nature which can harm persons and/or tangible assets.

<u>Natural hazard in specific:</u>

Danger resulting from geomorphologic and/or meteorological processes. In the context of ProAlp, only important natural hazard - caused by gravitational forces - are included in the alpine area:

- Avalanches (Lawinen, avalanches, snežni plaz),
- Rockfall (Steinschlag, chute de pierre, padanje kamenja),
- Erosion (Erosion, erosion, erozija),
- Landslide (Hangrutsch, glissement, zemeljski plaz),
- Debris flow (Murgang, laves torrentielles, hudourniški nanos) and
- Floods (Überschwemmung, inundation, poplava).

These hazards are also known as “gravitational natural hazards” (gravitative Naturgefahren, dangers naturels gravitationnels).

<u>Civilization danger (Zivilisationsgefahr, -, civilna nevarnost):</u>

Materials and processes caused directly by human residential and economic activities, which are harmful to people and material goods e.g. smog, noise or light pollution caused by traffic. Civilization dangers are not taken into consideration at ProAlp.

<u>Natural hazard potential/area of natural hazard process (Naturgefahrenpotenzial, potentielle de dangers/aléas naturels, nevarnost naravnih nesreč/potencialno območje naravnih nesreč)</u>

The natural hazard potential indicates where a natural hazard can occur potentially and how far its impact may reach. Besides, the protective effect of existing stockings is not taken into consideration. The danger potential describes spatially the frequency and intensity of natural hazards processes to be expected. The result is a modelled susceptibility and impact area of natural hazard processes, which can be separated in 3 zones:

- *Starting zone* (Startgebiet), called release area (Anrissgebiet, Anbruchgebiet) in the case of avalanches and landslides,

- *Transit zone* (Transitgebiet), the fall track, where the masses move without deposition due to the topography.

- *Run-out zone* (Auslauf- und Ablagerungsgebiet), where the masses are stopped and deposited due to the topography.

The natural hazard potential results from the analysis of the potential natural hazards (susceptibility for hazard release), the analysis of the dynamic and the impacts of natural hazard processes (see risk analysis).

Damage potential ≈ potentially endangered objects (Schadenpotenzial ≈ potentiell gefährdete Objekte, dégats potentials ≈ objets menacé)

The possible degree of damage to people and asset endangered (see Kienholz et al. 1998). In ProAlp the damage potential is a function of the value, of the vulnerability and the presence likelihood of the endangered asset (simplified explanation).

Protective effect (Schutzwirkung, effet protectrice, zaščitni učinek)

A) The protective effect by forests in the meaning of the effect mechanism (totality of the effective processes like interception, transpiration, soil stabilization, mechanical resistance, friction etc.). By contrast the term "protective function" means the protecting task of forest in the spatial planning context assigned by society.

B) The magnitude of protecting effects of these effect mechanisms. The protective effect of a forest strongly depends on the hazard type and can have different aspects, i.e., prevention or mitigation of natural hazards. According to hazard type a different potential contribution of forests to the protection is possible. For snow avalanches, for instance, the protective effect of a forest is rather preventive than mitigating (Margreth 2004). For single rockfall events, tree stems and even dead trees lying on the ground allow to effectively mitigate the hazard by slowing down or even stopping the falling rocks (Dorren et al. 2005). However, forest cannot prevent the release of rockfall completely, but could even cause rockfall release. Tree roots reduce shallow landslide hazard by mechanical reinforcement of the soil (Hamilton 1992, Rickli et al., 2001). Tree roots can also increase the soil volume available for water storage, in particular on soils with moderate permeability (Hegg et al., 2005). Additional effects of forests on erosion and hydrological processes include e.g., the permanent input of litter reducing surface erosion and increasing the water-holding capacity of the soil by building-up an organic layer (cf. Hamilton, 1992) or the influence on interception and evapotranspiration leading to an improved water balance of the soil (Rickli et al., 2004, Frehner et al., 2005)

Susceptibility (Disposition, -, občutljivost)

Tendency of a certain area to trigger dangerous processes. Kienholz et al. (1998) defines two different types:

Basic susceptibility: Permanent or long time tendency or readiness to (dangerous) processes.

Variable susceptibility: Temporally fluctuating tendency or readiness to (dangerous) processes due to changing site parameters.

Vulnerability (Vulnerabilität = Verwundbarkeit, Verletzlichkeit, ranljivost):

The quality magnitude of an object (asset) regarding its resistance against being damaged. For example, two objects (assets) of the same monetary value or with the same space-functional importance can be vulnerable differently (e.g. a single family dwelling made from wood or made from concrete).

Risk analysis (Risikoanalyse, analyse des risques, analiza tveganja)

Detailed examination including risk assessment, risk evaluation and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property or environment; analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks (source: Glossary of the Society of Risk Analysis: http://www.sra.org/resources_glossary_p-r.php).

In the context of natural hazards, the risk analysis consists in

- Analysis of the potential natural hazards (Gefahrenidentifikation, Dispositionsanalyse, Ereignisanalyse).
- Analysis of the dynamic and the impacts of a natural hazards process (Wirkungsanalyse).
- Analysis of the potential damage at people/settlements and assets/infrastructure respectively and analysis of affected assets by natural hazards (Expositionsanalyse).
- Analysis of the consequences of a possible natural hazard for the endangered objects (Folgenanalyse, Risikoanalyse bei gravitativen Naturgefahren. Umwelt-Materialien Nr. 107/I. BUWAL (Hrsg.), Bern, 1999).

Appendix II: Facts and Figures

Table II-1: Definition of protection areas

Category	Subcategory (damage potential/sites)	AT	FR	DE	SI	CH
Direct protection ("Objekt-SW")		x	(x)	(x)	x	x
Direct protection	people	x	(x)		x	x
	settlements	x	(x)		x	x
	infrastructure	x	(x)		x	x
	cultured ground	x			x	
Indirect protection ("Standort-SW")		x	x	x	x	x
Indirect protection	sites with susceptibility for karstification	x	x	x	x	
	rocky, shallow or steep slopes	x	x	x	x	
	slopes endangered by landslides	x	x	x	x	
	timberline	x			x	
	improvement of hydrological retainment capacity	x	x		x	x
	sites endangered by erosion	x	x	x	x	x
	high altitude and ridge areas			x		
Consequences of the designation as forest with protective effect						
Restriction of forest management	interdiction of deforestation	x		x	x	x
	interdiction of clearcutting	x		x	x	x
	interdiction of other silvicultural practices					
	obligation of reforestation of unstocked forest areas	x				
Toleration of interventions directed by public forestry organisation		(x)		x	x	x
Financial aids	only in registered forest with protective effects			x		
	mainly in forests with direct protection					x
	in all kind of forest with protective effects	x			x	

Table II-2: Gravitational natural hazards mentioned by forest law

Type of natural hazard (main cause)	Subcategory	AT	FR	DE	SI	CH
Nivological	avalanche	x	x	x	x	x
	snowgliding	x				
Geomorphological	rockfall	x		x	x	x
	landslide	x	x	x	x	x
Hydrological	flood	x	x	x	x	
	water erosion	x			x	x
Other	wind erosion	x		x	x	
	karstification	x		x	x	

Table II-3: Mapping/modelling of forests with protective functions

	AT	FR	DE	SI	CH
Instrument for the mapping/modelling of forest with protective effects	forest development plan (WEP)	plan of prevention of the foreseeable natural hazards	forest with protective effect register	regulation on protective forests and forests with special purpose	forest development plan of the Cantons (WEP)
Delineation of forest with protective effects	by expert		by expert	by expert	by expert, based on models
Natural hazard indication map (Gefahrenhinweiskarte)					by models
Scale of forest function map	1:50'000		1:50'000	1:25'000	1:10'000 1:25'000
Scale of forest with protective effect map			1:5'000	1:5'000	1:10'000 1:25'000
Scale of natural hazard map (risk zone planning)					1:5'000 1:10'000

Table II-4: Geographical data as basics to characterize the risk of natural hazards

Information		AT	FR	DE	SI	CH	EU
Terrain model		DGM-R10	BD-ALTI	DGM 25	DHM12.5	DHM25	SRTM V.2
	Extension	100%		100%	100%	100%	100%
	Resolution	25x25/10 m	50x50/25 m	50x50 m	12.5x12.5 m	25x25/10 m	100x100 m
	accuracy of z	± 20 m		0.1 m	3.2 m	2 to 3 m	16 m
	Availability	yes	yes	yes	yes	yes	yes
	cost-free	yes (BFW)	no	no	yes	no	yes
Land use/land cover		land use map				statistics	CORINE
Grid data	Extension	100%				100%	EU27 a. o.
	Resolution	1:10'000				100x100 m	100/25 m
	availability	limited				yes	yes
	cost-free					yes	yes
Landscape model		DLM,KM-50V	IGN Vector	ATKIS25	DTM25	Vector25	CORINE
Vector data	Extension	100%	100%	100%	100%	100%	EU27 a. o.
	Resolution	1:10'000	1:25'000	1:25'000	1:5'000	1:25'000	1:100 000
	availability	yes		yes	yes	yes	yes
	cost-free	no		no	yes	no	yes
	thematic layers	see 2.1.2	see 2.1.2	see 2.1.2	see 2.1.2	see 2.1.2	see 2.1.2
Geological maps		GÖK 50	BRGM		GMS	Geotechnic.	
	Extension	50%	100%	100%	100%	100%	
	Resolution	1:50'000	1:50'000	1:200'000	1:100'000	1:200'000	
	availability	yes		yes	yes	yes	
	cost-free			no	yes	yes	
Pedological maps		eBOD	INRA	concept	PMS	digital map	soil data base
	Extension	(100%)			100%	100%	100%
	Resolution	1:50'000	1:100'000	1:25'000	1:25'000	1:200'000	1:1000000
	availability	yes		yes	yes	yes	yes
	cost-free			yes	no	yes	yes
Phytosociol. Maps		no uniform	no uniform	Pnfc, model	PMS	Cantons	forest types
	Extension			100%	100%	≈50%	
	Resolution			1:500'000	1:100'000	1:25'000	
	availability			yes	yes	yes	
	cost-free			yes	yes	yes	

Information	AT	FR	DE	SI	CH	EU
Forest maps	ÖWI	IFN	FM maps	FM/stand	statistics	Europ. Map
Extension	100%	100%	w/o private	100%	100%	100%
Resolution	30x30 m	1:4/25'000	1:10'000	1:25'000	100x100 m	25x25 m
availability	yes	yes	yes	yes	yes	yes
cost-free	yes	yes	yes	yes	yes	yes
min. crown cov.					20%	10-30%
Climatological data	ÖKLIM				climate atlas	SYNOP
	Climate atlas	1:1'000'000		1:1'000'000	1x1 km	1:800'000
Hydrol. atlas	1:1'000'000		1:2'000'000		1:500'000	
availability						
cost-free						yes

Table II-5: Thematic layers of landscape models

	AT	FR	DE	SI	CH
Thematic layer	ÖROK				Vector25
Road network	x	x	x	x	x
Railway network	x	x	x	x	x
Other traffic network			x	x	x
Waterbodies	x			x	x
Primary land use/land cover	x	x			x
Buildings/settlements	x	x	x	x	x
Hedgerows and single trees					x
Constructions					x
Single objects					x
Relief			x	x	
Regions			x		

Table II-6: Natural hazard potential

Natural hazard potential			AT	FR	DE	SI	CH
Avalanche	Starting zone	model	ISDW	Cemagref 1996	expert	ZRC-SAZU	SilvaProtect
		minimal slope	25°	28°	25°	21°	28°
		maximal slope	(55°)	55°	55°	60°	60°
		minimal altitude		1000 m	800 m	1200 m	900/1100/ 1200 m
		minimal area		500 m²			5000 m²
		minimal length		50 m	50		50 m
		min. snow cover height	≥ 0.5 m			≥ 1 m	
		relief class	x		x		
		exposition			x		
		surface roughness	x		x		x
		ground vegetation			x	x	
		durability of snow cover				≥ 75 days	
		climatic zone				x	
	Run out area	statistical model	x				
		1D-model	AVAL-1D	Nor-way/Salm	(AVAL-1D)		AVAL-1D
		2D-model	ELBA+			ZRC-SAZU	AVAL-2D
		3D-model	SamosAT				
		snow density		x	x		x
		snow depth		x	x		
		snow volume					x
		friction coefficients		x			
Rockfall	Release area	model	no model			no model	
		slope		≥ 41°			≥ 34°
	Run out area	model1	velocity	Pauschal-gefälle			Pauschal-gefälle
		model2	RockyFor	RockyFor	Zinggeler GEOTEST		Zinggeler GEOTEST
		slope gradient	x	32°			34°
		surface roughness	x	x			x
		ground damping	x	x			x
		block dmt /rock vlm	x	x			x
		stand structure	x	x			x
		relief	x	x			x

Natural hazard potential			AT	FR	DE	SI	CH
Debris flow	Starting zone		see landslide				MGSIM
	Run out area	1D-model	divers				dfwalk
		2D	divers				
Landslide/ erosion	Starting zone	model/evaluation	ISDW				SliDisp
		geomorphic Indicators	x				
		mass movement cat.	x				
		intensity of mass mvmt	x				
	Initiating factors	geology				x	x
		slope				x	x
		max. 24-h-precipitation				x	x
		forest cover				x	
	Process area	model	no model		no model		SlideSim

dmt: diameter, vlm:volume, mvmt : movement

Table II-7: Damage potential according to WEP/regional planning

Object class	Details	AT	FR	DE	SI	CH
Settlements		3			x	3
Residential area	more than 10 houses		3			
	between 2 and 10 houses		2			
	isolated houses		1			
	areas assigned for building	1				
Industry and commerce	industrial centre	3	3		x	3
	commerce	3	2			
	craft industry	2	1			
Public roads	national interest	3	3		x	3
	regional/communal interest	3	2			3
	local interest	3	1			2
Farm roads		2				
Forest roads		2				
Railways	national interest	3	3		x	3
	regional/communal interest	3	2			3
	local interest	3	1			
Infrastructure (water, electricity, gas)	high voltage line	2	2		x	3
	cross country lines for communication	2				3
	of local distribution	2	1			
Public welfare and communication facilities	hospitals etc.	3				3
Tourism	campgrounds	3	3			1
	frequent used walks	2				1
	ski path, touristy equipment	2	1			1
Patrimony	churches	3			x	
	cultural monuments	3			x	
	historical buildings	3	2		x	
Agricultural areas	buildings for alpine pasture	2			x	
	cultivated lands	1	1		x	
	agricultural installation					2
Forest	production forest		1			
Other	infrastructure for air traffic control	2			x	
	cable cars for material transportation	1			x	
	cross country lines for communication	1			x	

3 … high importance
2 … medium importance
1 … few importance

Table II-8: Protective effects of forests, according to regulations or silvicultural guidelines

Natural hazard process	Zone	AT	FR	DE	SI	CH
Avalanche	starting zone	2	2	2	2	2
	transit zone	0	0	0	0	0
	run out zone	0	0	0	0	0
Rockfall, < 1 m³	starting zone	1	1	2	2	2
	transit zone	2	2	1	1	1
	run out zone	2	2	2	2	2
Rockfall, 1-5 m³	starting zone	1	0	2	2	2
	transit zone	2	1	1	1	1
	run out zone	2	2	2	2	2
Landslide, profound	starting zone	1	0	0	0	0
	transit zone	0	0	0	0	0
	run out zone	0	0	0	0	0
Landslide, superficial	starting zone	2	1	1	1	1
	transit zone	1	1	1	1	1
	run out zone	1	1	2	2	2
Erosion	starting zone	2	1	1	1	1
	transit zone	0	1	1	1	1
	run out zone	0	0	0	0	0
Torrent/bed load	starting zone	2	2	2	2	2
	transit zone	0	1	1	1	1
	run out zone	0	1	1	1	1
Debris flow	starting zone	1	1	1	1	1
	transit zone	0	0	1	1	1
	run out zone	1	1	2	2	2

Table II-9: Indicators of current protective effects of forests

Natural hazard process	Indicator	AT	FR	DE	SI	CH
General	slope				x	
	parent rock				x	
	ground vegetation				x	
Avalanche	gap length		x			x
	gap width	x	x			x
	crown cover	x	x	x		x
	dimension (development stage)	x				x
	dimension (tree height)		x			
	density (stem number)	x				
	density (basal area)		x			
	composition (tree species)	x	x	x		x
	fraction of evergreen conifers	x	x			x
	laying deadwood	x				
Rockfall	gap length	x	x			x
	gap width					x
	crown cover					
	dimension (development stage)	x				x
	dimension (tree height)		x			
	density (stem number)	x	x			x
	density (basal area)		x			
	composition (tree species)		x			
	laying deadwood	x				x
	length of forested zone		x			
Landslide, erosion	gap length					
	gap width	x				
	gap size					x
	crown cover	x	x			x
	dimension (development stage)	x				x
	composition (tree species)					x
	fraction of evergreen conifers					
	fraction of tree species with deep roots	x				(x)

Table II-10: Indicators to evaluate the long-term protective effects of forests

Criterion	Indicator	AT	FR	DE	SI	CH
	silvicultural guideline	ISDW	GSM	no		NaiS
Mixture	tree species composition of tree stratum	x	x		x	x
	tree species composition of regeneration	x	x			x
Structure	number of layers		x			x
	horizontal distribution (dispersed, clustered)		x			x
	number of development stages, diameter distribution	x	x			x
					x	
Stability	relative crown length (coniferous)		x			x
	crown symmetry (broadleaves)		x			x
	degree of slenderness		x			x
	anchorage		x			x
	structural deterioration of thickets/pole stands	x				
	insufficient vitality of timber trees	x				
	overmaturity of stands without regeneration	x		x		
Damage	damage of existing stand regeneration	x		x		
	deterioration area (storm, fire) w/o regeneration	x		x		
	damage of single trees				x	
Regeneration	vegetation concurrence		x			x
	presence of laying deadwood		x		x	x
	favourable small areas		x			x
	crown cover of regeneration		x			x
	number of regeneration patches		x			x
	stem count of silver fir/beech		x			x
	existence of regeneration	x			x	
	vitality of regeneration	x				

Table II-11: National monitoring and reporting systems for forest with protective effects

	AT	FR	DE	SI	CH
Specific national or regional monitoring system	ISDW	in preparation	no	no, but FMP	NaiS
Forest with protective effect state valuated with data of NFI	yes	no	no	no	yes
Reporting system on forest with protective effect	ÖWI	bilan patrimonial ONF	no	no	LFI
Method of the national or regional monitoring system					
Concept	permanent systematic sampling	permanent systematic sampling	permanent systematic sampling	permanent systematic sampling	double sampling for stratification
Grid of aerial photographs	3.89 x 3.89 km	1x1 km		yes	500 x 500 m
Grid of field survey	3.89 x 3.89 km	1x1 to 8x8 km	4x4 km	4x4 km 250x250 m	1.41 x 1.41 km
Plot size	300 m²	491 m²	WZP ca.300 m²	200/500 m²	200/500 m²
Repetition rate	5 to 10 years	10 years	15 years	5 to 7/10 years	10 years

FMP…Forest management planning, WZP…Bitterlich-plot (=Relascope-plot)

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Abstract

The present study was developed in the context of Regulation (EC) 2152/2003 on the monitoring of forest and environmental interactions, the so-called "Forest Focus" Regulation. The specific objective of this study was to explore the possible contribution of the national forest inventories (NFIs) to assess protective functions of forests in the alpine space. Key components of protective functions could be determined with the help of on-going national and international studies and processes. In order to grant consistency, definitions of forest area, damage potential and hazard potential had to be harmonised. Based on those, a strategy for monitoring and reporting aspects of protective functions of mountain forests in the alpine space was proposed. Estimation procedures based on existing NFI data and field assessments and their integration in different remote sensing techniques were tested for harmonised monitoring. Final results are presented in this report.

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