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1. INTRODUCTION

Guidelines which support mountain forest management in natural hazard risk mitigation and sustainable forest exploitation have been issued in several European countries. Natural hazard risk mitigation by forest management is based on two central fields of planning and action: 1) analysis of the protective functions and 2) assessment and maintenance (improvement) of the protective effects of forests.

The term "protective function" refers to the task of a forest (woody vegetation) to protect something of value like human settlements and infrastructures from the impacts and damage by adverse climate, or cultural and natural hazards (Tromp 1972 cf. Wullschleger 1982, BUWAL 1996, Brang et al. 2001, Perzl 2014, Perzl & Huber 2014). The setting of values to be protected, and of the protection targets, is primarily a political decision linked to questions of justice and to objectives of regional development (Hess 2011, Perzl & Huber 2014 p. 13). The assignment of (protective) functions to forests or other land reflects the (safety) interests of the society. Safety interests in forest management result from the hazard and damage potentials to assets without consideration of the forest conditions. The concept of the (protective) functions of forests does not include forest conditions, even if the trees of a forest might be a potential danger to assets (e.g. in case of a damage potential by windthrow of trees near buildings or roads). A protective function of forest may also be assigned to non-wooded areas suitable for forest growth and to forests of insufficient protective effects, since afforestation of non-wooded land and forest tending could be appropriate hazard mitigation measures (Perzl & Huber 2014 p. 11, Zeidler & Perzl 2017 p. 19). A protection forest is a forest with a protective function as its primary task in relation to other public interests in forest management (Brang et al. 2001).

In literature, the protective function of a forest is also called the protective role of the forest. However, there may be a slight difference in the meanings of the terms function and role, since authors frequently do not clearly differ (protective) functions, potentials, and effects of forests. The term "protective role of the forest" may also refer to the protective potential of a properly managed forest, which is also dependent on the hazard category, the hazard intensity, and the site conditions. Therefore, the protective role (potential) is a precondition of the protective function, but without consideration of safety interests. The protective function results from safety and landscape conservation interests identified by a damage potential because of a possible impact of a destructive process. The term "protective role" of a forest may also refer to the protective effect of a forest. We recommend to read Brang et al. (2001), to use their selected terms and not to use the term "protective role", since this term is ambiguous and confusing. We use this term in this study only because it is used in the existing guidelines for protection forest management.

A main classification of the protective functions of forests and of protection forests is to distinguish direct and indirect protective functions (Motta & Haudemand 2000, Brang et al. 2001 p. 55, Wehrli et al. 2007).

A forest with a direct protective function is located within a potential hazard zone between the potential area of hazard initiation and the damage potential. Hence, the protective function and effect can be spatially assigned to a certain damage potential (to assets and benefiters). The protective effects of forests with an indirect protective function do not have such a clear spatial reference of the potential sphere of influence and benefits. A forest with an indirect protective function helps to protect assets like buildings from impacts of hazards like floods or adverse climatic phenomena, but it is not possible to say that this forest protects one particular building.

The classification of protection forests into forests with direct and indirect protective functions does not fully cover the legal frameworks (of the Alpine countries) and the extent to which spatio-functional relationships can be differentiated in a more or less anthropocentric view. Nowadays, protective functions are classified into two main groups: object-protective and site-protective functions.

In case of an object-protective function, woody vegetation should protect assets outside of the forest or outside of the area prone to afforestation. For example, forests on steep mountain slopes shall prevent the settlements below from impact of snow avalanches or rockfall. There are direct and indirect object-protective functions of forest (Perzl & Huber 2014 pp. 15-22), since the task of the forest is to protect a specific building, e.g. from impact of snow avalanches, or to mitigate damage by flooding along the entire lower courses of rivers.

On sites of adverse ecological conditions, the maintenance of soil and forest (growth) may be of interest. Hence, there is a site-protective function of the woody vegetation providing indirect benefits to human. However, the asset is the forest itself. A forest, wooded, and non-wooded land can have (direct and indirect) object-protective as well as site-protective functions.

The degree of preventing damage that hazards or adverse climate would otherwise cause to the assets is the protective effect of the forest (Brang et al. 2001, Perzl 2014, Perzl & Huber 2014). Hazard risk analysis and prioritization of mitigation measures require the assessment of the protective effects of forests based on the forest functions in combination with an analysis of the stability of the forests.

The first comprehensive books giving practical advices especially for the management of Alpine mountain forests were published by Mayer (1976, second edition Mayer & Ott 1991) and Bischoff (1984). Their books are addressed to students and practitioners and focus on silvicultural topics (identification of the forest type, natural regeneration – reforestation, (high altitude) afforestation, stand tending in order to enhance stand stability). Although these books provide first checklists and evaluation matrices to support the assessment of the protective functions, of the protective effects and of the stability of forests, the recommendations and tools (manuals) are less orientated to natural hazard risks. These textbooks do not contain clear evaluation schemes like flowcharts.

A second generation of studies about planning methods (e.g. Pfister & Eggenberger 1988, BUWAL 1996), of technical workbooks and guidelines appeared in several Alpine countries (e.g. Wasser & Frehner 1996, Leclerc 1998, Angst 2000, Frehner et al. 2005, BFW 2006, Berretti et al. 2006, Gauquelin & Courbaud 2006, Romang 2008, BAFU 2008, Ladier et al. 2012). The debate on forest dieback caused by air pollution in the 1980s led to the first intensified examination of the protective effect of forests in the 20th century. For example, the study of Konetschny (1990) on the avalanche protection effect of forests was triggered by this discussion (Konetschny 1990 pp. 12-13). The discussion in Europe about forest dieback by air pollution was very quickly replaced by the issue of climate change.

At first two developments promoted the appearance of new technical workbooks and guidelines: 1) an increased interest in the evaluation of environmental programs in Europe as a consequence of the funding policy and 2) natural disasters. The outcome of public funding is also called into question for forestry measures, as there are technical alternatives for the use of these funds and leaving protection forest unmanaged is seen as a good solution too (Brang et al. 2006). Evaluations of the success in protection forest management require hazard-related and forest-related target systems. Additionally, after a decade of low storm damage, in the 1990s and the 2000s, storms and subsequent outbreaks of bark beetles destroyed or damaged large forest areas in many

European countries (Gardiner et al. 2010). That resulted in difficult situations especially in protection forest management, because of the natural hazard risks and the high costs of measures. Instructions for action should help to deal with them. At the same time, the consequences of climate change also became increasingly apparent in the alpine environment. A change of the natural hazard risk situation requires adapted silvicultural targets. These prospects increase the uncertainties in assessing the protective effect of forests.

The second generation of guidelines incorporated new scientific knowledge and structured the support of planning and decisions into A) assessment of the natural hazard risk (hazard potential, damage potential, protective effect), B) assessment of the stand stability and of the status of regeneration, and C) general recommendations on silvicultural treatment. Not all of the workbooks cover all of these three topics equally; some of them are limited to A), or they focus on B) and C). In addition, numerous national and regional models and manuals have been published to support the determination of forest associations and of regeneration targets (e.g. the choice of tree species). The assessments are usually based on target characteristics of the forest structure for the respective forest community, as empirical hazard and stand failure probabilities are difficult to calculate and to transform into operating targets.

The evaluation criteria and the usefulness of these guidelines are repeatedly the subject of discussion. Practitioners point out that due to the wide range of climate, terrain, forest, and risk situations there are no generally valid recipes and models. Bischoff (1984 p. 283) and Ott (1996) already addressed these discussions in Switzerland to the different needs of inexperienced and skilled foresters, to the question of narrowing of the necessary scope for action, and to reservations against control of success based on documented silvicultural targets. We could also observe such discussions in Austria, where publicly funded protection forest mitigation was not accompanied by effect-oriented controlling instruments until 1995 (Weiss 1999, Perzl 2006 p. 3). Moreover, lacks in scientific knowledge and contradictions to empirical knowledge especially as regards the hazard-related targets of the guidelines (Brang et al. 2006 p. 39) as well as the incompleteness of solutions for data sampling and risk assessment have soon become obvious to scientists and practitioners. The guidelines base on few data-driven scientific studies without any standards of survey and data quality. The data situation in natural hazard science related to forest is still sparse.

Most of these guidelines and workbooks follow the structure and the criteria of the Swiss guideline (Wasser & Frehner 1996) which is now called NaiS (second edition Frehner et al. 2005). Some guidelines just show copies of the Swiss criteria with some modifications in detail and without any critical appraisal. When comparing the guidelines, it is noticeable that they are similar and refer to the same scientific basis, but they refer to different spatial scales, and in many details, they interpret scientific literature differently in terms of hazard-related assessment operations and objectives (Perzl et al. 2012 c). For example, the Swiss guideline NaiS (Wasser & Frehner 1996) defines permissible dimensions of clear-cuts (so called "gaps") depending on slope to prevent snow avalanche initiation. If the length of a gap is greater, the width of the gap must be limited to a threshold. So, a gap should be smaller than a certain length or width. A second Swiss guideline appeared (the "Sturmschaden-Handbuch" SSH, Angst 2000), using the threshold values according to Wasser & Frehner (1996), but in this guideline both, lengths and widths, define gaps prone to snow avalanche initiation. The next version of SSH (BAFU 2008) returned to the or-condition. However, Konetschny (1990) and Meyer-Grass & Schneebeli (1992) investigated snow avalanche initiations in forests in Bavaria and in Switzerland, and they do not mention any relation to the length, but to the width of the gaps. Such obvious discrepancies may reduce confidence in hazard-related targets. Most of the guidelines cite the scientific sources in a general way, but they do not disclose the conclusions and contradictions drawn from the study of literature. Some of the differences of the guidelines might be caused linguistically.

The "SSH"-example shows the need and the objectives of this study. The topic of this study is the evaluation and the comparison of the hazard-related criteria and targets proposed by different national guidelines for protection forest management. The objective of the study is not a ranking of the guidelines. However, it is necessary to evaluate existing approaches before new concepts are developed. The study aims to clarify the concepts and to separate appropriate and valid assessment methods from concepts that cannot be recommended. This may yield in new criteria and topics of research. The study focuses on the hazard-related targets of forest structure which may prevent natural-hazard initiation or reduce the impact of hazard processes. To this end, it is also necessary to consider the indicators of the protective function of the forest depended on site characteristics.

We limited analysis to snow avalanche, shallow slope failure and rockfall and included the following guidelines: The Swiss guideline NaiS (Frehner et al. 2005) also available in English (Frehner et al. 2007), the Italian (Valle d'Aosta) guideline SFP (Berretti et al. 2006), the French guidelines GSM-N (northern French Alps, Gauquelin & Courbaud 2006) and GSM-S (southern French Alps, Ladier et al. 2012), and the Austrian guideline ISDW (BFW 2006).

In order to respect all copyrights, we do not present any copies of figures or tables from the guidelines. Hence, it may be sometimes difficult to follow the descriptions and analyses. We recommend to take insight to the originals.

2. METHODS AND DATA

We checked the guidelines for logical consistency, plausibility, operationality and applicability of the proposed assessment rules. Operational systems define the spatial scale of application and the criteria clearly. Since this is necessary for a valid representation of the behavior of environmental systems, operational assessment procedures consider the interdependence and the completeness of key criteria as well as non-linear relations (De Montis et al. 2000).

Guidelines for protection forest management should not only deliver hazard-related targets on the forest structure, but also give information how to delimit appropriate units of assessment spatially and how to measure the criteria of assessment. Without clear definitions and flowcharts, the interpretation of the criteria is difficult and may lead to different and incorrect applications by users.

The definition of units of assessment should be based on the object-protective function of forests. The protective function of a forest results from the hazard and damage potential. The identification of the hazard potential means the mapping of zones where natural hazards might occur. This includes the diagnosis of the possible hazard category like snow avalanche, rockfall and soil movement and the zoning into potential areas of starting, transit and deposition. However, concepts for forest management have to consider that a differentiation of starting and transit zones is more difficult especially in forested terrain, as hazard categories and zones spatially overlap each other. Then it is necessary to identify the hazard zones with a damage potential to assets like settlements and infrastructures as well as to grade the damage potential. The term "potential" means that the protective effect of the forest and of existing technical protection measures is not considered in forest function mapping. Mapping of the protective functions of forests is best implemented through large-area spatial modelling. In some European countries, protective function mapping of forests has already been done by spatial modelling, e.g. in the Autonomous Province of Bolzano (Italy) (Staffler et al. 2008), in Switzerland (Losey & Wehrli 2013) and Austria (Perzl et al. 2019). However, such basics about the object-protective functions of the forests or similar information like hazard indication maps do not exist in all countries of the Alpine space or the information may not be complete, appropriate for forest management or up-to-date. The guidelines should be linked to the national forest function mapping and enable practitioners to identify at least hazard potentials. The mapping of damage potentials may not be the issue of foresters and silvicultural guidelines. Hence, we classified the assessment criteria in hazard potential indicators (in the French guidelines "détermination des aléas naturels") and protective effect-related characteristics of the forest (structure). Notice, that the hazard potential is not the same as the hazard risk. The hazard potential refers to the probability of a hazard occurrence, but without any consideration of damage potentials and of protective effects of vegetation or artificial measures.

The assessment procedures for protective functions and effects of forests should be designed and documented in such a way that at least the quantitative criteria lead to a clear and logical result. Therefore, we have theoretically gone through the proposed diagnostic and evaluation procedures and searched for undefined issues and decision criteria. The guidelines present the proposed assessment procedures and criteria in the form of flowcharts or assessment matrices (tables). In some guidelines, information relevant for hazard assessment is also mentioned in the text outside these figures. Due to the general nature of accompanying text, we only consider such criteria, if they are linked to the flowcharts or tables explicitly.

We also compared the hazard-related targets proposed by the guidelines with knowledge from scientific literature. Many publications deal with the protective effects of forests. But in relation to this, only few works are based on appropriate empirical observations.

The methodical core of the study is the comparison of the protective effect-related characteristics of the forest structure proposed in the guidelines with the pre-event forest characteristics of real hazard events. In the potential starting zones of natural hazards, forest should prevent hazard initiation. Hence, the proportion of observed hazard initiations on terrain of forest use which do not match the proposed targets of the forest structure are true classifications and should be considerably higher than the proportion of hazard initiations in forests compliant to the targets of a guideline (false classifications).

The evidence of this simple comparison may be biased by the total proportions of forest stands that meet or do not meet the targets. Therefore, it is necessary to consider the ratio between the proportions of forests compliant or non-compliant to the targets in hazard initiations and the total proportions of compliant or non-compliant forests potentially prone to hazard initiation. Another method to identify appropriate indicators is the comparison of the targets with forest characteristics of event and nonevent cases. Building up unbiased samples of "event" and "nonevent" cases in forest is difficult, as there are no long-term observation areas of the forest structure and the hazard activity. Especially observations of snow avalanche initiations in forests are rare and rather from an anecdotic character. Control sample plots established next to locations of observed avalanche initiations are from limited representativeness, if they tend to be in relatively dense forests, although avalanche activity was also low in clear-cuts. Avalanches may also occur at the control plots in the time period of no observation.

The comparison of the proportions of hazard initiations in forests compliant or non-compliant to the targets with the total proportions of these groups is of varying importance depending on the point of view. Even though, a hazard from a target compliant forest might be an exception (an outlier) in relation to the large-area proportion of such forests, the usefulness of the guideline will be called into question. Interest in hazard protection is a local interest. Owners of estates rarely consider statistical relations and probabilities.

The comparisons on base of hazard samples are also biased by the fact that high targets of forest characteristics like the canopy cover percent or the stem density automatically lead to a higher proportion of correct classifications. Hence, the objective is not to define targets that would have prevented all hazard events, but to find thresholds, which reduce the probability of hazards within the frame of natural capacities of forest growth and stability.

All the guidelines examined are designed for an application in the field. The evaluation of the guidelines requires the survey of the pre-event condition of the forest at the location of the hazard. However, the available forest inventory data usually do not match the information needed in terms of spatial resolution, content, and timeliness (Glanzmann 2012, Perzl & Walter 2012 p. 46). Hazards like landslides destroy the forest, and thereafter it is difficult to reconstruct the forest structure. In case of snow avalanche initiation and non-destructive rockfall, field investigations of hazard sites are appropriate but expensive. Since there is no generally accepted survey standard, there is a lack of comparable terrain surveys of the forest conditions on hazard sites. Therefore, we had to limit ourselves to the analysis of those criteria that could be derived from available data and from remote sensing.

At first sight, all guidelines seem to use more or less the same criteria. But parameter definitions differ in detail or they are missing. We only included in the comparison the defined and quantitative criteria of the guidelines whose characteristic values could be approximated with the available data. However, many of the targets are from a qualitative or a semi-quantitative nature and they are difficult to measure (e.g. the "proportion of well anchored trees"). All guidelines use undefined terms; for example, no guideline explicitly mentions the proportions of broadleaved trees above which a forest is considered to be a mixed or a deciduous forest, although evaluation and decision-making criteria depend on this.

Due to the qualitative character of many criteria and undefined junctions in the guidelines, it was mostly not possible to apply the complete assessment process proposed by the guidelines to the hazard examples. Qualitative criteria can be important, and they enable to bring the experience of practitioners into the assessment process. But they are not verifiable intersubjectively.

2.1 Data about snow avalanche initiation on terrain of forest use

All guidelines limit the avalanche protection effect of forests to the prevention of snow avalanche initiation and to the reduction of the slab propagation in potential release areas. They do not consider the braking effect of the forest in the transit zone as normally slab avalanches with critical fracture size will flow through forests or destroy them until they run out on slopes of low inclination or the energy is dissipated by the fall over steep cliffs (Frey 1977 pp. 137-140, Laatsch 1977, Gubler & Rychetnik 1991, Margreth 2004). Forests may stop or slow down small-to-medium avalanches starting within dense forests, in small gaps of dense forests or next to the upper timberline (Gubler & Rychetnik 1991, Teich et al. 2012, Feistl et al. 2014). As scientific results and recommendations on cutblock sizes and on critical distances to timberline (see Perzl & Huber 2014 pp. 17-18) as well as forest conditions along avalanche paths vary considerably in time and space, hazard risk and forest management focus on preventing snow avalanche initiations.

Table 21-1 shows the criteria used by the guidelines and refers to the sources of information and the data measurement methods.

Table 21-1: Snow avalanches – hazard indicators and protective effect-related characteristics

Criteria (due to avalanche initiation)	Guideline	Source, method
Hazard potential indicators		
Forest type[1] (tree composition)	NaiS, SFP	MOP[12]
Slope gradient[1] [°] (SLOPEG)	NaiS, SFP, GSM-N, ISDW	DTM[12], on-site measurement
Altitude above sea level [m] (ALT)	GSM-N	DTM[12], on-site measurement
Aspect (ASP)	GSM-N	DTM[12], on-site measurement
Mean maximum snow depth [cm] (MMXHS)	ISDW	snow cover models (Austria)
Slope roughness	ISDW	qualitative, few EOP[12] data
Terrain morphology	ISDW	semi-quantitative, few data
Effect-related characteristics		
Gaps and blanks[2]		EOP[12]
Width[4] [m] (ARWGB)	NaiS, SFP, GSM-N, ISDW	MOP[12]
GAPWIDTHSLF [m]	additional measure	on-site measurements of SLF
Length[5] [m] (ARLGB)	NaiS, SFP, GSM-N, ISDW	MOP[12]
GAPLENGTHSLF [m]	additional measure	on-site measurements of SLF
Mean height of tree species [m]	GSM-N, ISDW	on-site measurements of SLF
Single canopy cover[6] of the tree layer[7]	NaiS[8], SFP[8]	
ARTLCC [%] h[8] > 5 m		MOP[12]
GESAMTDECK [%]	additional measure	on-site measurements of SLF
GESKRPROJ [%]	additional measure	MOP[12] of SLF
Single wintergreen canopy cover[6] (tree layer[7])	GSM-N[9], ISDW[9], GSM-S[10]	
ARTLWCC [%] h[8] > 5 m		MOP[12]
GESAMTDECKW [%]	additional measure	on-site measurements of SLF
GESKRPROJW [%]	additional measure	MOP[12] of SLF
Stem density[11] [No/ha]	GSM-N, GSM-S, ISDW	
Stem density DBH ≥ 7 cm	(GSM-N, ISDW)	on-site measurements of SLF
Stem density DBH ≥ 16 cm	(GSM-S)	on-site measurements of SLF

[1] NaiS and SFP differentiate slopes prone to avalanche initiation (the hazard potential) by tree species composition

[2] NaiS and SFP refer to canopy openings in the tree layer (dominant DBH[11] ≥ 12 cm) with and without young growth[3]. ISDW refers to openings in the canopy cover of living trees with a height above 1.3 m (also in the thicket and pole tree stage). Therefore, we considered that the NaiS definition of gaps include areas dominated by young growth and gaps within the sapling stage. GSM-N does not provide a gap definition. However, criteria refer to openings in woody vegetation with no or few young growth.

[3] Young growth (seedlings and saplings) of trees and shrubs other than dwarf shrubs.

[4] We measured the width at the reference point (center of the slab) in direction of the contour line (plan distance).

[5] We measured the length at the reference point (center of the slab) in flow direction (plan distance).

[6] Canopy cover (CC) is the area of ground covered by the vertical projection of the outermost perimeter of the spread of the branches of woody plants other than dwarf shrubs. Small openings within the canopy and inter leaves are included. Canopy cover may be measured in units of area or as a percentage of the reference unit (canopy cover percent). The single canopy cover does not include the overlapping of canopies and is limited to 100 % (aerial perspective).

[7] Definitions of the tree layer are different: NaiS - DBH ≥ 12 cm, SFP - DBH ≥ 8-12.5 cm, ISDW - woody plants higher than 5 m.

[8] NaiS and SFP do not provide a clear definition of the lower dimension of effective (protective) trees in the assessment tables. Since seedlings and saplings in gaps are not considered as effective for protection regardless of the respected snow depth, we used a tree height > 5 m (ARTLWCC). However, in the BFW sample data, the height of the trees are estimations on base of crown dimensions.

[8] DBH - Diameter at breast height (1.3 m), h - tree height

[9] GSM-N and ISDW refer to the wintergreen canopy cover of trees that are twice as high as the expected snow height. As the mean heights of the tree species was not available in sample data, we used the canopy cover of the tree layer from EOP (h[8] ~ > 5 m)

[10] The guideline GSM-S does not provide a definition of the dimension of (protective) trees. We used a tree height > 5 m (ARTLWCC).

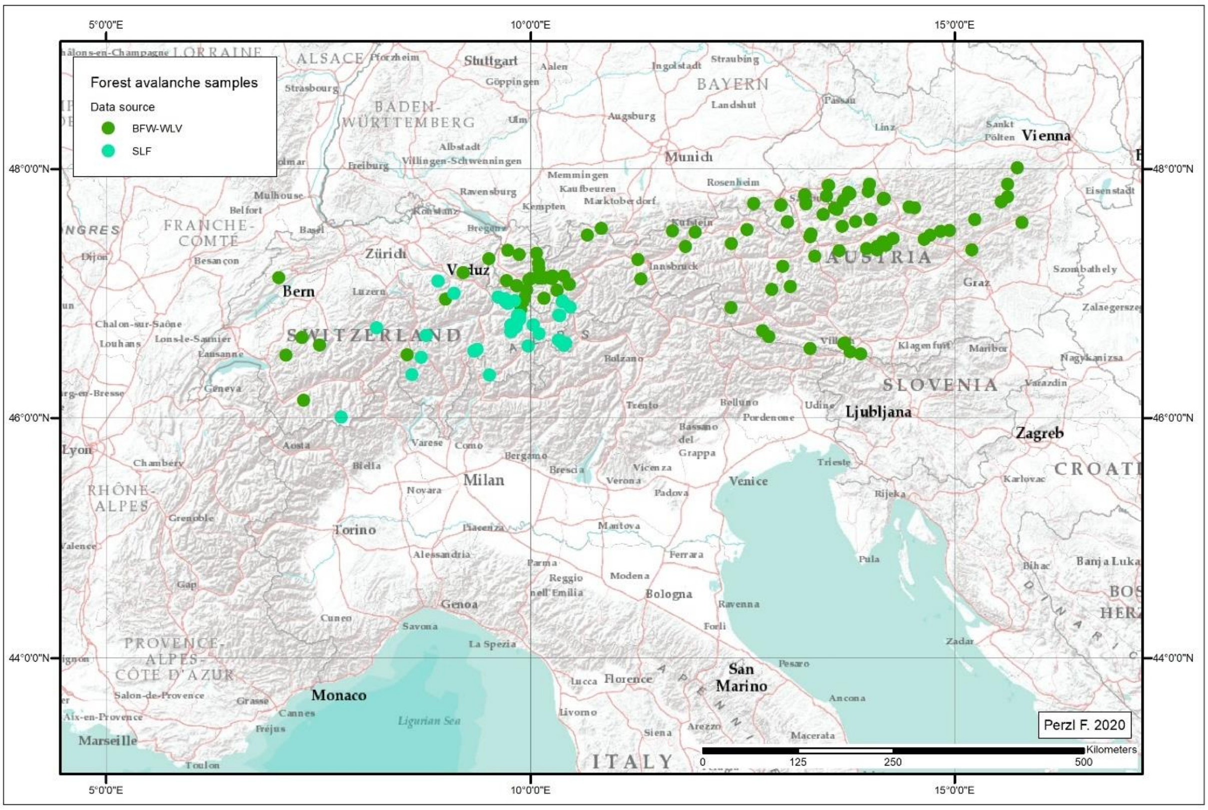
[11] GSM-N refers to the stem density of trees with DBH ≥ 5 cm. GSM-S refers to DBH > 17.5 cm and ISDW to h > 5 m ~ DBH ≥ 5-9 cm

[12] MOP, EOP - measurement, estimation on orthophoto; DTM - calculated from digital terrain model

We compiled a dataset of observed forest avalanches to compare them with the guidelines' recommendations (Figure 21-1). Snow avalanches which originate from forest use terrain are called forest avalanches (Konetschny 1990, Meyer-Grass & Schneebeli 1992). The compiled data come from two sources: 1) the avalanche documentation of the Austrian Research Center for Forests

(BFW) and 2) a sample of forest avalanches provided by the Swiss Institute for Snow and Avalanche Research (SLF).

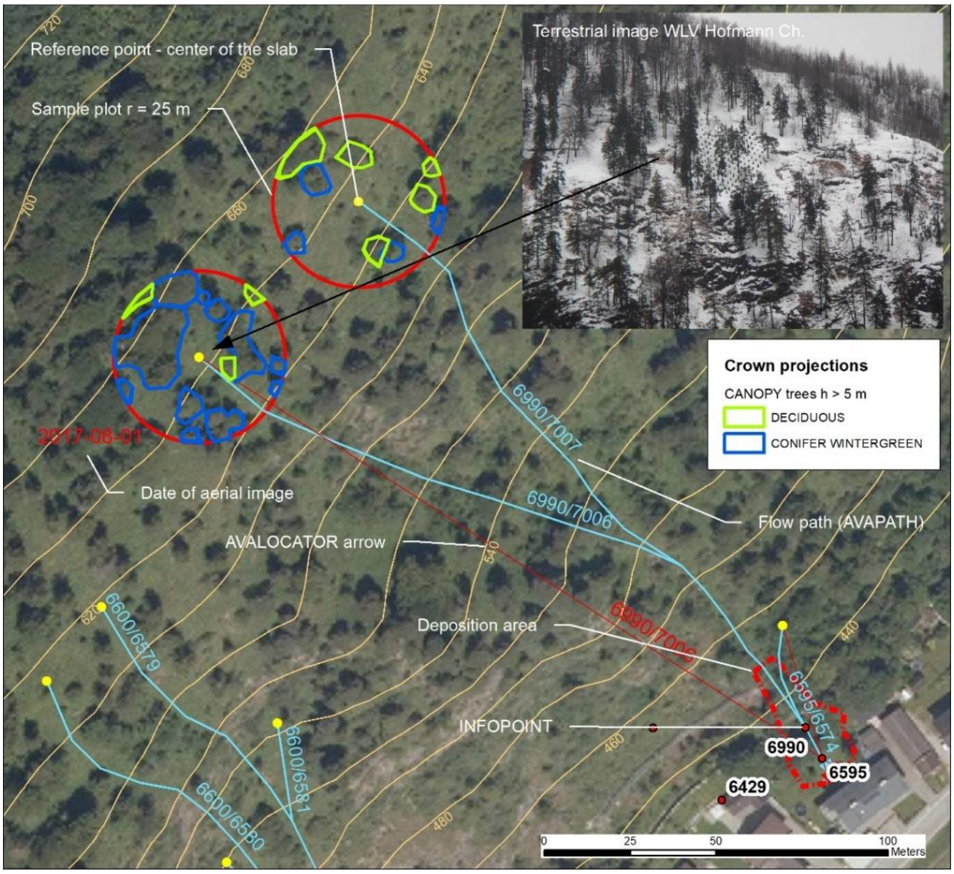
Figure 21-1: Positions of the forest avalanche samples



In Austria, snow avalanche hazard documentation is not organized centrally like in Switzerland or Bavaria. The Austrian dataset originates from hazard reports provided by different primary sources including reports from the Austrian Avalanche and Torrent Control Service (WLV), the Avalanche Forecast Services, the police authorities, scientific literature, and mass media. Reports on forest avalanches are occasionally. Forest avalanches that come to the knowledge of the BFW are located at the first level of mapping on orthophotos with three basic features based on the information available: the INFOPOINT, the AVALOCATOR and the AVAPATH (Figure 21-2).

The INFOPOINT is only used to roughly locate a hazard event. The INFOPOINT is set in the deposition or in the starting area depending on the information available. The AVALOCATOR is an arrow showing the approximate direction of flow down of the snow movement. The INFOPOINT and the AVALOCATOR have no significance for our analyses in this study. The AVAPATH represents the precise center of the flow path of the avalanche according to the energy line or travel angle concept of Heim (1932 p. 113). The starting point of the AVAPATH is the point of release (in case of loose snow avalanches), the center of the slab or the center of the fracture line in case of unclear lower slab boundaries. This point is also the reference point to document the forest conditions in the release area. The assignment of the release area to forest use and to a type of forest is a point decision at the reference point.

Figure 21-2: Sampling design of forest survey on hazard sites and mapping features – BFW method



The forest use definition used in the natural hazard documentations of BFW differs from the Austrian Forest Act and the definition used by the national forest inventory. Among other reasons, this should not exclude the reaction of sparsely wooded areas.

We surveyed the forest characteristics within a circular sample plot with a radius of 25 m around the reference point by analysis of aerial images (orthophoto interpretation) (Figure 21-2). Another method would be to survey forest characteristics on stripes along the fracture line which vary in size (Konetschny 1990). We decided to use fixed sample plots which only vary in size by cutting off sections, if site conditions change considerably. This method is easier to implement and also covers the wider surrounding of the release.

We surveyed the canopy cover (ARTLCC) and the proportions of wintergreen, deciduous and Larch trees of the tree layer (height ~ > 5 m) by digitizing crown projection areas within the sample plot on base of orthophotos taken as shortly as possible before and after the avalanche release. Terrestrial photos supported tree species recognition.

We also measured the width of openings in the woody vegetation cover (ARWGB) with a minimum size of 10 by 10 m (so called "gaps") along the contour line of the terrain and their length in flow direction (ARLGB) at the reference point. We only recorded clearly defined openings as gaps. Delimitation and measurement of gaps becomes increasingly difficult with decreasing density and homogeneity of stockings. A more objective method would be the derivation of gap areas from canopy height models (CHM) on base of high-resolution digital terrain (DTM) and surface models (DSM). But only a small part of the forest avalanches matches the available high-resolution elevation data from airborne laser scanning (ALS) temporally. We used the available data to detect canopies in the shadow and to assess tree heights. The Austrian data provide few information about the stem densities at locations of avalanche initiation. Only data from three samples are from aerial image interpretation and field surveys which include terrestrial tree measurements. In terrain, at the centers of the slabs, we measured all trees (species, DBH) including young growth within squared area plots of 20x20 m or 10x10 m.

The forest avalanche data provided by SLF were collected in the field during the forest avalanche project between 1985/86 and 1989/90 (Meyer-Grass & Schneebeli 1992, Schneebeli & Meyer-Grass 1993). Sites were investigated twice in winter immediately after the avalanche initiation and in summer to survey snowpack and forest characteristics. The sampling designs of SLF and BFW-data differ considerably.

SLF did not use fixed circular sample plots but adapted sample sizes to the sizes of fractures. The canopy cover and the proportions of wintergreen coniferous and deciduous tree species were estimated in the field and measured by crown digitizing from aerial images. Among many other site, snow and forest characteristics, the stem densities, and the dimensions of canopy openings ("gaps") were measured in the field. Therefore, available data also include information about the densities of trees with DBH < 1 cm, DBH > 1 cm, DBH > 6 cm, and DBH > 16 cm.

The usage of different caliper thresholds and classification systems of tree dimensions all over the world makes it difficult to compare results and to homogenize data. SLF- and BFW-data also refer to different concepts of canopy openings called "gaps". Gaps in the meaning of the BFW are discretely delimitable areas of at least 10 m width and length, whereas SLF gaps rather correspond to tree distances also in case of diffused tree distribution and have a minimum size of 5 m. Both concepts measure from boundary to boundary of crown projections and not from stem to stem. This method is difficult in step terrain, and results depend on image quality in case of measurement on aerial photographs. The differences of the criteria shown in Table 21-1 and 22-1 may also be addressed to the different national classification and measurement systems rather than to actual inflection points of the protective effects. Therefore, we call for international standardization of forest structure sampling in a scientific context as well as of data presentation and delivery.

Since the different survey methods could have an impact on the results from the combined SLF-BFW data sets, we have also recorded the Swiss samples using the BFW method. For this purpose, we used historical orthophoto series provided by Swisstopo Geoservices WMS from the Swiss Federal Office of Topography. The survey of forest characteristics by feature interpretation and measurement on aerial images depends on the spatial and spectral resolution and quality of the images as well as on orthophoto processing. Due to the quality and timeliness of the available images, the required characteristics could not be collected completely for many Swiss and Austrian samples.

The BFW dataset contains 303 avalanche initiations in forested terrain. Of these, 281 occurred in Austria, 14 in Switzerland, 7 in Bavaria and one in Canada. The SLF provided 153 forest avalanches on Swiss territory. The available sample size from the merged data sets is 456. Not all of them deliver the required information on site and forest conditions. Database delivers 295 records of the canopy cover percent of the tree layer, 285 records of the wintergreen proportion, 233 records of the gap width (ARWGB), 230 records of the gap length (ARLGB), and 155 records of stem densities of trees with DBH ≥ 7 cm for example.

Especially the number of records with information on stem density is low. Hence, we accepted small inconsistency of DBH class boundaries in the data (e.g. DBH > 6 cm SLF, DBH ≥ 7 cm data from Bavaria and BFW).

Because of the different methods used by SLF and BFW, the SLF samples provide three different values of the canopy cover percent and of the wintergreen canopy cover percent (Table 21-1). Since these characteristics are key indicators used by the guidelines, we tested the hypothesis that the canopy variables represent the same forest conditions as well as canopy measurements.

Canopy covers measured by the BFW-method (ARTLCC) significantly differ from the on-site estimations (GESAMTDECK) and from aerial image analysis (GESKRPROJ) made by SLF (Table 21-2). BFW-method results in a higher mean and standard deviation (STDEV). The coefficient of variation (CV) is smaller. This indicates no differences in the quality of the measurements, but possibly a levelling effect of larger sample plots. The on-site estimations and the results of image analysis made by SLF also differ significantly. Although, the estimations and measurements of the wintergreen (evergreen) canopy cover depend on the values of total canopy cover, values measured by BFW (ARTLWCC), on-site (GESAMTDECKW) and on aerial image by SLF do not differ significantly (Table 21-3).

Table 21-2: Descriptive statistics of different canopy cover variables and tests of hypothesis

Canopy cover variables	Descriptive statistics						Percentiles			Wilcoxon-Tests p values	
	N	mean	STDEV	CV	min	max	25.	50.	75.	ARTLCC	GESAMTDECK
ARTLCC	137	45.09	26.02	0.58	6	97	27.0	35.0	69.0	- - -	- - -
GESAMTDECK	137	37.42	25.23	0.67	0	100	20.0	33.0	55.0	0.000***	- - -
GESKRPROJ	137	35.93	22.57	0.63	0	91	21.0	30.0	47.0	0.000***	0.022*

Table 21-3: Descriptive statistics of the wintergreen canopy cover variables and tests of hypothesis

Canopy cover variables	Descriptive statistics						Percentiles			Wilcoxon-Tests p values	
	N	mean	STDEV	CV	min	max	25.	50.	75.	ARTLWCC	GESAMTDECKW
ARTLWCC	135	10.46	11.63	1.11	0.0	64.3	1.6	5.9	17.8	- - -	- - -
GESAMTDECKW	135	12.58	15.02	1.19	0.0	100.0	1.8	8.4	8.4	0.082	- - -
GESKRPROJW	135	10.34	9.32	0.90	0.0	37.0	3.0	8.5	8.5	0.191	0.089

The comparisons of gap widths (ARWGB, GAPWIDTHSLF) and gap lengths (ARLGB, GAPLENGTHSLF) according to the concepts of BFW and SLF also shows considerable differences especially in the lengths of gaps (Table 21-4). This result was to be expected due to the different gap concepts. Nevertheless, the results indicate a greater agreement in interpretation of gap widths than of gap lengths. Note that the absence of a gap may be coded with a width and length of zero or as null values. BFW database use zero in case of there is definitely no canopy opening larger than 10 m in width and length. No data indicate a diffuse spatial distribution of the trees, which does not allow a clear measurement, or the missing of data. The comparison includes zero values in line with the measurements of the Swiss samples.

Table 21-4: Descriptive statistics of the gap length and width variables and tests of hypothesis

Gap dimension variables	Descriptive statistics						Percentiles			Wilcoxon-Tests p values	
	N	mean	STDEV	CV	min	max	25.	50.	75.	widths	lengths
ARWGB	107	12.1	14.3	1.18	0	80	0.0	10.0	20.0	0.000***	- - -
GAPWIDTHSLF	107	16.8	14.5	0.86	0	65	6.0	15.0	23.0		- - -
ARLGB	105	21.1	35.5	1.68	0	297	0.0	13.0	29.5	- - -	0.001***
GAPLENGTHSLF	105	26.1	19.3	0.74	0	90	13.5	25.0	36.5	- - -	

Because of the significant differences of the canopy cover and gap dimension measurements, we decided to base the comparison of the hazard-related targets on both, the values available for the merged SLF-BFW dataset (ARTLCC, ARTLWCC, ARWGB, ARLGB) and for the SLF samples. The BFW method tends to result in higher values of the canopy cover percent. This is most likely a result of the fixed and larger sample areas, while the SLF samples with an average sample area of 775 m² represent smaller structural units.

To evaluate the indicators of the basic hazard potential we used a subsample of the avalanche cadaster of the Aosta valley provided by the Ufficio neve e valanghe (Portale delle Valanghe Regionali v1.0, Regione Autonoma Valle d'Aosta). The sample includes the historical avalanche hazard records from Champdepraz, Cogne, Fénis, Gran San Bernardo, La Thuile, Val D'Ayas, Val Ferret and Valle di Champorcher.

2.2 Data about shallow landslide initiation on terrain of forest use

We used a dataset of 555 scar points of spontaneous (shallow) landslides in terrain of forest use (but not on forest roads) to compare the guidelines' recommendations on protective forest structures with the forest conditions temporally prior to the landslide hazard events. The dataset is a subsample of the landslide data provided by the geohazard database (BFW-GeoNDB) of the BFW (Perzl et al. 2017).

We selected the data about landslide hazards initiated in terrain of forest use by the heavy rain on August 22nd/23rd 2005 in Austria. This landslide event inventory was made by orthophoto interpretation and partially by terrestrial survey for several regions in the Austrian federal state Vorarlberg (Markart et al. 2007, Zieher et al. 2016) (Figure 22-1).

Figure 22-1: Forest landslide examples

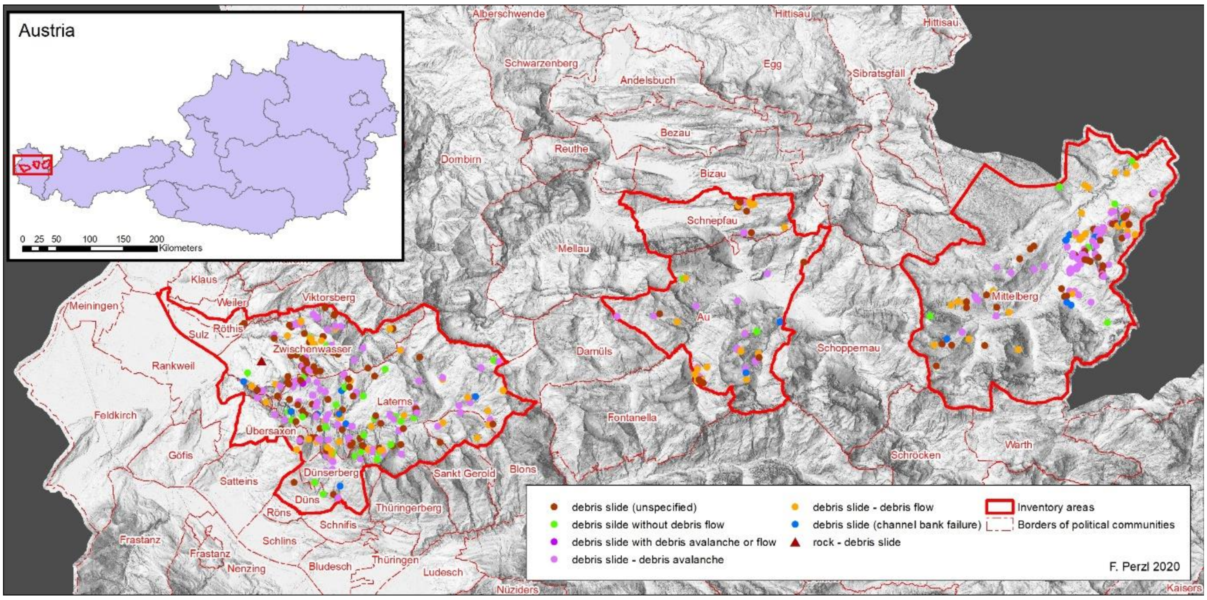


Figure 22-1 only shows the position of slope failures (scarpoints), which happened in forests. The landslide inventory covers a mountainous area of 251.1 km² dominated by the Penninic (Flysch), Helvetic, Ultrahelvetic and Austroalpine (limestone) nappes.

The forest percent of the inventory area is 47.5 including forest roads. The total number of recorded landslides is 1199 and 564 on forest use terrain. So, total landslide density was 4.8 slides/km² and similar in and out of forest use. The landslide scar mapping (point features) base on orthophotos taken immediately after the heavy rain in 2005 (partial cover, true-color images, ground sampling distance GSD 0.25 m) and in 2006 (complete cover, true-color, GSD 0.125). We used these landslide data, because the pre-event forest structure could be taken from the orthophoto flight campaign in 2001 (color infra-red and true-color version, GSD 0.25 m) and from the first high-resolution digital terrain model (DTM) and normalized digital surface model (nDSM, spatial resolution 1x1 m) available from ALS in Austria. ALS was done in 2002-2004. Therefore, the time interval between the landslide events and the time, when the aerial photographs and surface elevation data were taken, may minimize the temporal mismatch problem.

Land cover and forest structure data frequently do not match the conditions present at the time of landslide initiation (Van Westen et al. 2008, Guzzetti et al. 2012, Petschko et al. 2014, Steger et al. 2016 all cf. Schmaltz et al. 2017 p. 251). In order to minimize the temporal mismatch problem, we compared forest canopies on base of the nDSM and on base of the optical images. We corrected the forest characteristics from aerial image interpretation to the conditions shown by nDSM for 65 samples. The proportion of a temporal mismatch of forest structures due to tree cutting or landslides was 11.7 % of the samples within a period of one to three years. Despite the short event-to-data time interval and these corrections, a bias of the pre-event forest conditions cannot be excluded completely. Analysis of precipitation data and of the images indicate, that some landslides visible on the orthophoto series from 2006 may have occurred in 2006 and few in 2002, but not in 2005. Orthophotos and elevation data were provided by the Department of Geoinformation of Vorarlberg.

The sampling design of the BFW-GeoNDB for forest characteristics on landslide scars is similar to that for snow avalanches (Figure 21-2). The surveys also base on circular sample plots with a radius of 25 m.

The BFW-GeoNDB does not provide all the criteria used by the guidelines (Table 22-1). Hence, in this study, we had to add parameters used by the guidelines (Table 22-1).

The landslide data from BFW-GeoNDB do not show the canopy cover in the same way than the BFW snow avalanche data. Due to the large number of landslides to be recorded, the information on the crown coverage was based on an orthophoto estimate of the canopy cover of the woody vegetation in five classes (0 < 15 %, 25 = 15-34 %, 45 = 35-54 %, 65 = 55-74 %, 90 ≥ 75 %) for the reference unit (stand) at the landslide scar point (Table 22-1, SCSTOCKD2M). A time-consuming digitalization of the crown projections within all circle sample areas was not possible. Crown cover estimates for the reference unit differ from the crown cover within the sample plots as different types of forest stands are frequently within the plot around the scar point. That's why we derived the single canopy cover of the woody vegetation and the single canopy cover of the tree layer from the nDSM 2002-2004.

Tree height retrieval based on nDSM is dependent on the quality of the ALS data and the DTM extraction as well as influenced by topography (Gatziolis et al. 2010, Bühler et al. 2012, Duan et al. 2015). nDSM-values may underestimate tree top heights especially of smaller and coniferous trees and in steep terrain by an average of about -0.5 m (Morsdorf et al. 2004, Heurich 2008, Gatziolis et al. 2010, Hollaus & Wagner 2012, Smreček 2012, Duan et al. 2015, Smreček et al. 2018). However, although the cell values may represent tree top heights rather occasionally, a gridded 1x1 m nDSM corrected by ground cover of infrastructures like buildings and pylons is a canopy height model (CHM) suitable to separate low from high vegetation layers.

We calculated the local maxima of the CHM within a 3x3 m moving window. As an approximation of the canopy cover of woody layers was the objective, but not single tree segmentation, we selected all cells with CHM values > 1 m and greater than the respective tree layer threshold of the local maximum. We used local maximum thresholds of > 4.5 m, > 9.5 m, > 17 m and > 34.5 m to approximate the canopy cover of the tree layers (ISDW h > 5 m, NaiS DBH ≥ 12 cm ~ h > 10 m) and of the saw- (DBH ≥ 20 cm ~ h > 17.5 m) and large-sized timber (DBH ~ > 49 cm ~ h > 35 m) definitions of the guidelines (Table 22-1).

Table 22-1: Shallow landslides - hazard indicators and protective effect-related characteristics

Criteria (due to slope failure)	Guideline	Source, Method
Hazard potential indicators		
Soil conditions (soil texture)	(NaiS)	semi-quantitative, no data
Mean slope gradient [°] (ASLOPE)	(NaiS)	DTM 10 X 10 m
Signs of slope movements	all guidelines	qualitative, no data
Effect-related characteristics		
Gaps and blanks[1] without[2] young growth[3]		BFW-GeoNDB, EOP
Width[4] [m] (GAPWIDTH)	ISDW	BFW-GeoNDB, MOP, nDSM
Length[5] [m] (GAPLENGTH)	SFP	MOP, nDSM
Area [m²][6] (GAPAREA)	NaiS, SFP	MOP, nDSM
Gaps[1] and areas dominated[2] by young growth[3]		BFW-GeoNDB, EOP
Width[4] [m] (YWIDTH)	NaiS	MOP, nDSM
Length[5] [m] (YLENGTH)	SFP	MOP, nDSM
Area [m²][7] (YAREA)	NaiS, SFP	MOP, nDSM
Single canopy cover[8] of woody vegetation[9]	GSM-N, GSM-S, ISDW	
SCSTOCKD2M [%]		BFW-GeoNDB, EOP
CCW, CCPW [%]		nDSM
Single canopy cover[8] of the tree layer[10]	NaiS, SFP	
h[11] > 5 m (CCT5, CCPT5 [%])	additional parameter	nDSM
h[11] > 10 m (CCT10, CCPT10 [%])	NaiS, SFP	nDSM
h[11] > 17 m (CCT17, CCPT17 [%])	additional parameter	nDSM
h[11] > 35 m (CCT35, CCPT35 [%])	additional parameter	nDSM
Proportion of well anchored trees [%]	SFP	semi-quantitative, no data
Absence of unstable trees	NaiS	qualitative, no data
Absence of trees DBH[11] > 47.5 cm [%]	SFP	substituted by: CCPT35
Canopy cover of trees DBH[11] > 50.0 cm [%]	ISDW	
Proportion of species with shallow root system [%]	ISDW	no data

[1] NaiS and SFP refer to canopy openings in the tree layer (dominant DBH[11] ≥ 12 cm) without or with "secured" young growth[2]. ISDW refers to openings in the canopy cover of living trees with a height above 1.3 m (also in the thicket and pole tree stage). Therefore, we considered in the analysis that "gaps" according to the ISDW (BFW-GeoNDB) definition may be areas dominated by young growth[2, 3] (gaps with young growth) according to the NaiS-definition.

[2] NaiS and SFP refer to the presence of "secured" regeneration. The definitions of assured regeneration vary according to forest community. Some of the definitions include qualitative terms. They are not feasible with remote sensing methods, and it is also difficult to address this criterion in the field. According to NaiS, the minimum ground coverage of the saplings of assured regeneration is between 3 and 9 % (in case of no consideration of seedlings). We used a limit of 15 % to differentiate between areas with and without (sufficient) occurrence of young growth.

[3] Young growth (seedlings and saplings) of trees and shrubs other than dwarf shrubs.

[4] We measured the width at the center of the landslide scar in direction of the contour line (plan distance).

[5] We measured the length at the center of the landslide scar in flow direction (plan distance).

[6] We measured the area only, if the area is enclosed by woody vegetation or clearly delimitable from the non-forest area.

[7] We measured the area only, if the young growth is enclosed by a tree layer or clearly delimitable from the non-forest area.

[8] Canopy cover (CC) is the area of ground covered by the vertical projection of the outermost perimeter of the spread of the branches of woody plants other than dwarf shrubs. Small openings within the canopy and inter leaves are included. Canopy cover may be measured in units of area or as a percentage of the reference unit (canopy cover percent). The single canopy cover does not include the overlapping of canopies and is limited to 100 % (aerial perspective).

[9] Trees, young growth of trees and shrubs other than dwarf shrubs.

[10] Definitions of the tree layer are different: NaiS - DBH ≥ 12 cm, ISDW - woody plants higher than 5 m.

[11] DBH - Diameter at breast height (1.3 m), h - tree height

BFW-GeoNDB - available from BFW-GeoNDB; MOP, EOP - measurement, estimation on orthophoto; nDSM - calculated from normalized digital surface model; DTM - calculated from digital terrain model

Height threshold setting for the woody vegetation (CCW) including bushes and young growth is difficult, since nDSM values may show the height of the ground vegetation like dwarf shrubs and another surface roughness. As in the BFW-GeoNDB data the stage of development is a point decision, we used a smaller circular sample plot with a radius of 10 m to analyze the focal maxima of the CHM of all scar points classified as young growth (without gaps) on base of the orthophoto series 2001. The mean value of the focal maxima is 3.1 m, and the mean standard deviation is 2.6 m. We decided to use a threshold of > 1 m of the local maximum and a threshold of > 0.5 m of the CHM to separate woody vegetation from ground vegetation.

Then we have calculated the single crown coverage percent of the woody vegetation (CCPW), of the tree layer according to NaiS (CCPT10), SFP (CCPT17) and ISDW (CCPT5) as well as the canopy cover of the large-timber layer (CCPT35) within the circular sample plots of aerial image interpretation. We also derived tree top points > 4.5 m, > 9.5 m, > 17 m and > 34.5 m from the local maxima of the CHM to approximate stem densities.

As the BFW-GeoNDB do not provide information about the area (YAREA), length (YLENGTH) and width (YWIDTH) of secured young growth stands and shrubland according to the NaiS definition, we performed a simple approximation on base of the CHM. Manual digitizing was not possible, because large areas of alpine bushes cover the slopes in the study area. They are highly fragmented and difficult to map. We calculated the canopy cover percent on base of the cover layer of woody vegetation (CCW) by summation of canopy pixels within a 5 m radius moving window. After that, we selected all pixels with a CCPW ≥ 15 % and CHM > 0.5 m which are not covered by the tree layer according to the NaiS definition (CCT10 = 0). Then we smoothed the results three times to (1) remove artifacts and (2) to fill gaps. The first smoothing (1) was a majority-filter with a rectangle neighborhood of three cells to remove almost all spatially insolated young growth cover of only one or two pixels. The second majority-filter with a rectangle neighborhood of nine pixels filled gaps smaller than about 100 m² after the second run. We selected all pixel zones representing young growth or pole timber area of at least 100 m², which intersect scarpoints. We converted them to polygons to derive the areas of the young growth (YAREA, Table 22-1). We calculated the length of these zones (YLENGTH) in flow direction on base of the hydrological flow length and the width (YWIDTH) on base of interpolated terrain contour lines. The method delivered seven landslide samples assigned to young growth as well as to a gap or blank according to the aerial image interpretation. We checked these situations manually.

2.3 Data about rockfall in forests

Scheidl et al. (2020) provided a sample of 32 non-destructive rockfall hazard events in forests with information about average runout lengths and fall heights of single blocks as well as on average stem densities and basal areas weighted by stand unit slope lengths along the hazard zones. The data are from Italy, Germany, Slovenia, and Austria. The data was compiled within the framework of the Alpine Space Rock the Alps (RTA) project.

However, because of the data sampling on plots within forest units which were crossed by rockfall paths, the data do not fully cover all forest characteristics addressed by the guidelines, for example gap lengths (tree distances) in forests. We used the hazard reduction factor proposed by Scheidl et al. (2020) to test a sensitivity of critical stem densities recommended by NaiS and SFP. We interpret these critical stand densities as average values that are also valid on a slope scale.

3. RESULTS

3.1 General concepts of the assessment procedures

3.1.1 NaiS

NaiS is explicitly not made for forest function mapping and also refers to additional diagnostics necessary to assess the achievement of protection targets (Frehner et al. 2005 annex 1 p. 1). The main function of NaiS is the controlling of the silvicultural measures in protection forests on plot or on stand scale in order to evaluate target achievements of protection forest management and furthermore of the forest policy.

The controlling is limited to selected example plots of about 0.5 to 1.0 ha within silvicultural units. Therefore, the system is not fully applicable to ascertain the protective effect of the forest within hazard zones with a damage potential on slope scale.

The protective effects of forests do not only result from the protective effect of a single forest unit and might be supplemented or even replaced by another forest unit or not. It is important to consider that protective effects result from complex interactions of hazard, site, and forest characteristics along the hazard zones on slope scale. And protective effects of forests are limited. Therefore, a concept that focuses on the evaluation of silvicultural measures has different target settings than systems directly aiming to the assessment of the protection against natural hazards, or to the risk of damage to infrastructures. From a silvicultural perspective, forest conditions may be optimized, although the protective effect of the forest is limited. However, NaiS is frequently cited regarding the assessment of the protective functions and protective effects of forests. NaiS is based on a previous version known as "Wegleitung" (Wasser & Frehner 1996). There are several differences of the current version in detail, but the general structures are identical.

Most of the NaiS guideline describes the Swiss forest associations and specifies site-related objectives of silvicultural management in terms of tree species composition and occurrence of forest regeneration. NaiS also presents hazard-related targets to optimize the protective effect of forest against snow avalanches (initiation), landslides (initiation), rockfall (propagation) and flooding (flow initiation). The hazard-related targets are presented in combination with indications of the basic hazard susceptibility, but without a linkage to protection targets (assets at risk) and without a clear separation of indicators of the protective function and of targets to maintain the protective effect.

NaiS provides two levels of hazard-related targets, (1) the "minimum" and the (2) "ideal" requirements on the density and structure of the forest. Therefore, NaiS (and SFP) also implements a kind of classification of the protective effect like GSM-N, GSM-S and ISDW. However, NaiS refers to the "minimum requirements" (Frehner et al. 2005 p. 17). It is not shown what the minimum and the ideal requirements stand for in terms of protective effects and hazard risks. NaiS refers to a long-term protective effect provided by the ideal requirements (Frehner et al. 2005 p. 17). The ideal requirements are more restrictive than the minimum requirements; for example, the sizes of clear-cuts allowed are smaller. We do not recognize a direct relationship between the hazard-related targets and the temporal extent of the protective effect.

The targets are presented in tables without – and this is an important point – a description or a flowchart how to link the targets in order to quantify the protective effect. This is more clearly presented in the previous version. For example, the previous version includes the instruction to use the canopy cover targets in case of diffuse opened forests and consequently the gap targets in case of delimitable gaps like clear-cuts. This may be obvious, but such an instruction is missing in the current version. And according to our experiences, it is difficult to delimit gaps in mountain forests, which frequently show irregular and highly fragmented canopy covers. It is necessary to read the first version of NaiS to fully understand the second version. Texts accompany the tables, giving information about natural hazards, protective effects of forests and appropriate silvicultural actions.

NaiS provides a glossary. This is very important, since the meanings of the same silvicultural terms vary by country even in German language. For example, the German term "Deckungsgrad" (degree of coverage) according to the definition in NaiS refers to the canopy cover of trees. In Austria, the term "Überschirmungsgrad" is used for the canopy cover and "Deckungsgrad" refers to the foliar cover, which varies seasonally. The descriptions in the glossary do not include measurement instructions, which are crucial to apply technical guidelines in practice. The definition of gaps for example, does not correspond to the critical sizes presented in the target section of the guideline, and critical lengths may refer to planar or to inclined lengths.

3.1.2 SFP

The spatial scale and structure of SFP is similar to NaiS. The guideline also differentiates between minimum and ideal conditions of forests, which are presented in tables without rules or flowcharts to connect specific assessment indicators. Most of the criteria seem to be copies of NaiS, but there are also some modifications in detail. A glossary and technical measurement instructions are missing.

3.1.3 GSM-N

GSM-N also provides information to identify the forest associations of the northern French Alps, to define site-specific silvicultural targets and to assess the protective effect of forests against natural hazards including management recommendations. In contrast to NaiS and SFP, GSM-N provides flowcharts to identify the protective function and the protective effect of forests.

The forest function assessment procedure (Gauquelin & Courbaud 2006 pp. 31-43) starts with references to existing hazard indication maps. As the number of such mappings based on spatial modelling increases considerably, it is important to communicate the existence and messages of the maps. However, the procedure does not include the classification of the protective function on base of the importance and vulnerability of the human infrastructures to be protected. A classification of the importance of the human infrastructure is presented in the chapter "Risques naturels" (Gauquelin et al. 2006 p. 195), but without any linkage to the procedures of hazard and protection assessment. Protection forest mapping methods of Switzerland (Losey & Wehrli 2013) and Austria (BMLFUW 2006, BMLFUW 2012, Perzl & Huber 2015, Perzl et al. 2019) for example, refer to protective functions of forests as a consequence of the social and economic importance of human infrastructures within potential hazard zones and the expectable hazard probability and intensity without a forest cover. The social and economic importance of human infrastructures determine the direct object-protective function of forests and furthermore the protection targets, which may require different demands on forest conditions and management.

GSM-N distinguishes between a procedure for identifying the basic hazard potential (without consideration of forest conditions) and criteria to assess the protective effect of the forest. However, depending on the natural hazard, the issue of hazard potential or forest function assessment is also mixed to varying degrees with indicators of the protective effect by using the term "rôle de protection". For example, the flowchart in order to determine the "protective role" of the forest regarding landslides includes the criterion canopy cover. According to GSM-N, the forest has no role of protection, if the canopy cover is smaller or equal than 30 % (Gauquelin et al. 2006 p. 43). However, this condition does not refer to the protective function of forest, but to the protective effect. Some concepts like GSM-N only allocate a protective function against natural hazards to forests, if the forest might be able to mitigate the hazard (Perzl & Huber 2015 p. 11). However, these concepts refer to optimized forest conditions in properly managed forest and not to the current forest conditions. Another example may show the consequences of this difference. According to GSM-N, the forest has no protective role in transit and deposition zones of rockfall, if the slope inclination is equal or higher 25° and the volume of single blocks is higher than 5 m³ (Gauquelin et al. 2006 pp. 35). In such situations, there may be no or a limited protective effect of the forest even in case of an optimized forest structure. However, the concept does not consider that blocks smaller than 5 m³ also may be mobilized from the same rockfall sources. Hence, the forest may be able to mitigate the propagation of smaller blocks, especially if the length of the transit or deposition zone covered by forest is long enough. It is therefore not justified to exclude a protective function or "role" of the forest on base of the GSM-N criteria, even if the protective effect is limited in case of extraordinary hazard events. An exclusion of the protective function could also have legal and financial consequences, since funding of measures to maintain the forest is conditional on the status of a protection forest in many European countries.

The indicators of the "rôle de protection" are organized in clear flowcharts with few logical inconsistencies (Gauquelin et al. 2006 pp. 31-43). However, similar to NaiS and SFP, the criteria to assess the protective effects of the forest (Gauquelin et al. 2006 pp. 193-211) are listed in tables without any instructions to combine them. The criteria might be linked by restrictive "and" conditions. But this is not appropriate for each type of hazard and hazard zone. For example, NaiS and GSM-N recommend inclined gap lengths smaller than 20 m (NaiS) or 40 m (GSM-N) in rockfall transit and deposition zones in case of high-forest systems. These are clear statements usable in forest management, but foresters have to decide who is right, NaiS (SFP) or GSM-N. However, a single and narrow gap slightly longer than 20 or 40 m within a dense forest cover of medium- or large-sized trees may not lower the protective effect completely, if the length of the fully stocked forest cover is long enough (Zürcher 2010 p. 14). Therefore, the "and" condition may not reflect the protective effect of the forest especially in case of the hazard breaking functions of forests in transit and deposition zones.

3.1.4 GSM-S

GSM-S also provides much information for protection forest management similar to GSM-N. The procedure to assess the "rôle de protection" starts with an overall ranking of the intensity of the hazard types erosion, torrential flood, landslide, rockfall and snow avalanche according to Rey et al. (2009 cf. Ladier et al. 2012 p. 16). The ranking table shows three ordinal scales of hazard process intensities called "Note d'aléa", but only two nominal ratings, "low" and "high".

The guideline recommends to map and note the five hazard categories independently. This is the usual standard of hazard indication mapping. The guideline provides qualitative and semi-quantitative criteria for hazard (intensity) classification including the class "zero", which is the code for no susceptibility to hazards like in the Austrian forest function mapping and ISDW.

In contrast to all other guidelines, the concept allocates the hazard classification of torrential flooding to the whole watershed based on the erosion susceptibility of the stream bed. However, the concept does not consider the steepness of the riverbeds and the hydrological response conditions of forest units like NaiS (Frehner et al. 2005 annex 1 p. 19) and ISDW. The hazard classification of landslides is also limited to the assumed depth of the landslides like in NaiS, SFP and GSM-N. The threshold between a high and a medium hazard intensity is 2 m similar to other guidelines, but the guideline also does not consider slope inclination, and a "zero" class is missing. Obviously, like in all other guidelines, landslide hazard mapping is limited to terrain showing landslide activity. This approach contains the risk of overlooking landslide potentials. Rockfall hazard mapping is also limited to zones, where rockfall sources and rockfall activity is obvious. A block volume greater than 1 m^3 separates the medium from the high hazard intensity. Snow avalanche hazard indication differs situations, where avalanche activity is known, and potential avalanches, which could occur in future, if existing forest would disappear. This concept is also part of the hazard indication proposed by GSM-N. The GSM-S concept implements an assignment to the "low" intensity class in case of potential and to "high" in case of known avalanches. The guideline refers to historical avalanche mappings and to avalanche susceptibility mappings drawn expertly. All other guidelines provide information about elevations and slope inclinations susceptible to avalanche formation in case of forest deteriorations.

The protective function of the forest results from the combination of the hazard classification and the ranking of the human infrastructure within the potential hazard zones by a combination matrix (Ladier et al. 2012 p. 23) similar to the Austrian approach (BMLFUW 2006 pp. 44-45). The classifications and rankings of the human infrastructures (Ladier et al. 2012 p. 22) are identical to the approach presented in GSM-N (Gauquelin et al. 2006 p. 195).

The GSM-S concept to map and classify the protective functions of forests clearly differs the protective function from the protective effect in form of a simplified risk-based approach, whereas the GSM-N approach mixes functions and effects which might result in inappropriate assessments. Risk assessment concepts for practical use in forest management require some simplifications, since land use, hazard and forest managers have a variety of task to fulfil. The basic surveys required for more complex systems might be too costly. However, many examples show (e.g. Staffler et al. 2008, Losey & Wehrli 2013, Perzl et al. 2019) that spatial modelling is able to provide preliminary information that relieves practitioners.

A drawback of the GSM-S approach is that the probability and the expected intensity of the natural hazard (in case of not protective forests in future, but without consideration of current forest conditions) is considered in very general terms. For example, in case of potential avalanche zones, the snow avalanche protective function is set to "low" or to "medium" depending on the infrastructure to be protected, as the concept assigns all potential avalanches to the "low" hazard class without any consideration of the avalanche formation probability and the expected hazard intensity. The avalanche hazard probability and the possible hazard intensity vary considerably, among others, depending on the elevation and slope inclination of the potential starting zone. Therefore, the GSM-S approach assigns a high relevance of the protective functions of forests to hazard zones, where forest maintenance or afforestation is not the most effective measure of hazard mitigation, for example within active starting zones of avalanches.

The procedures of GSM-S to assess the protective effects of the current forest (Ladier et al. 2012 pp. 28-33) are presented in form of clear flowcharts. Just like GSM-N, GSM-S refers to the protective effect as "rôle de protection", and in some cases a protective effect of the forest is also excluded. The system distinguishes three levels of protection: "effective", "medium" and "very low" (Ladier et al. 2012 p. 28), also symbolized by different colors in the flowcharts.

The information on protective forest conditions provided by GSM-S are somewhat confusing, since two chapters of the guideline provide two different concepts of hazard-related targets. The guideline presents assessment procedures of the protective effect in (1) the chapter "Diagnostic du rôle de protection" (Ladier et al. 2012 pp. 16-34) and (2) in the "Fiches thématiques" (Ladier et al. 2012 pp. 256-261). The targets or critical values provided in (2) are identical to the hazard-related targets of GSM-N. Therefore, we refer to the first chapter (1) in the following.

GSM-S also refers to the future protective effect of the forest under consideration of forest development and stability. The priority of silvicultural measures results from the current and the future protective effect of the forest. There is also an evaluation matrix for this purpose (Ladier et al. 2012 p. 34). However, it is not possible to exactly reconstruct how the future protective effect of the forest is derived. From the risk analysis perspective, the damage potential as a result of the infrastructure to be protected and the hazard probability and intensity is crucial for the priority of measures. Although the combination matrix to assess the protective function of the forest (Ladier et al. 2012 p. 23) is shown once again in the context of identifying priorities for action on page 34 of the guideline, there is no link to the matrix that defines the priority of measures.

3.1.5 ISDW

ISDW was developed for the same purpose as NaiS, the evaluation of silvicultural measures in protection forests. ISDW is an internal guideline of the Austrian forest authorities, only used in the frame of funding to support the rural development by the European Agricultural Fund for Rural Development 2007-2013. The guideline was not published, because responsible editors and forest practitioners were aware that the assessment of the protective effects of forests still involves considerable uncertainty. However, without a definition of targets concerning forest characteristics, an evaluation of protection forest policy is not possible. The guideline itself is small (just 21 pages, for example in relation to GSM-N with 289 pages) and was an appendix of the handbook for planning measures in protection forests which is no more available. Forestry practitioners have rejected such guidelines and target-settings as too inflexible and not adaptable to the manifold situations in forests, a discussion which has also taken place in Switzerland (e.g. Zürcher 2010). The handbook also included instructions to measure or estimate the site and forest characteristics based on instruction manuals of forest inventories.

The guideline focuses on the assessment of the protective effect of forests against avalanches, rockfalls, landslides and initiation of surface flow. Like NaiS, the guideline was explicitly not developed to map and classify the object-protective functions of the forests. The guideline assumes that there is an object-protective function identified by forest authorities.

The assessment procedure consists of the following steps (Perzl 2008): (1) assessment of the basic hazard susceptibility to snow avalanche initiation, rockfall propagation, landslide initiation and near surface flow without consideration of forest conditions; (2) assessment of the protective effects of the forest depending on the basic hazard susceptibility and forest characteristics; (3) classification of the forest texture; (4) assessment of inhibiting factors of a sustainable forest growth and (5) overall assessment of sustainable protection by the forest.

For each hazard category there is an evaluation matrix for the basic hazard susceptibility and the protective effect of the forest. The guideline does not use flowcharts like GSM-N and GSM-S. However, the matrix combination of site and forest characteristics leads the users to a clear result.

The basic hazard susceptibility is called "hazard potential" or "level of hazard". The basic hazard susceptibility only considers approximately unchangeable site factors, because the existing forest will change in the future. The concept differs four ordinal scales of the hazard susceptibility: "no" (coded with "zero"), a "low", a "medium" and a "high" basic hazard susceptibility (Perzl 2008 p. 555). The basic hazard susceptibility refers to the probability of hazard initiation in case of snow avalanches and landslides. The basic hazard susceptibility of rockfall considers the capability of a section of the rockfall path to hamper rockfall propagation without a forest cover. And the susceptibility to fast near surface overland flow considers the infiltration and water storage capacity of the soil similar to the approach of NaiS.

The assessment of the protective effect of the forest is based on the current conditions of forest. The objectives or critical values of the forest characteristics vary depending on the basic hazard susceptibility. The assessment matrix yields into four levels of the protective effect (Perzl 2008 p. 559): "zero", which means there is no basic hazard susceptibility, "sufficient", "reduced" and "very low". The level of the protective effect refers to a section of forest under consideration similar to the NaiS approach, and not to the entire forest relevant for protection of an infrastructure.

The assessment of the forest texture includes generalized minimum requirements on the occurrence of regeneration, on the age-gradation and tree species composition. The classification of inhibiting factors of forest growth like instability of trees is purely qualitative.

The overall assessment of target achievement is also organized by an evaluation matrix to combine the lowest level of the protective effect, the forest texture, and the inhibiting factors of forest stability. Since target control of protection forest management is the objective of the concept like in NaiS and SFP, the overall assessment results into three ordinal scales of target achievement, which may also indicate the priority of measures, but without any consideration of the risk of damage to infrastructure.

The ISDW concept shows considerable differences to the structure of all other guidelines. The superior principle of spatial organization is not a differentiation into starting zones, transit zones and deposition zones, since such a classification is often not clearly possible in the forests. Site-specific targets of forest structure are compressed to few but generalized targets. The planning handbook and the guideline do not include identification keys to forest communities, as there are numerous sources for this in Austria, and skilled foresters are able to classify forest sites. The guideline does also not provide information to assess the stability of forests like critical values of crown lengths and height-diameter-ratios, since this is known, and such indicators do not guarantee sustainability of forest growth. The principles of protection forest management are limited to few general recommendations. The necessities for action and suitable measures in protection forests cannot be programmed as each forest is unique (Leibundgut 1983 cf. Ott 1996 p. 228), but require individual treatment and specific considerations by skilled and experienced foresters (Ott 1996 p. 228).

The aggregation of indicators to an ordinal benchmark of the basic hazard susceptibility is suitable for the classification of the protective function, as is also done in GSM-S ("Note d'aléa"), but in the ISDW concept without a link to the infrastructures at risk. However, this aggregation reduces the adaptability of the assessment of the protective effect to specific situations and to new findings. The assumed influence of the site factors on the basic hazard susceptibility and on the protective effect during aggregation does not necessarily have to be valid locally. The evaluation matrices force site conditions into a rigid pattern, whereas assessment procedures like the flowcharts used by GSM-N and GSM-S that are primarily independent of the overall assessment of the basic hazard susceptibility allow better adaptation to specific situations.

3.1.6 The problem of spatial units to assess effects of forests

Measurements of site and forest characteristics depend crucially on how the evaluation units are delimited as well as on the measurement methods (Glanzmann 2012).

All of the guidelines do not define exactly how to form evaluation units which are necessary to measure the evaluation criteria, e.g. the canopy cover percent and the stem density. NaiS refers to stand mapping by aerial image interpretation (Frehner et al. 2005 annex 8 p. 2). In case of torrential flooding, GSM-S relates to the whole watershed (Ladier et al. 2012 p. 19) and to starting zones (maybe of runoff or of sediment mobilization) without considering the potentially high variability of hydrological response units within a watershed. The ISDW-handbook recommends formation of homogeneity units of about 0.5 to 3.0 ha within units of the forest function mapping (BMLFUW 2010 pp. 16-17). GSM-N and GSM-S refer to existing hazard indication maps in France and, like all guidelines except ISDW, to separation of (potential) hazard zones into starting, transit and deposition areas, but without any recommendations and criteria with regard to forest unit mapping. The concept to differ starting, transit and deposition zones of natural hazard processes sounds simple and is suitable for channeled large avalanches and for rockfall from steep cliffs. However, this scheme is too simple for other processes and situations in relation to the manifold effects of forests. Potential and active starting and transit zones of several hazard categories are mixed spatially and overlap in steep forested terrain. The boundaries of ecological and stand structure units of forests are clearly aligned only in rare cases to the envelopes of potential or active starting and transit zones. The union of forest stands and hazard zones, classified by hazard category, hazard process, hazard activity and damage potential, usually leads to extreme fragmentations of evaluation units and thus to no longer suitable management and operation units.

The guidelines are addressed to foresters. Most of them will apply the criteria to units similar to the units ("stands") of forest management plans. However, stands of forest management plans are not inevitably appropriate for the assessment of protective effects of forests (Glanzmann 2012, Perzl & Walter 2012 p. 46). Usually they do not consider terrain geomorphology in an appropriate manner, as they focus to timber production. In the mountains, forest is often highly dispersed and stand boundaries as well as hazard process zone boundaries are not clear. Mapping of stands by different foresters will differ considerably and therefore also measurements of forest stand characteristics.

The evaluation units of protective effects of forests have to consider two main functions of forests: 1) the primary ability and therefore function of forest is to prevent hazard initiation in potential starting zones (snow avalanches, landslides) or 2) to break down and stop the propagation of the hazard process (rockfall).

Within transition and deposition zones, many completely different forest structure types of any sizes may occur. The protective effect of a forest - especially in transit zones of natural hazards - results from different impacts of all stands depending on their density, structure, size, and location in relation to the process intensity and propagation. An unwooded area like a clear-cut or a meadow may be completely irrelevant, if other sufficiently large and dense stands in the flow path can stop the process. This is called the effect of the forest stand texture. Therefore, an opening of the canopy or a stem density in the starting or transit zone that does not meet the target values of the guidelines does not necessarily mean that there is a risk of hazard process propagation, as this depends on the conditions in the transit zone. A complete assessment of the protective effect and of the damage risk requires the consideration of the transit zone, especially in case of the second function of forest which is the primary task in case of rockfall, but also important in order to protect from snow avalanches and debris flows.

The stem densities recommended by the guidelines may be average values over the entire hazard zone or minimum values required for each stand in the hazard zone. This is not the same situation. The guidelines give no indication of how to deal with this. As theoretical and experimental studies focus on rather homogeneous forest situations, knowledge about the influence of variations of the forest structure is low.

The nature of natural hazard processes and forest conditions require small- to medium scale considerations, since zones of hazard processes with high impacts may be small (e.g. rockfall) and the spatial variations are high. The criteria used by NaiS and ISDW to evaluate the first function require a spatial consideration of canopy openings of about 100 m². NaiS and ISDW define the minimum size of gaps with 10x10 m (Frehner et al. 2005 annex 9 p. 2, BMLFUW 2010 p. 56). However, the hazard-related targets for avalanche protection of NaiS do not fit this definition, as a permitted gap width in case of a too large gap length is < 5 m. The foresters and lumberjacks can use the target values of all guidelines as an orientation when planning logging operations. But the identification of such canopy openings by terrestrial mapping is hardly possible for larger areas and also very costly when interpreting aerial photographs. One method to overcome this problem is the derivation of structural characteristic of forests in a high spatial resolution from normalized digital surface models. However, it is not possible to obtain all forest and site characteristics necessary to assess the protective effects of forest from digital surface models and optical aerial images. Furthermore, the temporal mismatch problem limits the reliability of remote sensing.

The two examples of mapping provided in NaiS (Frehner et al. 2005 annex 8) show stand mappings of completely different spatial resolutions as an adaption to this practical problem by using existing base maps. The examples shown in SFP are plot scale surveys. The spatial resolution of forest management units usually does not deliver the same information. Applicability of assessment procedures to different spatial scales is important (De Montis et al. 2000 p. 15). Applicability to scales and a high degree of freedom may enhance the acceptance and usage of a system. Users feel more comfortable with systems which allow to use existing data and limit time and costs of implementation. However, it is important to keep in mind that NaiS and ISDW have been designed primarily for controlling purposes on base of selective evaluations, whereas GSM-N and GSM-S refer to hazard and risk identification. Nevertheless, GSM-N and GSM-S also do not offer practicable concepts to establish spatial units appropriate to assess the protective effects of forests, since there is also no or just a simplified consideration of the effect of the forest stand texture and of the length of the forest cover in the direction of the potential hazard propagation.

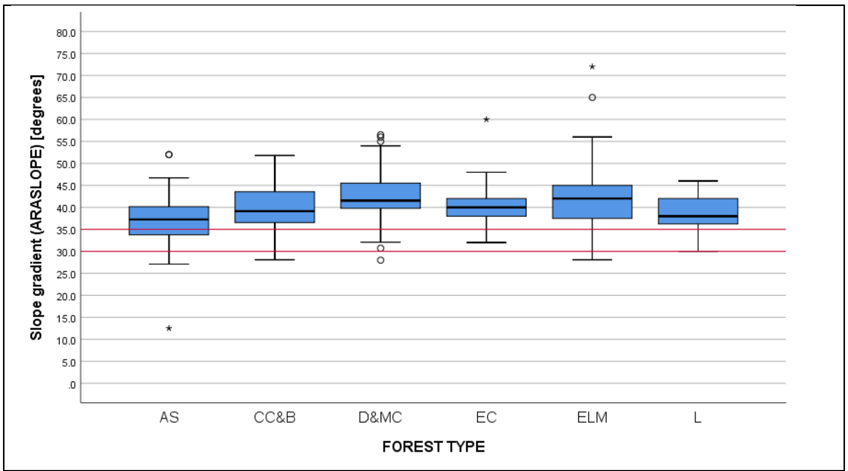
3.2 Snow avalanche: hazard potential indicators and targets of forest structure

3.2.1 Snow avalanche: hazard potential indicators

The guidelines NaiS and SFP do not provide procedures for quantifying the probability and possible magnitude of snow avalanche initiations. However, since the management of forests requires the assessment of the possibility of avalanche initiation in case of logging or forest destruction, NaiS and SFP contain general information on terrain that is prone to avalanche formation in the tables of criteria (NaiS, SFP) and in the accompany text (SFP).

According to NaiS for conditions in Switzerland, "*the potential contribution of forest (to avalanche protection) is great*" in Larch forest on slopes ≥ 30° and in evergreen coniferous forest on slopes ≥ 35° of the high montane and subalpine zone. The "*potential contribution of forest is medium*" in mixed and deciduous forest on slopes ≥ 35° in the submontane and montane zone. This division into high-montane to subalpine and sub-montane to montane sites indirectly describes two zones with different avalanche hazard potentials. This concept is also used to assign the hazard-related targets of forest structure to forest sites in the assessment table. This makes it easier to structure the table and – on the first sight – to apply the criteria. The criteria consider that at lower altitudes and in evergreen and deciduous forests avalanches usually occur on slopes above about 35° and at higher altitudes in larch forests on slopes above 30°. As snow depth and energy height increase with increasing altitude, the hazard (and damage) potential of terrain in higher altitudes may usually be higher than in lower altitudes. However, avalanche initiation (in forests) and the protective function of forest is not limited to these thresholds (Figure 321-1).

Figure 321-1: Boxplots of slope gradients on sites of forest avalanche initiations



N =	40	48	100	29	28	55	∑ 300

Figure 321-1 base on the merged Swiss-Austrian forest avalanche dataset. The 25th percentile of slope steepness for all forest types weighted by case number (N) is 37° and in line with the critical slope of terrain with a canopy cover ≤ 30 % according to the classification tree analysis made by Bebi et al. (2009). Perzl et al. (2015 p. 27) found a value of 35° for the 25th percentile, and of 37° for the 50th percentile on base of a sample of 1432 avalanches which mainly released on terrain of no forest use in Austria. Hence, critical slope gradients of slopes are lower on terrain of no forest use than on terrain of forest use, but the values are close together. As the transition from forest use to other land use may be fuzzy in space and time, thresholds of slope inclination should not be linked to forest types. The (lower) whiskers of the Tukey boxplots indicate slopes which are not statistical outliers of terrain prone to avalanche initiation in forests (Figure 321-1). On terrain covered by Alpine shrubs (AS), in clear-cuts and other blanks (CC&B), in evergreen coniferous forests with a share of Larch trees ≥ 25 % (ELM) and in Larch forests (L) avalanche formation on slopes < 30° is not frequent, but also not a statistical outlier. In deciduous forests and mixed forests (deciduous broadleaved trees and conifers, D&MC) as well as in evergreen coniferous forests (EC) avalanches usually release on slopes steeper than 37°, but also on slopes < 35°.

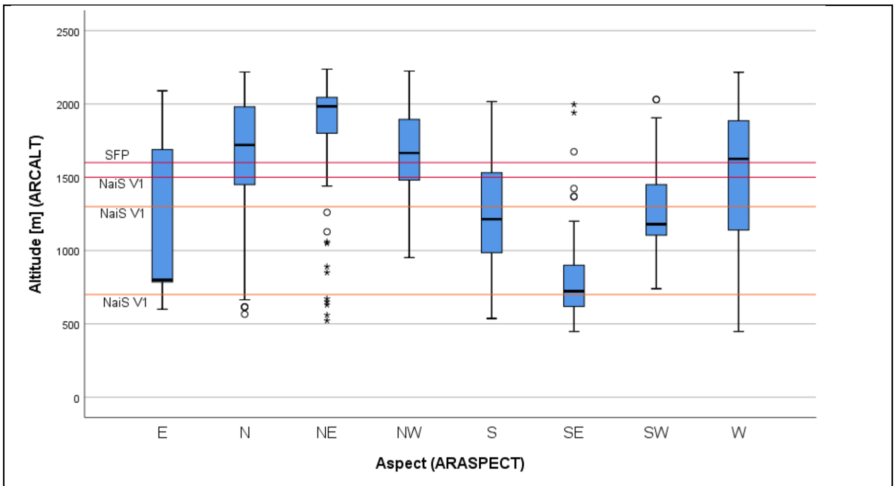
The criteria of NaiS are semi-quantitative and do not provide lower altitudinal thresholds of the terrain prone to avalanche initiation which are applicable in hazard indication mapping. Whereas the previous version of NaiS (Wasser & Frehner 1996 annex 4 p. 5) specifies a concrete lower altitudinal limit - albeit with a considerable range (700-1300 m) - the current version reduces the recommendations to fuzzy ecological terms. Both versions are not in line with the criteria of the Swiss protection forest mapping by spatial modelling (SilvaProtect-CH). According to SilvaProtect-CH, in Switzerland, slopes from 28° to 60° and above lower altitudinal thresholds of 900 m (Northern Alps), 1100 m (Inner Alps) and 1200 m (Southern Alps) are prone to avalanche formation (Losey 2013 pp. 12-15).

The concept of NaiS is from limited logical consistency and completeness, as Larch forests and coniferous forests also grow in lower altitudes and not only in the high montane and subalpine zone. Furthermore, it is not considered that unstocked areas like clear-cuts cannot be assigned to any forest type defined by the tree species composition.

SFP follows the concept of classifying slopes steep enough for snow avalanche release by forest types using the same thresholds as NaiS. Moreover, similar to the table of criteria in the first version of NaiS, SFP mainly locates avalanche protection forests to slopes 1) from 1600 to 2200 m above sea level oriented to Northeast to Northwest (NE-N-NW) and 2) to broadleaved or mixed forests on south-facing slopes below 1600 m in the accompanying text. The first version of NaiS recommends lower altitudinal thresholds of 700 to 1300 m (and south-facing slopes SE-S-SW) for the medium level and of 1500 m (all aspects) for the high level of the protective role (function) of forests. All of these guidelines do not contain information about lower altitudinal limits on east- (E) and west- (W) facing slopes.

The forest avalanche sample of this study does not contain cases from the western Italian Alps, but may reflect the situation in Austria and Switzerland. On the first sight, the distributions of elevations grouped by aspect confirm the NaiS (and also the SFP) criteria (Figure 321-2).

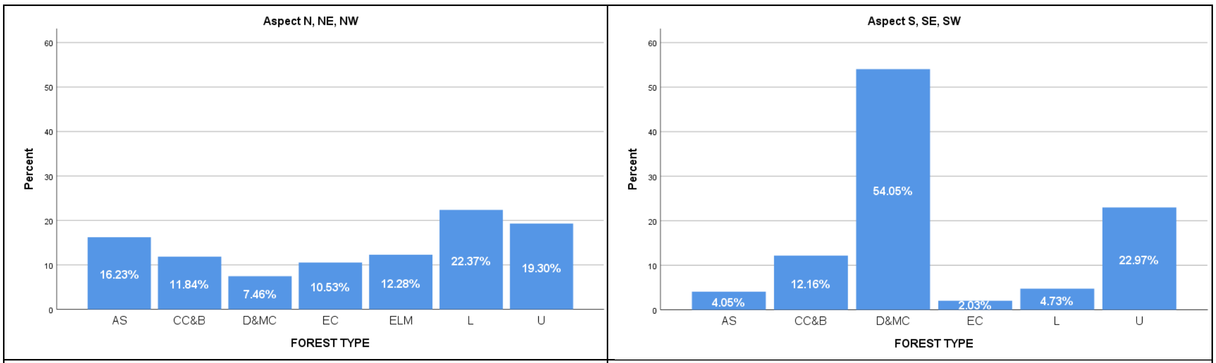
Figure 321-2: Boxplots of elevations of forest avalanche initiations



N =	33	78	70	28	35	46	27	24	∑ 341

Avalanche formation in forest was mainly observed above about 1450 m on north-facing slopes, and below 1450 m on south-facing slopes. Yet, forest management has to keep in mind 1) that the limits of lower outliers are below 700 m also on north-, east- and west-facing slopes, and 2) the bias in these observations. Observations of sites with avalanche initiations are biased by the forest itself and by a varying degree of observability depending on slope orientation. In the montane zone, north-facing slopes are frequently covered by dense (evergreen) coniferous forests with a high protective effect, whereas growth of deciduous forests focus on south-facing slopes. Open larch forests also have their focus on south-facing and on subalpine zones of north-facing slopes. Because of the spatial concentration of settlements and impacts of land use, the forest cover on south-facing slopes often is fragmented. It is therefore difficult to draw conclusions about the influence of the aspect on the hazard potential. Figure 321-3 shows the shares of forest types on observed sites of avalanche initiation grouped by north- (left image L) and south-facing slopes (right image R). Without consideration of samples of unknown forest type (U), deciduous broadleaved and mixed forests (D&MC) clearly dominate forest avalanche occurrence on south-facing slopes, whereas Larch forests (L, ELM), Alpine shrubs (AS) and clear-cuts (CC&B) dominate avalanche formation on north-facing slopes. Therefore, Figures 321-2 and 321-3 rather show the locations of forests and forest types with insufficient protective effect than slopes prone to avalanche initiation.

Figure 321-3: Shares of forest types on observed sites of avalanche initiation grouped by aspect

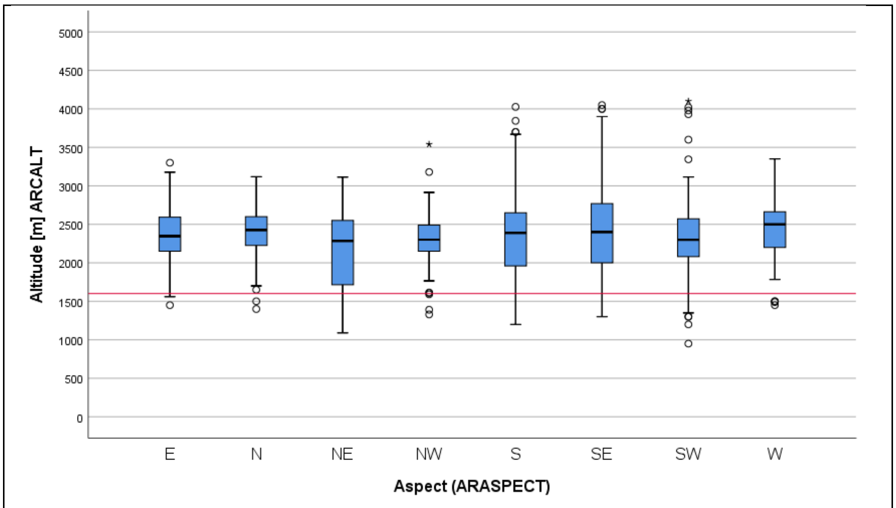


N = 228	N = 148

Inventories of the total avalanche activity (in forested and unforested terrain) are also biased by forest, technical measures and observational issues. We used the subsample of the avalanche cadaster of the Aosta valley in the western Italian Alps to test the hypothesis of the SFP guideline that avalanche release zones are frequently located above an altitude of 1600 m on slopes from NE to NW and below 1600 m on south facing slopes. We selected all dated avalanche hazards and grouped the altitudes of the avalanche formations by aspect. Only 1.3 % of the dated records refer to avalanches triggered by humans artificially and accidentally. Hence, this database mainly reflects the natural avalanche activity.

Avalanche initiation on north-facing slopes focus on slopes higher than 1700 m which is close to the guideline's recommendations (Figure 321-4). However, on slopes oriented to NE, avalanche formation at an altitudinal level of 1090 m is not a statistical outlier. The lower limit of statistical outliers (lower whisker) of all exposures is 1290 m (Figure 321-4).

Figure 321-4: Aosta subsample – Boxplots of elevations of observed avalanche initiations



N =	113	114	164	172	118	179	161	98	∑ 1119
Lower whisker	1560	1700	1090	1765	1200	1300	1350	1784	1290

Observed avalanche releases in the Aosta sample focus to slopes above 2000 m with the exception of NE slopes. Analysis of variances (ANOVA) show high significant inhomogeneity of variances and groups, but only slopes oriented to NE show a tendency clearly different from all other orientations (Table 321-1). Classification of a slope to NE, N or E may be influenced by the observer and slope orientations are scale-dependent and rather fuzzy indicators.

Table 321-1: Aosta subsample – ANOVA of avalanche starting zone elevations grouped by aspect

<table>
<tr><th>ANOVA</th><th colspan="3">Square sum</th><th>df</th><th colspan="2">mean square</th><th colspan="2">F</th><th>p</th></tr>
<tr><td>between groups***</td><td colspan="3">10152606.301</td><td>7</td><td colspan="2">1450372.329</td><td colspan="2">6.922</td><td>0.000</td></tr>
<tr><td>within groups</td><td colspan="3">232772885.122</td><td>1111</td><td colspan="2">209516.548</td><td colspan="2"></td><td></td></tr>
<tr><td>total</td><td colspan="3">242925491.423</td><td>1118</td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>Levee-Test mean***</td><td colspan="3"></td><td></td><td colspan="2"></td><td colspan="2"></td><td>0.000</td></tr>
<tr><td>Levee-Test median***</td><td colspan="3"></td><td></td><td colspan="2"></td><td colspan="2"></td><td>0.000</td></tr>
<tr><td>Welch-Test***</td><td colspan="3"></td><td></td><td colspan="2"></td><td colspan="2"></td><td>0.000</td></tr>
<tr><td rowspan="2">Groups different to (Tukey-HSD, 0.05)</td><td>all</td><td>E</td><td>N</td><td>NE</td><td>NW</td><td>S</td><td>SE</td><td>SW</td><td>W</td></tr>
<tr><td>NE</td><td>NE</td><td>NE</td><td>all</td><td>NE
SE</td><td>NE</td><td>NE</td><td>NE</td><td>NE</td></tr>
</table>

GSM-N, ISDW and GSM-S have a different approach of hazard diagnostic than NaiS and SFP. GSM-N, ISDW and GSM-S distinguish more clearly between the assessment of the basic hazard potential and forests that are prone to avalanche initiation. For this purpose, GSM-N provides a flowchart (a decision tree) and ISDW an elevation matrix. GSM-N and GSM-S refer to external cartographic information (hazard indication maps).

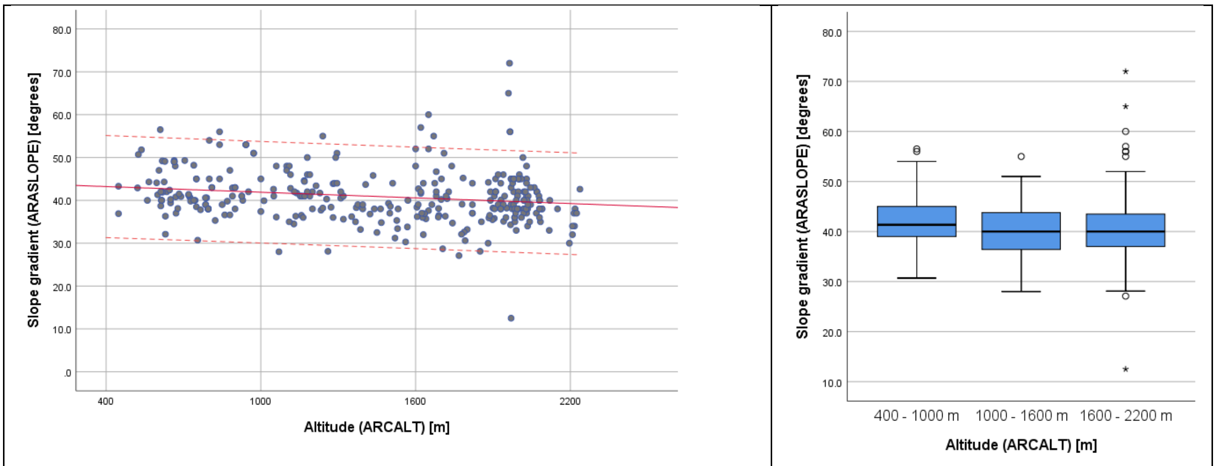
The decision tree of GSM-N starts with the query whether the site is a zone with avalanche activity originating from unwooded area or not. In the case yes, the next decisive question is whether avalanches have already been observed in the forest. If no avalanches have been observed, a sufficient protective effect is assumed (Gauquelin & Courbaud 2006 p. 37). If the observed avalanches stop within the forest, it is assumed that the forest has a limited protective effect, which may require additional construction measures. Otherwise the protective effect is not sufficient.

The purpose of the first junction is clear - a division of the assessment procedure into already active and potential process zones. The information provided is banal (for experts). The procedure avoids to provide methods for the difficult assessment of the avalanche release activity and intensity in unwooded zones as well as for the protective effect of the forest in the transition and deposition zone. This is done by using the observed and obvious avalanche behavior as a criterion. However, the first junction of the decision tree may be already difficult to answer and may implement high uncertainty. The system assumes that all active avalanche zones are known more or less. Avalanche release activity is difficult to observe completely and may change. Active avalanche zones and therefore hazard and damage potentials are not obvious in each case. There are also examples of destructive avalanche hazard events from unwooded and (rather small) release areas where avalanche activity never was observed before.

In case of a wooded potential avalanche release area, the main criterion of GSM-N for a basic susceptibility to avalanche initiation is the slope gradient. According to GSM-N, slope gradients prone to avalanche initiation range from 28° to 55°, and convex terrain breaks promote fractures.

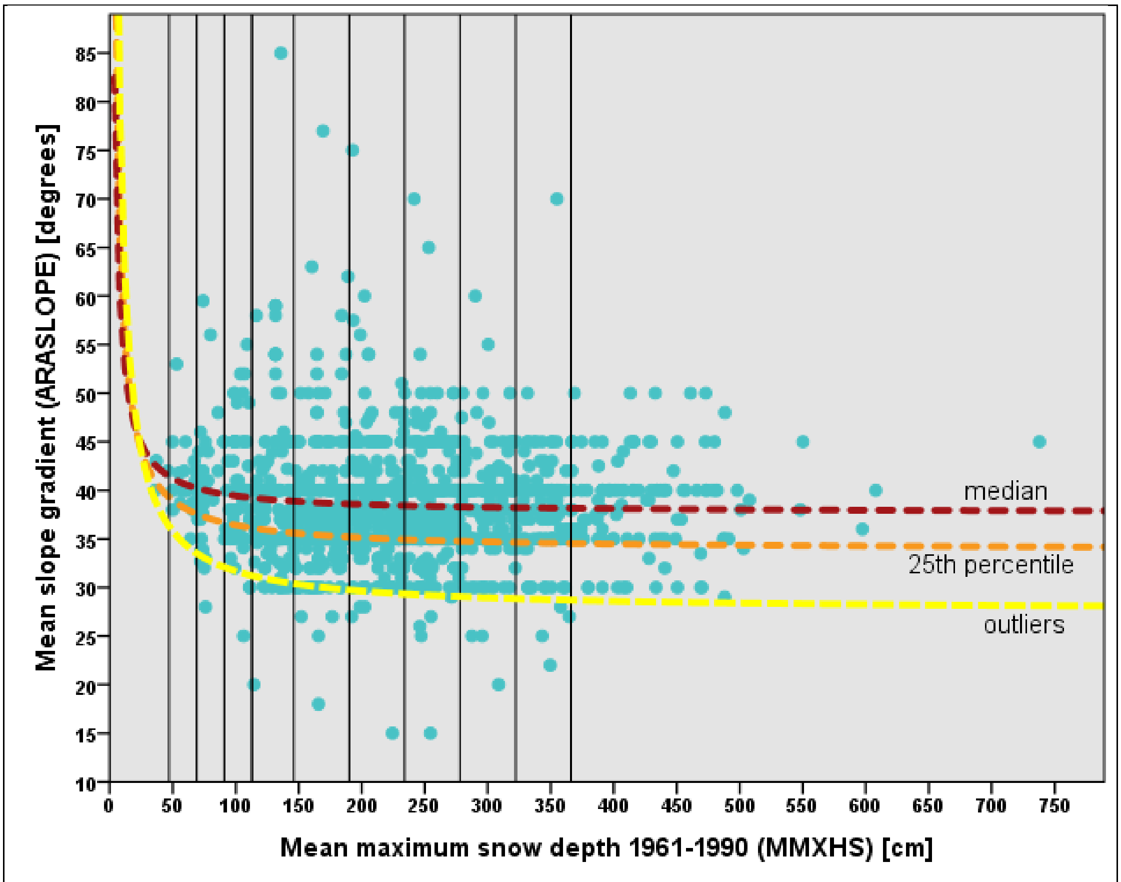
This slope range is frequently used for avalanche susceptibility mapping (Perzl et al. 2015 p. 13, pp. 26-27), as avalanche initiation on slope inclinations smaller than 28° is not frequent and snow accumulation on slopes above 55° is low. These limits cover 97 % of the forest avalanche samples (N = 339). However, a fixed lower limit may also implement an overestimation of the avalanche initiation probability as slope gradients tend to decrease significantly with increasing elevation. Although the correlation of slope and elevation is low, the scatterplot of the forest avalanche sample shows this trend (Figure 221-5 L). Grouping the samples into low, medium and higher altitudes shows a statistically significant higher median, 25th percentile and lower whisker of low than of medium and high altitudes (Figure 221-5 R).

Figure 221-5: Forest avalanche sample - slope vs. altitude



--------	estimated mean	N =	86	75	156
- - - -	95 % confidence interval of prediction	Lower whisker	31	28	27

Figure 221-6: Avalanche initiations in Austria - slope vs. snow depth (Perzl & Huber 2014)



Groups of MMXHS	36-58	58-80	80-102	102-124	124-168	168-212	212-256	256-300	300-344	344-388
Lower whisker of slope	38°	32°	32°	30°	30°	28°	30°	29°	30°	28°

There is a non-linear interdependence of snow conditions and slope inclination independent on the type of land use or forest (Figure 221-6). Perzl & Huber (2014) showed on base of 1432 avalanche hazards observed in Austria that Tukey's hinges and lower whiskers of slope gradients of release areas decrease with an increasing 30-year mean of the winter maxima of snow depth (MMXHS). Smoothing by regression results in a non-linear relation of slope threshold to mean maximum depth of snowpack. MMXHS is an indicator of the climatic susceptibility to avalanche formation (Smith & McClung 1997, Jamieson & Brooks cf. Campbell et al. 2007).

Similar to the approach of NaiS and SFP, the slope query of GSM-N is formally limited to forest use and does not provide information to identify potential release areas of other types of land use. Wooded land in mountainous terrain may be fragmented without clear boundaries to unwooded land. Snow gliding and avalanches from snow gliding are also possible on slopes with slope gradients < 28° with a lower limit of about 25° in case of very smooth, south-facing slopes (Margreth 2016 p. 5). Afforestation of such slopes may be an appropriate eco-engineering alternative to technical measures in order to protect infrastructures. However, consideration of snow movement initiation on slopes < 28° is a question of objectives and risk perception.

Slab fracture formation at (convex) terrain breaks is occasionally cited and used for hazard mapping in literature (e.g. Pfister 1997, Ciolli et al. 1998, Bebi 1999 pp. 74-76) and also mentioned in the SFP guideline. Most literature refer to terrain curvature which influence snow accumulation and stress characteristics of the snowpack (Perzl et al. 2015 pp. 14-18). Strempel et al. (1996) and Suk & Klimánek (2011) did not find a clear relation which lies at the threshold of significance in the model of Bebi (1999). As perception and measurement of terrain breaks as well as of curvature in the field is difficult and subjective, such indicators are only suitable for spatial modelling based on high-resolution digital terrain models.

If the slope gradient is in the range of 28° to 55°, the GSM-N concept distinguishes two cases: 1) the elevation of the slope is ≥ 1300 m, or 2) < 1300 m. In case of an altitude < 1300 m a protective role (function) of forest is assigned to south-facing slopes (SW-S-SE) or to smooth grassland within the range of the slope gradient. The available data did not allow to evaluate the altitudinal threshold of 1300 m for the northern French Alps. However, according to GSM-N, the slopes in the range of 28° to 55° on south-facings or grassland are prone to avalanche initiation without a lower altitudinal limit. That's not plausible, as avalanche initiation depends on a minimum depth of snow cover (Teich et al. 2012 b, Perzl et al. 2015 pp. 10-12) which may be improbable in lowlands.

ISDW provides a matrix to assess the basic avalanche initiation susceptibility of slopes without consideration of hazard observations and forest conditions. The matrix results in an ordinal ranking of the susceptibility (no, low, medium, and high). The main indicators of the basic susceptibility are the 30-year mean of the winter maxima of snow depth (MMXHS) and the slope gradient. The classification on base of these two main criteria is modified by terrain characteristics and the surface roughness of the slope with emphasis on the roughness. Slope orientation to sun or wind is not considered.

The lower altitudinal threshold is a MMXHS of 50 cm which corresponds to an expected 30-year total snow depth maximum of about 100 cm and a 150-year maximum of about 130 cm as well as to a 150-year maximum of 3-day new snow depth of about 80 cm (Perzl & Walter 2012 b) in the mean in Austria. A total snow depth of about > 100 cm to > 120 cm promotes the occurrence of new snow avalanches in forests (Frehner et al. 2005, Teich et al. 2012 b). However, snowpack conditions prone to avalanche initiation out of forests may not differ significantly. Perla & Martinelli

(1976) and Schaerer (1981) state a critical total snow depth of 100 cm in general (Perzl et al. 2015 pp. 12). A second version of ISDW (Perzl 2008) implemented a lower MMXHS limit of 70 cm as a result of discussions with forest engineers (Perzl et al. 2015 p. 12). However, hazard documentations Perzl et al. (2015 p. 28) show a lower limit of avalanche activity at the MMXHS level of about 40 cm. The lower limits of the medium and high levels are 100 cm and 250 cm which correspond to a 30-year expectation of about 180 cm and 410 cm. The basic susceptibility to avalanche initiation increase with increasing classes of slope steepness (25°- 27°, 28°- 34°, 35° - 39°, 40° - 54°, ≥ 55°). The approach does not suggest an upper limit of the slope gradient, as in bedrock hollows of steep rocky terrain ("couloirs") also loose snow avalanches may start (Perzl 2008 p. 557). Avalanche initiation susceptibility is lowered for terrain steeper than 54°. Surface roughness and terrain characteristics shift the susceptibility to avalanche release as a result of snowpack and slope steepness up or down by expert.

The altitude is a more suitable criterion for practical purposes than snow depth, since it can be taken easily from topographic maps. BFW provided a snow depth map from suitable resolution for Austria (Perzl & Kammerlander 2010, Perzl & Walter 2012 b). The lower limit proposed by ISDW fits the avalanche activity in Austria. However, such snow depth maps are not available for the whole Alpine space. A relation of avalanche activity to snow depth limits used by ISDW is not evident for other parts of the European Alps. The ISDW limits of the medium and high hazard level are assumptions. Perzl et al. (2015 pp. 29-30) suggest to use the proportion of wet and dry avalanches to form altitudinal levels of the hazard potential appropriate for forest function mapping instead of forest types. This approach on base of a rather small dataset resulted in considerably lower limits of 80 cm and 150 cm MMXHS for the medium and the high level of the hazard potential. Surface roughness classes of ISDW do not consider woody vegetation in order to keep the concept of separation of site (forest function) and management effects. This further complicates the assignment to the roughness class. Although an influence of other terrain characteristics (Wakabayashi 1971) and of the surface roughness (Feistl et al. 2013, Veitinger et al. 2013, Feistl et al. 2014) on avalanche release probability and size is evident, the semi-quantitative nature of descriptions of terrain and surface properties as well as their small-scale spatial variations and transitions especially in forest terrain may result into considerable intersubjective differences. Measurements of heights of terrain and vegetation irregularities are too complex and expensive in practice.

GSM-S does not include a procedure for estimating the avalanche initiation susceptibility. Similar to GSM-N, the guideline distinguishes between zones of potential and currently active avalanching. GSM-S and GSM-N refer to the national hazard indication maps providing information about the hazard potential and the largest historical extends of observed avalanches per expert. GSM-S does not show an example of these maps and how to use them. Interpretation of hazard indication maps is not trivial.

NaiS and SFP do not clearly distinguish between the basic avalanche potential (the forest function) and the protective effect. They use forest types to assign protective functions to forest sites. This concept is not sensitive to regional situations and to moving climatic and forest conditions. Hence, the concepts of NaiS and SFP are from limited suitability for the determination of the basic hazard potential (for forest function mapping). Susceptibility to snow avalanche formation is primarily determined by the snow conditions (snow depth) and the slope inclination (Schaerer 1981) and not by the tree species composition. The allocation of snow precipitation to slopes of different orientation (by wind transport) and the influence of the slope orientation to sun are medium- to small-scale effects which vary regionally and temporally (Perzl et al. 2015 pp. 19-20). Therefore, it is not recommended to link the basic avalanche initiation susceptibility to the slope orientation like in NaiS (first version), SFP and GSM-N. Only the occurrence of sliding snow movements on smooth slopes < 28° may be limited to south facings. Avalanche initiation is possible on slopes of any orientation if snow depth and slope gradient achieve a critical basic combination. From then on, meteorological factors that vary in time and space as well as forest conditions determine whether an avalanche is triggered. The national guidelines use considerable different lower (and upper) limits of slope steepness prone to avalanche initiation which perhaps reflect national discrepancies in objectives and risk perception. ISDW considers interdependence of snow depth and slope gradient. Only the first version of NaiS and ISDW provide lower altitudinal limits of terrain prone to avalanche initiation which are key criteria for protection forest mapping. Surface roughness is only directly addressed by the Austrian guideline ISDW and by GSM-N.

3.2.2 Snow avalanche: protective effect-related characteristics of forest structure

The main characteristics used by the guidelines to distinguish protective from not protective forests are canopy cover (NaiS, SFP), evergreen canopy cover (GSM-N, GSM-S, ISDW), stem density (SFP, GSM-N, GSM-S, ISDW) and the size (length, width) of gaps (NaiS, SFP, GSM-N, ISDW) (Table 21-1).

Canopy cover

Table 322-1 compares the target values of the canopy cover percent. NaiS and SFP use the canopy cover without consideration of the proportion of evergreen trees (ARTLCC). The protective target value is a canopy cover larger than 50 % without consideration of the slope inclination.

GSM-N, GSM-S and ISDW refer to the evergreen canopy cover (ARTWLCC). GSM-N and ISDW reduce the evergreen canopy cover percent with decreasing slope inclination. The canopy cover criteria of GSM-N are not in line with the hazard indicators, which propose a lower limit of 28° for terrain prone to avalanche initiation. The ISDW targets of evergreen crown cover are coupled by a multiple matrix to targets of stem density and to indicators of the hazard potential missing in the sample data. Therefore, it is not possible to compare them with the targets of the other guidelines directly. However, ISDW assumes a high ("sufficient") protective effect in case of an evergreen crown cover ≥ 45-65 % dependent on slope, and a low (reduced to very low) protective effect in case of an evergreen crown cover < 35 %.

Table 322-1: Snow avalanche – canopy cover targets

	Canopy cover percent of the tree layer (in total TCCP, in winter (evergreen) WCCP)												
	TCCP	WCCP	TCCP	WCCP	TCCP	WCCP				TCCP	WCCP		
	NaiS, SFP targets		GSM-N targets			GSM-S level of protection					ISDW level of protection		
Slope		- - -	- - -			"high"	"medium"	"low"	"no"		"high"	"medium"	"low"
≥ 30°	> 50 %	- - -	- - -	> 30 %	- - -	> 70 %	> 30 %	> 10 %	≤ 10 %	- - -	≥ 45 %	≥ 35 %	< 35 %
≥ 35°	> 50 %	- - -	- - -	> 50 %	- - -	> 70 %	> 30 %	> 10 %	≤ 10 %	- - -	≥ 55 %	≥ 35 %	< 35 %
≥ 40°	> 50 %	- - -	- - -	> 70 %	- - -	> 70 %	> 30 %	> 10 %	≤ 10 %	- - -	≥ 65 %	≥ 35 %	< 35 %

The canopy cover percent may be measured with and without consideration of clearly delimitable gaps. The first version of NaiS refers to the canopy cover as a criterion only in case of diffuse lightened forests (Wasser & Frehner 1996 annex 4 p. 5). The current version of NaiS and the other guidelines give no information how to measure the local canopy cover percent with the exception of ISDW. In ISDW, canopy openings like gaps are included, as the spatial transition from a gap area to the tree matrix may be fuzzy. The perception of the boundaries of a gap may differ individually. Furthermore, the conditions on the gap in winter may be influenced by the surrounding canopy cover.

The canopy cover targets provided by GSM-N refer to Spruce, Fir and Pine forests, whereas in deciduous and mixed forests the basal area or the stem density is used for indication of the protective effect (Gauquelin et al. 2006 pp. 203-204). However, there is no information about the decisive proportion of evergreen species in order to assign forests to evergreen coniferous or deciduous (broadleaved tree species and Larch) or mixed forest.

We calculated the relative frequencies of forest avalanche initiations in forests, which match the canopy cover targets of the guidelines ("Yes" – false classification) or not ("No" – true classification) (Figure 322-1).

The frequency of "Yes" should be small in relation to "No", since this indicates the possibility of a wrong risk estimation due to the use of the guideline. It is important to keep always in mind, that the comparison is biased by the total proportion of stands which match or do not match the criteria. Furthermore, a high target value of the canopy cover percent results into a smaller proportion of "Yes" inevitably. Therefore, the evidential significance of this comparison is limited. This method does not show ideal targets.

The comparison is based on the canopy cover including canopy openings on gap areas. We calculated the validity of the targets on base of the three measurement methods of the canopy cover in the data (Table 21-1), although the multiple statistical comparisons show no significant differences of the evergreen canopy cover (Table 21-3).

The suffix 1 refers to the BFW method (all SLF and BFW data), suffix 2 to canopy estimations in the field (SLF data) and 3 to the SLF-method of aerial image analysis (SLF data) (Figure 322-1).

Figure 322-1: Snow avalanche initiation – validity of canopy cover targets

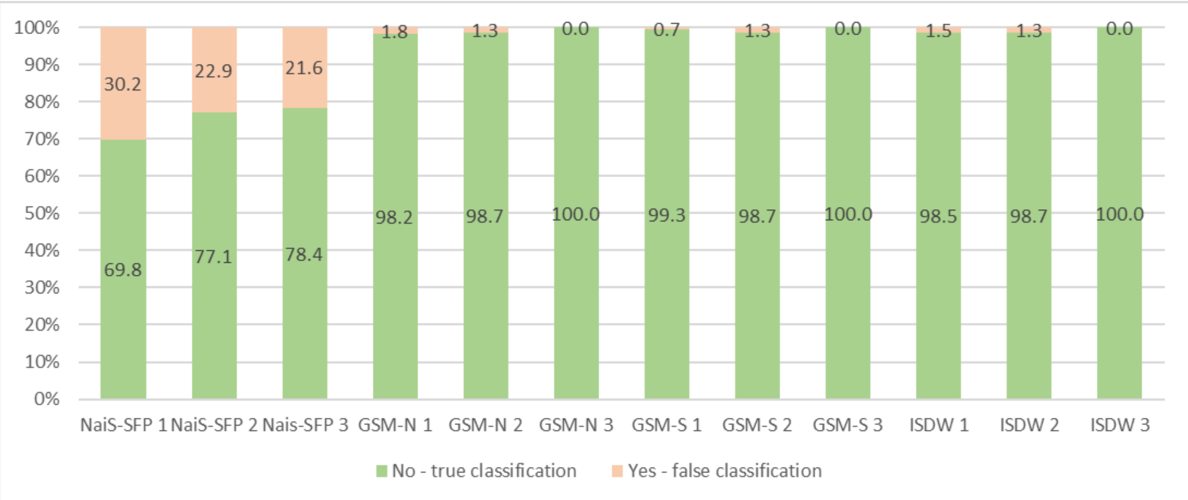
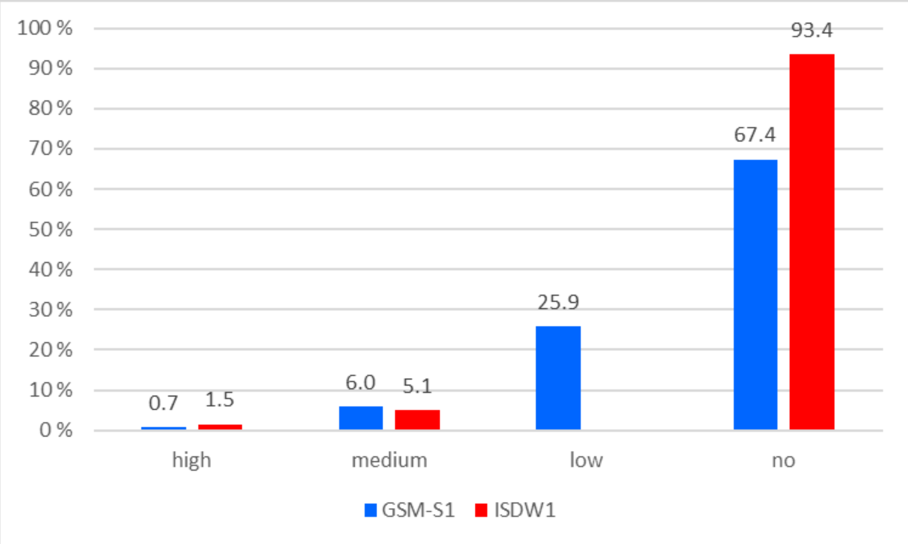


Figure 322-2 shows the percentages of misclassification of forest avalanches per level of protection according to the systems (GSM-S, ISDW), which classify the protective effect of the forest. The classification of observed forest avalanches as forests with "medium" or "low" protective effect may also be considered as misclassifications. Notice that ISDW does not differ the classes "low" and "no" protective effect, as the lowest level of protection is "very low" similar to "no" in GSM-S.

The canopy cover criteria of all guidelines result in considerable higher true classifications ("No") than false classifications (Figure 322-1). The misclassification rates of NaiS and SFP are in the range of 22 % to 30 %, whereas the misclassification rates of the other systems are neglectable.

The percentages of assignment of forest avalanches to a medium level of protection by GSM-S and ISDW are also low and about the same (Figure 322-2). The total misclassification rate of GSM-S and ISDW is therefore about 7 % at the maximum. Both systems result in a high differentiation of the number of forests assigned to the medium or to the low levels (low, no) of protection.

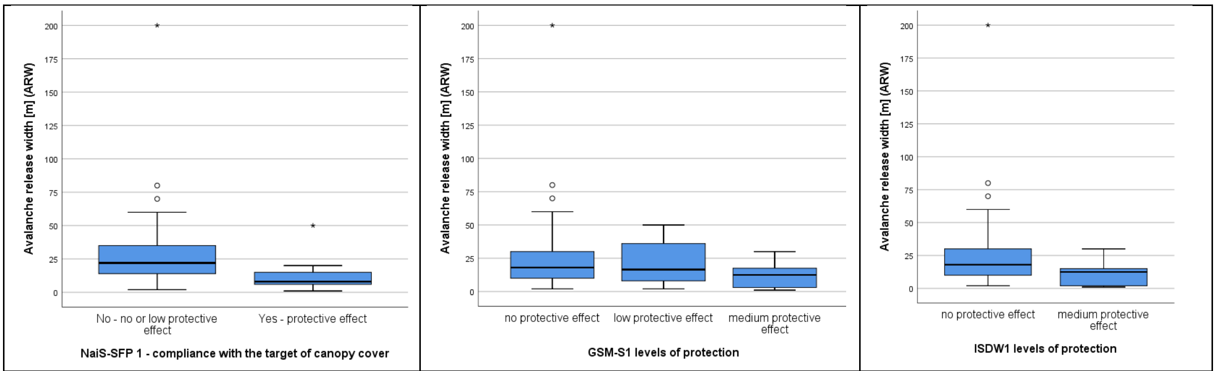
Figure 322-2: Observed forest avalanches – canopy cover: classification of the protective effect



Since a protective forest should also limit the size of an avalanche release, we also analyzed the observed avalanche release widths. The 50 % threshold of the total canopy cover used by NaiS and SFP results in statistically significant lower mean release widths of the forests, which fit this target (Figure 322-3 L).

The classification criteria of GSM-S and ISDW do not lead to statistically significant differences of the mean release widths between the medium or low levels of the protective effect (Figure 322-3 M, R). However, the upper limits of release widths, which are no outliers, also clearly decrease on base of the thresholds.

Figure 322-3: Observed forest avalanches – release widths grouped canopy cover targets



N =	123	37	N =	103	46	8	N =	149	6
Upper whiskers	60 m	20 m	Upper whiskers	60 m	50 m	30 m	Upper whiskers	60 m	30 m

Guidelines, which do not consider the evergreen canopy cover (NaiS, SFP), result in a significantly higher proportion of false classifications than guidelines using the evergreen canopy cover (Figure 322-1). The proportion of false classifications is about one third lower for the SLF-methods of canopy measurements. This is an effect of the sample, as measurements on base of the SLF-method (N = 153) are not available for all examples (N = 295). Furthermore, the proportion of D&MC in the SLF sample is smaller (25.3 %), than in the total sample (30.1 %). This also points to the high indication value of the evergreen crown cover. The higher proportion of false classifications of the canopy cover criteria measured by BFW method may also result from the larger plot size in combination with an influence of gaps.

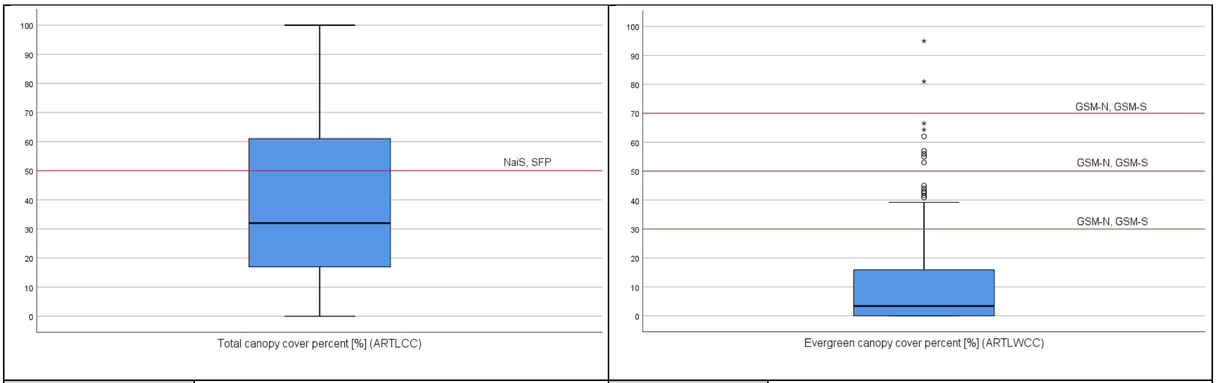
The guidelines, which lower the (evergreen) canopy cover targets with decreasing slope gradients (GSM-N, ISDW) do not show a notable higher amount of false classifications than the other guidelines (NaiS, SFP, GSM-S). The percentages of false classifications of GSM-N and ISDW are twice as high as of GSM-S, but on a neglectable level of about 1.5 %. This points to a high influence of the slope gradient on the probability of avalanche initiation as well as to a relationship of the protective canopy cover and slope inclination. An adjustment of critical values of the canopy cover percent to slope inclination - which is often done intuitively in protection forest management – may be justified and appropriate for practical issues.

Slope inclination is high significantly positively correlated to the total (Spearman-Rho = 0.34) and to the evergreen (Rho = 0.28) canopy cover, but on a low level. This, in combination with the low misclassification rates, indicates that the threshold values used by GSM-N, GSM-S and ISDW may be too high in relation to the real probability of an avalanche initiation in forest. The thresholds used by GSM-N, GSM-S and ISDW (Table 322-1) include most of the statistical outliers (Figure 322-4 R). Furthermore, dense crown canopies may reduce the mechanical stability of the trees and hamper forest regeneration. On the other hand, the authors of these guidelines may also have considered the second function of forest to break down avalanches starting above the assessment unit. A breaking effect requires more dense forests than necessary to prevent avalanche initiations.

The comparatively high misclassification rate of NaiS and SFP is an effect of the deciduous forests, especially of the broadleaved forests (European beech forests) with a small surface roughness. In such stands, with a low proportion of evergreen trees and a rather low stem density, avalanches initiate even when the canopy is fully closed (Konetschny 1990, Meyer-Grass & Schneebeli 1992, Schnetzer 1999, Perzl 2005). Therefore, snow avalanche initiations in forests with full canopy closure (100 %) are not statistical outliers (Figure 322-4 L). The protective effect of deciduous forests is more dependent on stem density and surface roughness than connected to the canopy cover (Pfister 1997, Perzl 2005, Viglietti et al. 2010). In Austria, the susceptibility of these forests to avalanche formation is only conditionally evident from damage reports, since in many of such forests with a high importance of the protective function, artificial snow supporting structures were already established at the beginning of the 20th century, which are often not visible under the crown canopy. Furthermore, decreasing snow depth and snow cover duration in lower altitudes (Günther et al. 1996, Laternser 2002, Bebi et al. 2016, Schöner et al. 2016) may have reduced the susceptibility to avalanche formation. Therefore, it is important to link the basic hazard indication to indicators of weather and snowpack conditions which are sensitive to climatic change.

Figure 322-4 R shows the canopy cover targets and that an evergreen canopy cover percent of more than 39.6 % is a statistical outlier in the total forest avalanche dataset. Most snow avalanches released in forests with an evergreen canopy cover less than 16 %. The canopy cover targets of the guidelines in terms of the evergreen canopy cover percent (GSM-N, GSN-S, ISDW) are high in relation to the canopy cover percentages of observed avalanche formation in forests. The protective canopy cover percent used by NaiS and SFP is within the interquartile range.

Figure 322-4: Observed forest avalanches – canopy cover percent on release areas

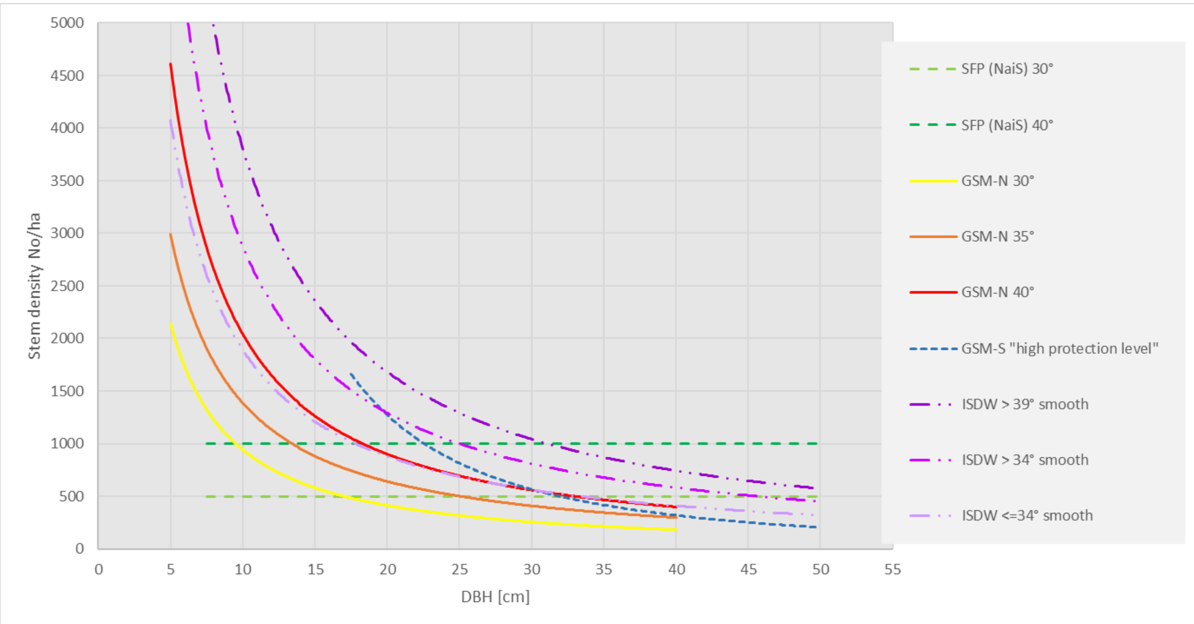


N =	295	N =	285

Stem density

Although there is evidence of an influence of the stem density on the avalanche formation in forests (Pfister 1997, Bebi 1999, Viglietti et al. 2010), stem density is not a NaiS indicator of the snow avalanche protection effect of forests. The stem densities of forests are more difficulty to measure than canopy covers and highly variable on small spatial scales. According to NaiS, the snow cover support by stems usually is not enough to prevent snow avalanche release (Frehner et al. 2005 annex 1 p. 7). However, in the accompanying text, NaiS refers to an effective density of stems with a DBH > 8 cm of 500 per hectare in case of a slope inclination of 30° and to 1000 per hectare in case of a slope inclination of 40°. These stem density requirements are not reduced with an increasing diameter of the trees (Figure 221-5). However, it is difficult to maintain a stem density of 1000 stems with a DBH > 8 cm in mountain forest stands on slopes ≥ 40° permanently. Therefore, we assume that the mention of these stem densities in NaiS is only an indication to a higher importance of the canopy cover.

Figure 322-5: Snow avalanche initiation – guidelines of critical stem densities (deciduous and mixed forests)



Nevertheless, the effective stem densities mentioned in NaiS are indicators of the protective effect in the table of criteria of SFP. They are used as minimum stem densities for terrain steeper than 30° and 40° to achieve an ideal level of protection (Berretti et al. 2006 p. 77). However, the guideline does not provide a clear information on how the targets of stem density relate to the canopy cover target (Table 322-1). Both stand characteristics may be required by the guideline, a canopy cover > 50 %, and a stem density above the target values. The description of the stem density targets refers to the consideration of the canopy cover. Since stand densities of 500 (in mature forests) or 1000 (in young forests) stems per hectares are usually linked to canopy cover percentages of more than 50 %, it is not necessary to use both criteria (stem density and canopy cover) in each case. The canopy cover is the more appropriate indicator of the stand density in case of a clumped spatial distribution of the trees (for example in coppice forest systems) and in evergreen forests. In deciduous high forest and coppice systems, a canopy cover of just over 50 % may not be sufficient to prevent avalanche initiations even in case of a high stem density.

The indicative function of the stem density in relation to the canopy cover and the dependency on the situation are more clearly presented in the GSM-N guideline. According to GSM-N, in deciduous (broadleaved and Larch) and mixed forests only the basal area is an indicator of the protective effect and not the stem density and the canopy cover. The protective basal area is a function of the average stem diameter (DBH) and can be converted into stem densities and vice versa. The guideline provides functions for three slope inclinations which may be minimum requirements for slopes with slope gradients ≥ 40°, ≥ 35° or ≥ 30° (Figure 322-5). The critical stem densities are non-linear functions of the DBH. The guideline does not specify the exact scope of the function lines. However, in case of evergreen forests, the guideline refers to both criteria, to the canopy cover and to functions of the basal area (stem density). A definition of the proportion of evergreen trees, which is necessary to select the basal area function for evergreen conifer or deciduous stands, is missing. Note that the GSM-N functions for deciduous stands shown in Figure 322-5 start at a mean DBH of 5 cm, whereas NaiS and SFP refer to trees with a DBH > 8 cm.

The ISDW matrix to assess the protective effect regarding snow avalanche initiation combines the target requirements for the evergreen canopy cover and the stem density. In case of an evergreen canopy cover in line with the values for the high level of protection presented in Table 322-1, the stem density is not used. In case of a lower evergreen canopy cover, the level of protection is differentiated according to the mean diameter and the stem density of the trees. Therefore, the stem density is more important in case of deciduous and mixed stands with a low canopy cover of evergreen trees. ISDW refers to stems higher than 5 m which is assumed to be equivalent to a DBH of about 5 to 10 cm depended on tree species and site-specific yield of growth. The stem density targets of the high level of protection in case of an evergreen crown cover smaller than 35 % vary from 8000 (thicket and pole stage) to 300 stems (large-sized timber) as a non-linear function of the DBH (Figure 322-5). The critical stem densities also depend on the basic hazard susceptibility. As the basic hazard susceptibility of the ISDW concept is also an issue of other factors than only the slope inclination (e.g. snow depth, semi-quantitative field estimates of surface roughness), a direct comparison with the stem density targets of the other guidelines representing the system is not possible. Similar to the canopy cover targets, we assumed no influence of the snow depth and a very smooth surface to compare these stem densities with the other guidelines.

GSM-S also refers to the basal area (stem density) in case of forest stands, which are not composed from evergreen tree species. However, a definition of the decisive proportion of evergreen species at the junction of the flowchart is missing too. The stem density (or basal area) targets are not linked to slope inclinations like in SFP and GSM-N. They refer to trees with a diameter (DBH) > 17.5 cm. According to GSM-S, a basal area of > 40 m²/ha (> 1663 stems/ha in case of a DBH of 17.5 cm) provides a high level of the protective effect. A basal area of 25 m²/ha (1039/ha) is the boundary between the medium and the low class. Basal areas smaller than 10 m²/ha (417/ha) do not prevent avalanche initiation. In Figure 322-5, we show the GSM-S stem densities instead of the basal area corresponding to an increasing DBH because of forest growth.

Notice that the curves shown in Figure 322-5 refer to the "best or sufficient" (high) level of snow support which depends on the slope according to SFP (NaiS), GSM-S and ISDW, but not according to GSM-S. Only the curves for deciduous and mixed forests are presented. If the stem density of a forest stand lies under the respective curve, the forest stand does not fully prevent an avalanche release. The guidelines assume different minimum diameters (DBH) of trees effective in support of the snow cover from 5 cm (GSM-N) to 17.5 cm (GSM-S). Therefore, recommendations on basal areas and stem densities refer to different elements of the stands. The definition of the critical values of the stem density according to GSM-S implies that trees with a DBH smaller than 17.5 cm do not contribute to the protective effect. This is not plausible and a logical error in the flowchart, as such trees may be more than 10 m high. However, a critical basal area is more simply to applicate than a DBH – stem density function, since it is just necessary to measure the basal area by angle count sampling and to estimate the dominant DBH.

As the stem densities in the SLF sample of forest avalanches are grouped in DBH > 6 cm and DBH > 16 cm, the count of true and false classifications does not reflect the guidelines' criteria exactly. Figure 322-6 shows a higher percentage of false classifications by GSM-N, GSM-S and ISDW in relation to the false classifications on base of the evergreen canopy cover (Figure 322-1). The false classification on base of the stem density criteria used by SFP (NaiS) is considerably smaller than on base of the canopy cover. This may also indicate that the stem density explains the susceptibility to snow avalanche formation especially in deciduous forests.

Figure 322-6: Snow avalanche initiation – validity of stem density (basal area) targets

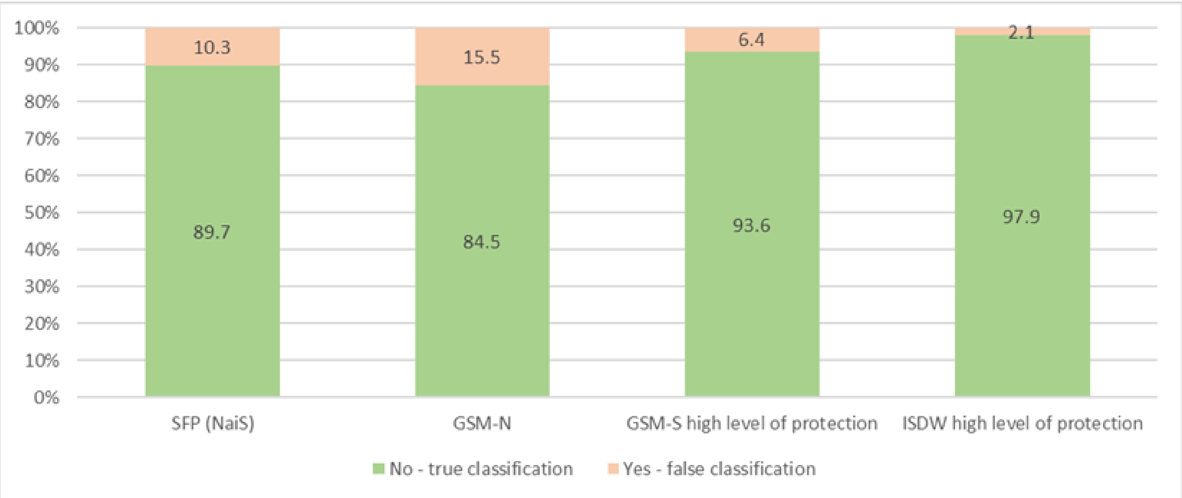
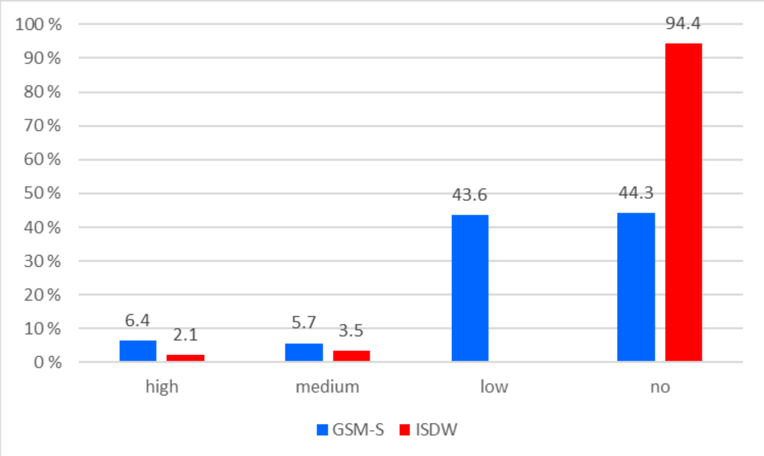


Figure 322-7 indicates a low discriminative power of the basal area criteria used by GSM-S. The proportion of forest avalanches assigned to the "low" and to the "no" classes are almost equal in size. The percentage of hazard events in the "medium" class is lower than in the "high" class on a comparable level of share. On the understanding that the assignment to the "medium" (or even to the "low" class) is a misclassification, the false classifications rise to 12.1 % (or to 55.7 %).

The discriminative power of the ISDW criteria is also limited, since the percentages of the "high" and the "medium" class do not differ considerably. The difference of the "medium" to "no protection" classification may also be to high considering the rare occurrence of avalanche formation in forests.

Figure 322-7: Observed forest avalanches – stem density: classification of the protective effect



One of the first concepts to calculate the stem densities necessary in order to prevent avalanche formation is from Ishikawa et al. (1969). The critical stem densities for trees with a DBH of 5 cm according to Ishikawa et al. (1969) range from ~ 580/ha (slope inclination 31°) to 21800/ha (slope inclination 55°). Salm (1978 p. 172) calculated 1000 to 2000 trees/ha for steep slopes and 300 to 500 trees/ha for less inclined terrain. Saeki & Matsuoka (1970) proposed stem densities from 200/ha to 900/ha in broadleaved forests to prevent ground avalanche formation. Findings of Meyer-Grass & Schneebeli (1992) range from 1100 stems (DBH > 16 cm)/ha (slope 50°) to 100/ha (slope 30°) for broadleaved forests. Pfister (1997) calculated critical values of stem densities of broadleaved and mixed forests with a DBH > 16 cm from ~3300/ha (slope inclination 50°) to ~100/ha (slope inclination 30°). The approach made by logistic regression with a threshold of the empirical failure probability of 50 % is based on the SLF sample of forest avalanches with a control sample (Meyer-Grass & Schneebeli 1992). The calculation does not consider the diameter of the mean basal tree, but the gap widths in terms of maximum tree spacing. Hence, these results are difficult to interpret. They point to an influence of the density of the stocking surrounding the gap rather than to critical stem densities in case of a more or less homogeneous spatial distribution of the trees. In case of a maximum tree distance of 10 m, the critical stem densities vary from ~1200/ha (slope inclination 50°) to ~150/ha (slope inclination 30°). Perzl (2005 p.95) calculated stem densities supporting a snow cover with a depth of 2 m for different forest stand types on base of the mechanical approach of Salm (1978). The stem densities range from about 300/ha (slope 30°) to 3000/ha (50°). Breien & Høydal (2013) calculated critical stem densities of about 2000/ha (DBH = 5 cm, slope = 30°) to 10000/ha (DBH = 5 cm, slope = 45°). The calculation is based on mechanical models (Salm 1987, Margreth 2007). Their results are in the range of the critical values proposed by ISDW which base on the same approach.

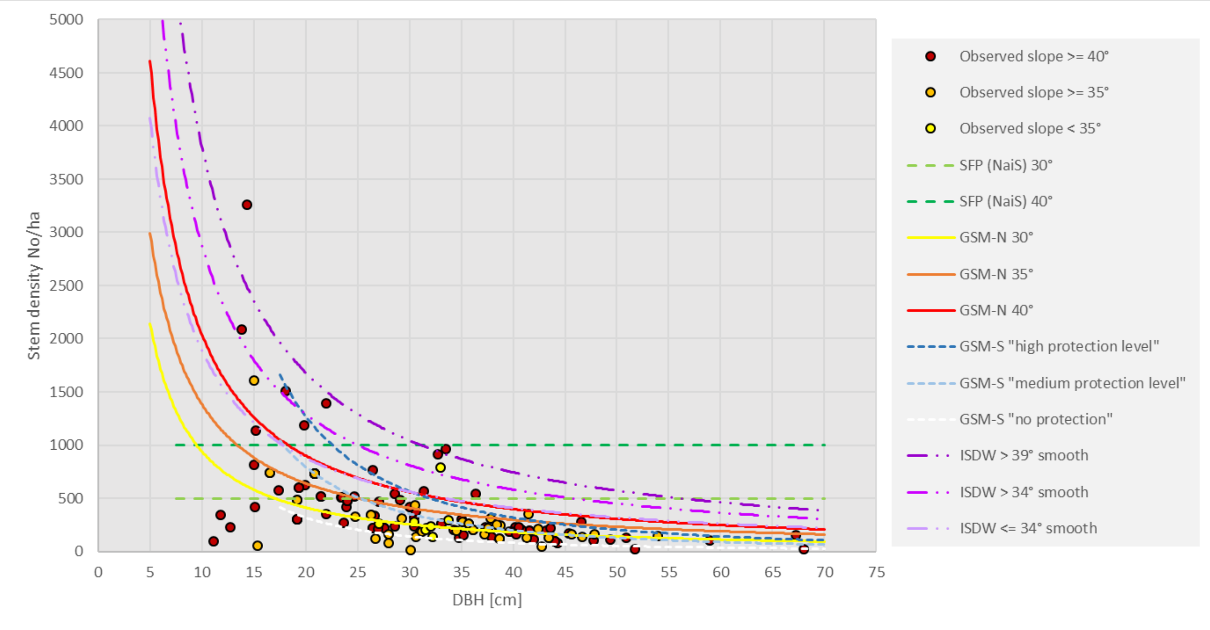
The misclassification rates on base of the stem density of all guidelines might be in an acceptable range (Figure 322-6). GSM-N shows the highest rate of false classifications, as the curve for slopes < 35° result in too low critical stem densities and is not able to differentiate forest avalanches on terrain flatter or steeper than 35°.

The discriminative power of the curve for the "no protection" class of GSM-S also delivers too low critical stem densities, as most of the forest avalanches occurred at higher stem densities (Figure

322-8). However, avalanche initiation at stem densities smaller than 150/ha may therefore not be usual in forests, as the proportion of broken stands and blanks is low and there is often a higher surface roughness of blanks than under the canopy covers.

ISDW resulted in the lowest percentage of false classifications. However, Figure 322-8 shows that the low level of false classifications is an effect of the high critical stem densities in relation to the sample.

Figure 322-8: Observed forest avalanches versus guidelines of critical stem densities



There are few reports in literature on avalanche release in forest stands with stem densities higher than 500 to 1000/ha.

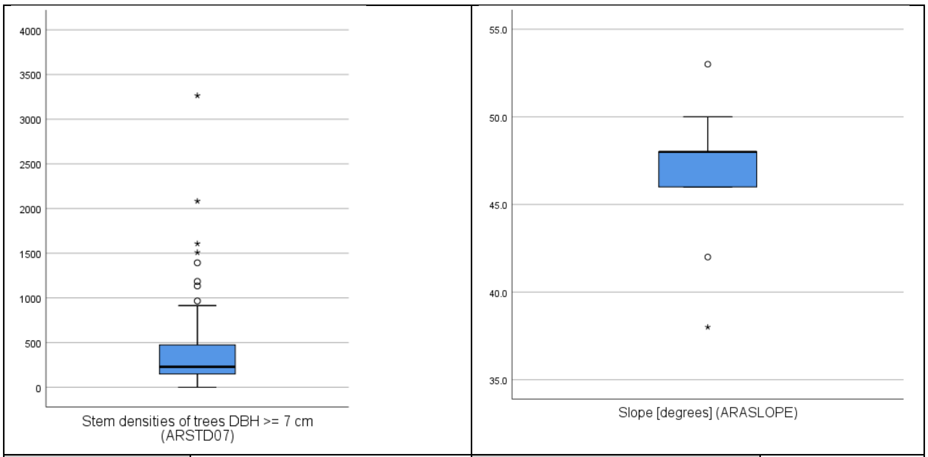
Breien & Høydal (2013) reported an avalanche release triggered by skiers in a Birch forest with a stem density (DBH ≥ 5 cm, h > 2 m) of 7600/ha.

Konetschny (1990 p. 158) reported a snow avalanche release in a broadleaved forest with a stand density of 789/ha (DBH > 7 cm) and a mean slope inclination of 28°. Hence, a critical value of 150/ha may be rather too small in order to support the snow cover in case of a smooth ground surface and snow cover conditions favorable for avalanche initiation. Konetschny (1992 p. 158) also reported an avalanche release in a mixed forest with a stand density of 1607/ha (DBH > 7 cm, slope 38°).

Perzl et al. (2012 c) documented an avalanche release in a steep closed mixed forest with smooth terrain and a mean stem density of 1200/ha (DBH ≥ 7 cm, slope 42°). Under consideration of the snags, the stem density was 1393/ha. The highest stem density in the SLF dataset is 3264/ha (DBH > 6 cm, slope 48°).

Stand densities of more than ~900/ha are statistical outliers in the data (Figure 322-9 L) and limited to mixed and broadleaved forests on very steep slopes (Figure 322-9 R).

Figure 322-9: Observed forest avalanches – stem densities and slopes of densities ≥ 900/ha



N =	155	N =	9

The GSM-N stand density curve for slopes ≥ 35° clearly discriminates the stem densities necessary to prevent avalanche initiation in terrain of a slope inclination < 40° from the stem densities, which only enable avalanche releases in steeper terrain. The GSM-N stand density curve for slopes ≥ 40° differs from the upper outliers of the statistic. These stand density requirements are almost identical to the curve of the "no protection" level used by ISDW.

Size of gaps or blanks

As the spatial distribution of the trees may vary considerably, the "gap" concept was introduced to consider larger canopy openings and larger distances between the trees. The definition of the size of critical canopy openings is important for the management of forests with an object-protective function. Forest regeneration may be hampered by too small canopy openings. Small canopy openings also place higher demands on felling and logging technology.

All guidelines except GSM-S refer to the critical width and length of canopy openings like clear-cuts (Table 322-2). However, none of the guidelines defines exactly in terms of a technical guideline how to measure the width and the length of a gap. The gap length is measured in flow direction but may refer to the inclined or to the projected distance. The terms used by the guidelines and a comparison with the scientific basics indicate that the guidelines refer to the inclined length. The critical gap lengths recommended by NaiS (and SFP) are identical to the inclined lengths calculated by Burkard (1990, cf. Kaltenbrunner 1993 p. 78), who used the approach of de Quervain (1978). De Quervain (1978) also referred to the inclined gap length. The gap lengths in the forest avalanche database (ARLGB, GAPLENGTHSLF, Table 21-1) are the planar distances. In order to compare them with the critical values, we reduced the critical values to planar lengths without interpolation of slope gradient classes.

Table 322-2: Snow avalanche – critical gap sizes in forest covers

	NaiS (minimum)				SFP (minimum)			GSM-N						GSM-S		ISDW		
Slope	Length		Width		Length		Width	Length		Width	Length		Width	Length	Width	Slope	Width	
			CF	D&MC				EC		EC	D&MC						EC	D&MC
≥30°	≥60 m	or	≥15 m	≥5 m	≥60 m	or	≥15 m	>1.5h	or	≥0.75h (?)	>1.5h	?	≥ 15 m	- - -	- - -	≤28°	>55 m	>30 m
≥35°	≥50 m				≥50 m									- - -	- - -	>28°	>45 m	>25 m
≥40°	≥40 m				≥40 m									- - -	- - -	>34°	>35 m	>20 m
≥45°	≥30 m				≥30 m									- - -	- - -	>39°	>25 m	>15 m
																>44°	>15 m	<10 m
CF/EC = coniferous/evergreen forests, D&MC deciduous (broadleaved) and mixed forests, h = (mean) stand height [m]																		

Recommendations of NaiS and SFP in Table 322-2 show the "minimum requirements" regarding gap lengths and widths. The "ideal gap lengths" of NaiS and SFP are also identical and mostly 10 m shorter within a range of 50 to 25 m.

According to NaiS, SFP and GSM-N, the gap length is crucial in order to prevent avalanche initiation. If the gap length is smaller than the critical length no avalanche propagation is probable. The critical gap lengths vary depending on the slope inclination. The critical gap lengths are linked to the gap widths via a logical "or"-condition. If a gap is longer than the critical length, a limitation to the critical gap width is recommended. Nevertheless, Angst (2000 p. 27) interpreted an "and"-condition in the Swiss guideline for management of forests damaged by storm which was changed to "or" in the next version (BAFU 2008 p. 42). The recommendations on critical widths of NaiS and SFP vary.

According to NaiS, the critical width is different in coniferous (15 m) and in deciduous broadleaved forests (5 m) (Table 322-2). However, a critical width of 5 m is not possible by definition, as gaps are canopy openings of 10 m width at least (Frehner et al. 2005 annex 9 p. 2). Therefore, to calculate true and false classifications, we replaced 5 m by 10 m. A gap with a width or a length of 5 m is very small, and it is difficult to regenerate forests with such small canopy openings.

SFP does not differ coniferous and deciduous broadleaved (and mixed) forests. The critical value of the gap width is 15 m for both.

The recommendations of GSM-N concerning gap sizes are difficult to interpret. They separate gap width and length targets for evergreen forests and deciduous forests (including Larch forest and mixed forest) (Gauquelin et al. 2006 pp. 203-204). The recommended gap lengths and widths are in relation to the (mean) height of the surrounding trees. According to GSM-N, a gap length of more than one and a half times of the mean tree height (1.5h) promotes avalanche formation in evergreen forests. In case of such a gap, the guideline also refers to the gap width. However, there may be a logical error of the Boolean operator presented in the guideline. The recommended gap width in this case is only valid for a length of exactly 1.5h (the Boolean operator is "=" and not ">") (Gauquelin et al. 2006 p. 203). This just may be a misprint. Therefore, the recommended gap width in case of gaps longer than 1.5h is smaller than 0.75h (Table 322-2). The same inconsistency with an operator is presented in case of deciduous forests. The gap length should not be smaller than (<) 1.5h, but equal to (=) 1.5h. This might be appropriate for forest regeneration, but not for prevention of avalanche formation. We also assume a typographical error. The linkage to the gap width is not defined with a Boolean operator and might be an "and" or an "or" condition. In case of deciduous forests, the gap width target does not depend on the mean stand height. The gap width should be smaller than 15 m, whereas NaiS recommends 5 m. This means that depending on the stand height in evergreen forests, the critical gap width proposed by GSM-N may be smaller than in deciduous forests. This is not plausible. Gap length and gap width recommendations of GSM-N do not consider the slope inclination but refer to "steep" terrain. We calculated the inclined gap lengths for comparison of the gap lengths in the forest avalanche sample with the critical values in terms of tree heights. Hence, we adapted the critical gap lengths of GSM-N to the slope indirectly.

The recommendations of the ISDW concept are limited to the gap width (Table 322-2). The critical gap widths vary from 55 m to 10 m depending on the slope gradient and the forest type.

As none of the guidelines clearly communicate a proportion of tree species to differ coniferous from deciduous (broadleaved) and mixed forests, we defined coniferous forests with a proportion of coniferous trees of at least 75 %. ISDW refers to stands dominated by evergreen and deciduous tree species. Hence, we used a threshold of the proportion of evergreen trees of ≥ 50 %. Figure 322-10 and Figure 322-11 consider the canopy openings of at least 10 m width and length. Gaps in young growth are excluded for NaiS and SFP targets in analysis, as an area covered by young growth is a gap according to NaiS. Figure 322-10 refers to the combination of gap length and gap width targets. Figure 322-11 shows the classification results for critical lengths and widths separately.

Figure 322-10: Snow avalanche initiation – validity of gap size targets

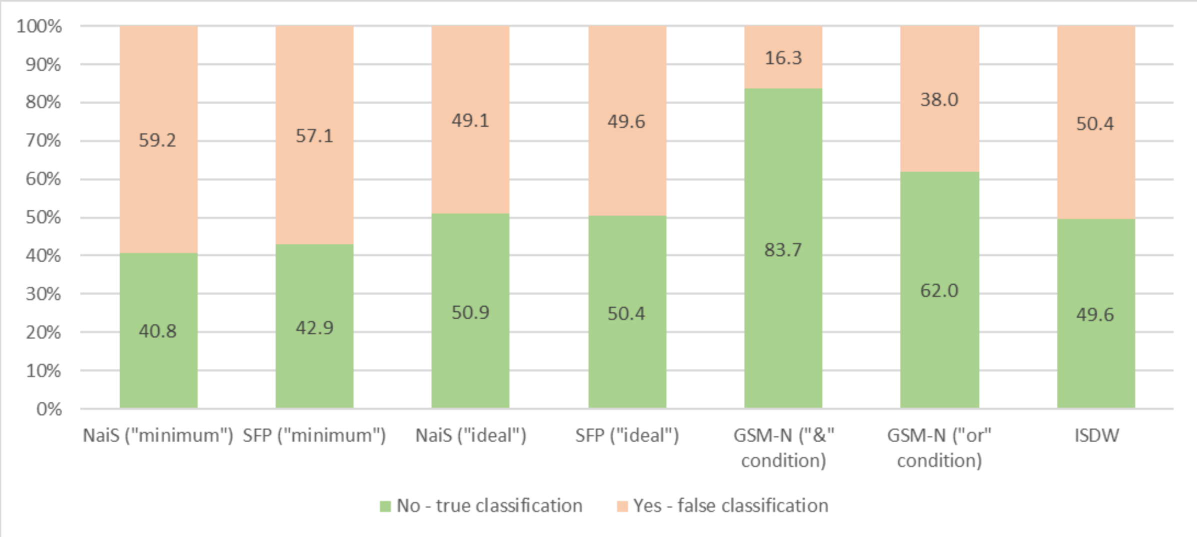


Figure 322-11: Snow avalanche initiation – validity of gap length and width targets

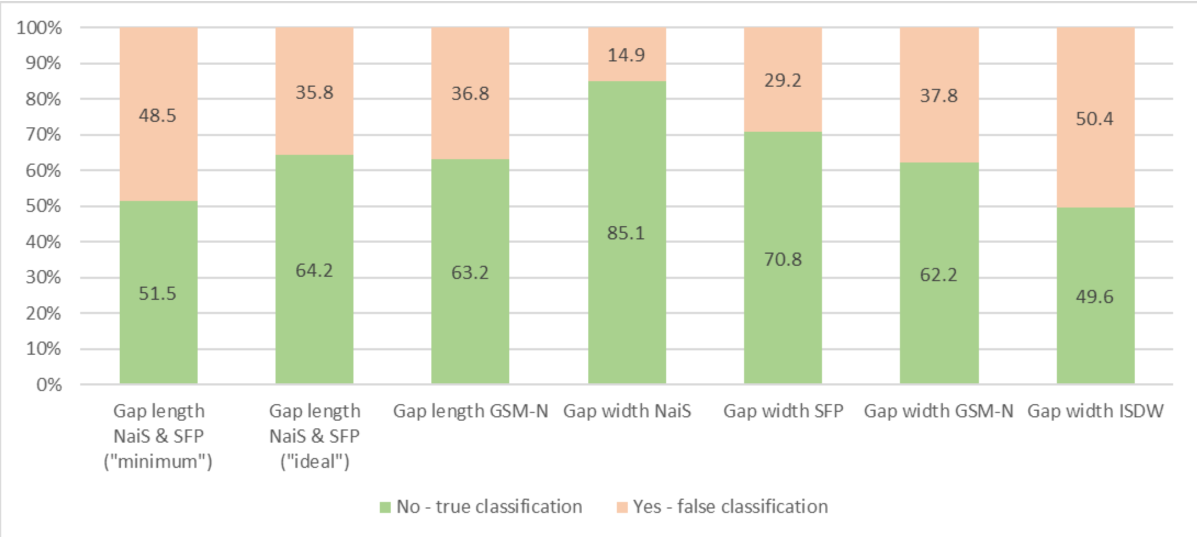


Figure 322-10 and Figure 322-11 show that the gap size targets recommended by the guidelines result in considerable high amounts of false classifications in the range of about 16 to 60%. The "ideal requirements" of NaiS and SFP show about 7 to 10 percent points lower false classification rates than the "minimum" requirements (Figure 322-10). However, these differences between a "very high" and a "sufficient" level of protection and respectively the increase of the reliability of assessment are rather small.

The lowest and small false classification rate of 16.3 percent of the GSM-N approach is an effect of the "&"-condition and of the small critical gap width for deciduous forests. In case of an "or"-

condition the false classification is more than twice as high (Figure 322-10). The "&"-condition is more restrictive and may complicate silviculture.

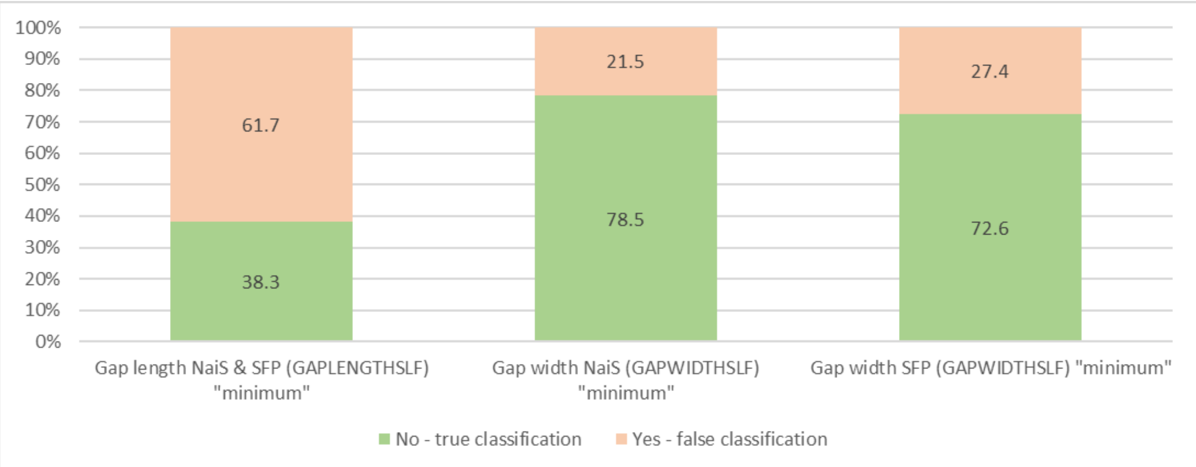
Especially the gap length is not able to indicate the possibility of an avalanche formation in forest (Figure 322-11). The false classification percentages of the critical values of the gap length are higher than for the gap width. The gap length indicator of NaiS results in false classification rates of about 36 to 49 %, whereas the false classification rate of the gap width is about 15 % (Figure 322-11).

The concepts, which do not define the critical gap width depending on the slope inclination (NaiS, SFP, GSM-N), result in considerable smaller false classification rates than ISDW (Figure 322-11).

The combination of gap lengths and widths lowers the results in relation to the results of the gap width and length indicators viewed separately because of error propagation. A differentiation of the critical gap width according to the tree species composition (NaiS) does not improve the final classification result. The classification results are only satisfying if the critical gap width is set very small. Therefore, the result of the gap width concept of NaiS is better than the result of SFP, GSM-N and ISDW (Figure 322-11).

Since there are statistically significant differences of gap and species mixture measurements using the SLF and the BFW method (Table 21-4), we calculated the classification rates for the critical values of the NaiS and the SFP concept on base of the SLF field measurements of the gaps and of the tree species composition. We again limited the samples to minimal (planar) gap widths and lengths of 10 m, and we excluded gaps in young growth. The statistics show similar results as for gap measurements using the BFW method: a high false classification rate of the gap length targets, and less false classification rates of the gap width targets (Figure 322-12).

Figure 322-12: Snow avalanche initiation – SLF data: validity of gap length and width targets



In order to detect an influence on avalanche propagation, we compared the observed runout lengths in cases of compliance or non-compliance with the critical gap lengths recommended by NaiS and SFP. The mean runout length of avalanches from gaps, which fit the gap length targets, are about 50 m shorter than mean runout lengths of avalanches from not recommended gaps (Table 322-3). However, the means do not differ statistically significant.

Table 322-3: ANOVA of avalanche runout lengths grouped by compliance to gap length targets

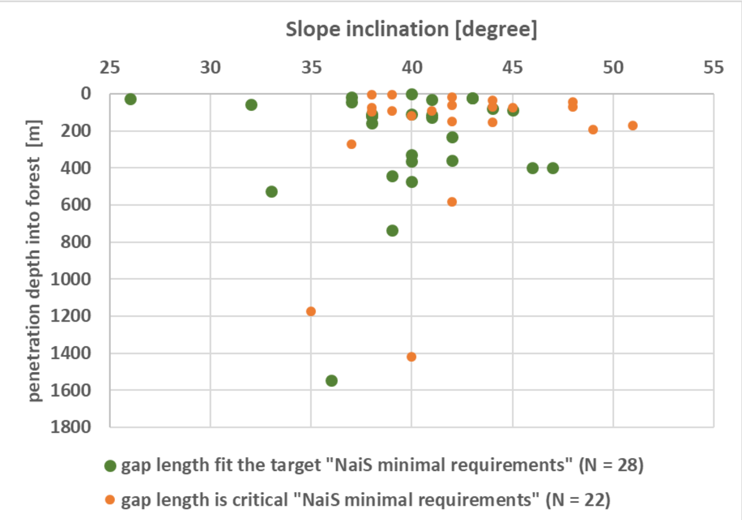
Group	N	mean	min	max
Not compliant with NaiS and SFP targets	29	317.85	20.0	1435.0
Compliant with NaiS and SFP targets	59	268.94	11.1	2140.0

ANOVA	Square sum	df	mean square	F	p
between groups	46503.845	1	46503.845	0.353	0.554
within groups	11330229.912	86	131746.859		
total	11376733.757	87			
Levee-Test mean					0.831
Levee-Test median					0.978
Welch-Test					0.550

The guidelines NaiS, SFP and GSM-N assume that limiting the length of cut blocks in the direction of flow will reduce the probability of avalanche initiation as well as the avalanche propagation. The assumption and the critical gap lengths base on physical calculations (de Quervain 1978, Burkard 1990 cf. Kaltenbrunner 1993 p. 78, Gubler & Rychetnik 1991). The data of the forest avalanche sample show no influence of the recommended critical gap lengths on the probability of avalanche release. Hence, the gap concepts result in a considerable high amount of false classifications. The influence of the gap length on the avalanche runout length is statistically not significant. The reduction of the avalanche propagation is not a primary question of the gap length in the avalanche release zone, but dependent on terrain and forest conditions along the total flow path.

The critical gap widths result into a considerably higher amount of true classifications than gap lengths. This is in line with literature. Konetschny (1990) and Meyer-Grass & Schneebeli (1992) analyzed the dependency of avalanche formation in forests on forest characteristics. Although they included gap lengths, they do not mention any discriminative power of the gap length, but only of the gap width. Feistl et al. (2014 b) compared observed and calculated avalanche release lengths (slab + stauchwall lengths) with the critical gap lengths proposed by NaiS (SFP). They conclude that stauchwall formation and avalanche propagation is only hindered by the critical gap lengths of NaiS in cases of low slope inclinations and rough ground surfaces. Perzl (2019 b) presented that the depths of penetration of avalanche releases in forests into the forest below the release area do not differ clearly depending on the critical gap lengths used by NaiS and SFP (Figure 322-13, Perzl (2019 b) modified).

Figure 322-13: Penetration depth of forest avalanches grouped by gap length targets



The lower false classification rates of the critical gap widths of NaiS (10 and 15 m) and SFP (15 m) in relation to the rates of GSM-N and ISDW result from these small permitted widths of cut blocks, which may be difficult to maintain in practical mountain forest management.

Laatsch (1977) mentioned an increasing critical gap width with decreasing slope inclination. Although the avalanche release probability clearly increases with an increasing slope inclination, the results of Meyer-Grass & Schneebeli (1992) and of this study do not indicate that larger critical gaps are not susceptible to avalanche initiation in case of lower slope angles. There may be a crucial influence of the surface roughness and of the snow depth, but all guidelines except ISDW do not consider this in the assessment procedures.

Combination of protective-effect related forest characteristics

Most of the guidelines do no define clearly how to combine the indicators. Definitions are missing at junctions of the assessment procedures. Assumptions must therefore be made to assess the protective effect of the forest by combination of the indicative forest characteristics. We limited the combination to the differentiation of a "high" and a not sufficient protective effect.

Our assumptions for NaiS and SFP follow the first version of NaiS (Wasser & Frehner 1996) and BUWAL (2008 p.42): the canopy cover targets are only valid for stockings without a clearly delimitable gap or blank; the gap targets refer to gaps and blanks without consideration of the canopy cover (within and around the gap). This sounds banal and logical but is not described in the current guidelines. We did not consider the stem density targets of NaiS and SFP. In case of gaps within young growth, we set the value of the canopy cover target.

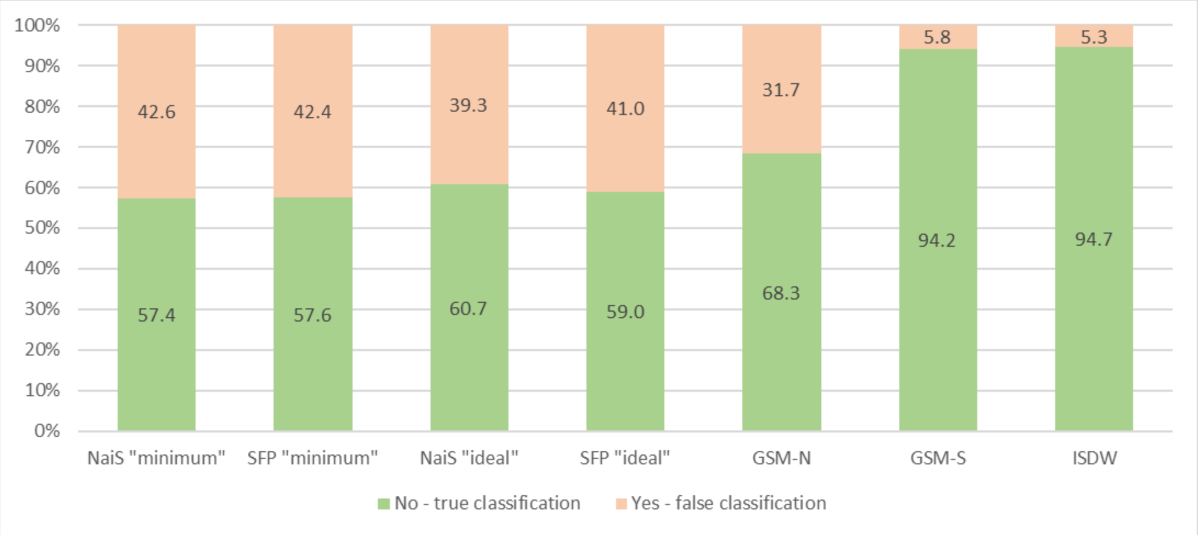
We have assumed that in the system of GSM-N the gaps should also be assessed separately from areas without gaps. The assessment procedure of GSM-N includes gaps within young growth. We used a proportion of ≥ 75 % to differ evergreen and deciduous forests. As the linkage of the gap width and the gap length targets is not clear ("&" or "or", Table 322-2), and the "&"-condition is very strict, we decided only to use the "or"-condition. In case of evergreen forests, we only considered the canopy cover target (Table 322-1), otherwise the stem density targets (Figure 322-5).

As a definition for this junction is missing in GSM-S too, we also used a proportion of ≥ 75 % to differ evergreen and deciduous forests. The further procedure is clearly described by the flowchart in Ladier et al. (2012 p. 33).

For an exact representation of the ISDW approach, information about site characteristics such as the surface roughness and the occurrence of lying deadwood in gaps is missing in the data set in an appropriate form. The ISDW concept uses a completely other combination of canopy cover, stem density and gap targets than NaiS, SFP and GSM-N. The protective effect is first determined with the critical values for the canopy cover and the stem density using the combination matrix. Secondary, if the gap width is critical, the result of the combination matrix is lowered to "no" or to a "medium" protective effect.

Figure 322-14 is limited to the question of a high (sufficient) or not high (medium or low) protective effect. The "ideal requirements" of SFP do not consider stem densities since the guideline gives no clear information in terms of a Boolean operator how to combine them with the critical values of the canopy cover.

Figure 322-14: Snow avalanche initiation – validity of the combined targets of forest characteristics



The classification results according to the "minimum" and "ideal" requirements of NaiS and SFP differ only slightly (Figure 322-14). Therefore, this differentiation is not effective.

The guidelines (NaiS, SFP), which use the total canopy cover (instead of the evergreen canopy cover) and which do not use the stem density in deciduous forests, show higher false classification percentages than the other approaches.

NaiS and SFP show also lower true classification rates since they use the gap length as a primary indicator. Analysis of the data and other studies indicate that the length of canopy openings does not say anything about the avalanche release probability in forests or about the avalanche propagation.

However, the quite low false classification rates of GSM-S and ISDW do also not indicate optimized procedures, as the low false classification rates are a result of too high critical evergreen canopy cover percentages (Table 322-1, Figure 322-4 R) and stem densities (Figure 322-5, Figure 322-8).

ISDW's high true classification, despite the poor result in terms of critical gap widths, shows how strong the influence of sequencing is in the combination of indicators. Since ISDW use the gap width as a secondary assessment criterion, the criteria with the higher discriminative power decide the result.

GSM-S gives no information about critical sizes of canopy openings, which are important for protection forest management. Additionally, GSM-S's stem density curves do not optimally differ between a "low" and "no" protective effect.

3.3 Landslides: hazard potential indicators and targets of forest structure

3.3.1 Landslides: hazard potential indicators

NaiS does not refer directly to the basic slope failure susceptibility, but differs two different main situations of a potential protective effect and therefore also of a protective function of forest against landslides: (1) the zone of origin of shallow landslides and (2) the infiltration zone in case of intermediate to deep-seated landslides (Frehner et al. 2005 annex 1 p. 9).

According to NaiS, the contribution of forests to landslide protection is high in the zone of origin of landslides, if the depth of the surface of rupture is at the most 2 m (shallow landslides) (Frehner et al. 2005 annex 1 p. 9). The potential contribution of forests is medium in the infiltration zone of intermediate- to deep-seated landslides (depth of the surface of rupture is ≥ 2 m), if it is possible to influence the water balance in the surface of rupture. Otherwise, the contribution of forest is low. The NaiS concept of basic landslide hazard and forest function indication leads to the following questions.

(1) Why should there be no influence of the forest in the infiltration zone of shallow landslides? Slope water inlet is not only a trigger of intermediate- or deep-seated landslides, but also of shallow landslides. Forest soils may have a very high infiltration capacity, and they may lead all storm rainfall and meltwater to areas susceptible to slope failures below via pipe flow, where the water flow concentrates (Tsukamoto et al. 1982, Sidle et al. 1995, Uchida & Mizuyama 2001). Therefore, pore and flow water in the zones of origin of shallow landslides are also depending on the water flow from areas above. The appearance of shallow landslides is associated with high precipitation or snowmelt levels, which usually exceed the infiltration capacity even of forest soils or lead to subsurface runoff that accumulates in the landslide zones. This might be an argument to limit the protective potential of forests in the zone of infiltration to deep-seated landslides, since dewatering by forest may only be effective in case of deep-seated soils and slide planes. However, mitigation of surface runoff and water storage in the soil may also be effective to prevent shallow landslides depending on the characteristic of the zone of infiltration and issues of hydrological connectivity.

(2) Why should the forest only be of great importance in case of soil depths less than two meters? Most authors (e.g. Johnson & Wilcock 1997; Swanston 1970; Wu et al. 1979, Ziemer 1981, Sidle et al. 1985 all cf. Johnson & Wilcock 2001; Sakals et al. 2006) agree that a protective role (function) of forests is given especially in case of a shallow soil depth, as the roots do not stabilize deeper soil layers. Several studies suggest that woody vegetation contributes to the stability of hillslopes by drainage, dewatering by evapotranspiration and root reinforcement of soil layers to a depth of about 1 to 2 meters significantly, but with no considerable effect deeper than about 5 meters (Sidle 2008 p. 44). However, there is no evidence that a high protective potential of forests is limited to soil depths or to depths of preformed surfaces of rupture smaller than 2 m. Forests and other woody vegetation may influence the moisture of soils rich in clay or silt, and therefore susceptible to slope failures, down to a depth of about 3 to 10 meters (e.g., Felt 1953 cf. Záruba & Mencl 1961 p. 242, Canadell et al. 1996, Li et al. 2008). On the other hand, shallow soils on steep slopes with a dense forest cover may failure, since the bedrock below is impervious and the pressure of the subsurface flow leads to an explosive collapse of the soil (Tsukamoto et al. 1982 p. 96, Uchida & Mizuyama 2001). This is frequently observed in Alpine regions. Hence, the protective effect of the forest cover may also be limited in case of shallow soils.

(3) How is it possible to ascertain that only soil ruptures not more than two meters deep can occur in an area? Foresters may be familiar with the soil depths within their area of responsibility. However, in mountainous areas, the soil depths may vary considerably on a small spatial scale. It cannot be determined with certainty from the signs of historical landslides where exactly the formation of slide planes is limited to depths of less than 2 meters. NaiS refers to information from natural hazard documentations, hazard indicator maps, soil maps and geologic maps. According to NaiS, landslide zones are well documented. The information given by such sources may be incomplete or limited to the mapping of historical landslides. Therefore, it is difficult to conclude from these maps where landslides deeper or not deeper than two meters might occur in future. Ardizzone et al. (2002) and Galli et al. (2008) demonstrated that landslide maps prepared by

different methods and investigators differ considerably. Perzl et al. (2020) presented that only about 13 % of the landslides recorded in the BFW-GeoNDB, which caused infrastructural damages, are located within the polygons of the landslide hazard indication map prepared by the Austrian Avalanche and Torrent Control Service. As it is difficult even for experts to determine where landslides of which type can occur, a differentiation of the protective function of forests according to the depth of soil or by reading features of historical landslides is not reliable.

(4) How should the user of the guideline ascertain the influence of the infiltration area on the water balance of the slide plane in the zone of origin? The authors of NaiS confirm that it can be difficult to delimit the infiltration areas of landslides, since the below ground ways of water are unknown (Frehner et al. 2005 annex 1 p. 11). The above ground watershed of a landslide may be mapped as an approximation by hydrological modelling on base of medium to high resolution digital terrain models. However, without such mappings or tracer experiments it is difficult to ascertain the infiltration areas of large and deep-seated landslide zones.

SFP follows the concept of NaiS to differ the protective role (function) of forests into functions within zones of water infiltration and zones of mass movements. In contrast to NaiS, Berretti et al. (2006 p. 79) do not limit the protective function of the forest in the infiltration area to intermediate- and deep-seated landslides. SFP also refers to a higher protective effect of forests in case of a shallow position of slide planes within the soil, but without a restriction to depths of slide planes less than two meters. This approach is more plausible and takes into consideration, the highly variable depth of soils and that shallow landslides may also happen on the slide body of deep-seated landslides.

GSM-N also limits the protective effect and therefore the protective function of forests to shallow landslides with a depth of the slide plane less than two meters. The Swiss guideline NaiS is the only scientific reference of GSM-N regarding landslides. The assessment procedure to determine the landslide hazard potential refers to signs of soil movements ("silent witnesses"). In case of such signs and a depth of the slide planes of at least 2 m, the flowchart shows that the forest has no significance for the protection against landslides (Gauquelin et al. 2006 pp. 42-43). According to GSM-N, a protective role of the forest is dependent on the total vegetation cover (or forest cover?), if the depth of the slide plane is less than 2 m. The protective role of forest is medium, in case of a vegetation cover higher than 70 % or a "presence" of "several" vegetation layers. Otherwise the protective role of the forest is low. These conditional clauses of the flowchart are vague since the guideline gives no information how to measure the presence of several vegetation layers. How much layers are several layers? Moreover, the hazard indication procedure mixes the issues of the protective function, the protective potential and of the protective effect of forest, which is called the protective role, without offering a solution for landslide probability estimation. The same indicators of the protective effect (role) of forests are presented once again in another section of the guideline ("Risques naturels", Gauquelin et al. 2006 p. 210), but not in form of a flowchart. This approach blows up the size of the guideline without offering any more substantial information.

The approach to present the same indicators once again, but in another chapter of the guideline and form, is also typical for the GSM-S guideline. The GSM-S concept of landslide hazard indication and forest function assessment is almost identical to the concept of the GSM-N guideline. The concept is presented in the chapter "Diagnostic du rôle de protection" (Ladier et al. 2012 p. 31) and in the "Fiches thématiques" (Ladier et al. 2012 p. 257). However, there is a slight difference to the flowchart of GSM-N. According to GSM-S, a protective role (effect) of the forest is given in case of a vegetation cover > 70 %, but not influenced by the "presence of several vegetation strata". This second criterion is missing in the flowchart of GSM-S but is mentioned in the table of criteria according to the "Fiches thématiques".

The ISDW concept of the landslide hazard potential is completely different from NaiS, ISDW, GSM-N and GSM-S. ISDW also refers to qualitative and semi-quantitative geomorphological signs of slope movements, since no hazard indication maps appropriate for forest function mapping were available in Austria at that time (Schweigl & Hervás 2009, Perzl et al. 2017 b pp. 34-36, Perzl et al. 2021 accepted). ISDW does not differ the protective potential of forests in the zone of infiltration and in the zone of the mass movement. The hazard potential and subsequently the protective role or function of the forest results from the combination of the landslide type, the landslide activity, and the prospected landslide intensity. ISDW classifies landslides into (1) spontaneous and (2) permanent landslides according to Keusen et al. (2004), but not on base of the depth of the soil or of the slide plane. The protective function of forest without consideration of the assets to be protected is high to medium in case of permanent landslides and high to low in case of slopes, which are susceptible to shallow landslides, but show no signs of permanent landslides. That is dependent on the signs of activity of permanent landslides and on the prospective landslide size in case of spontaneous landslides.

In case of a permanent landslide, a surface of rupture exists already in the soil or bedrock. The overlaying masses glide down continuously or in phases of increased activity due to different trigger mechanism. The destruction potential of permanently installed, activatable landslides is extremely high. Most of these landslides are geomorphologically recognizable and intermediate- to deep-seated. Because of the deep-seated slide plane and the high slide body mass, a forest cover is usually not able to stabilize them. However, this does not generally mean that the forest has no influence on these landslides. Most of these landslides are complex and tend to show superimpositions of more shallow landslides, because of the collapsed and weak material, the steepened slide bodies and toes and superficial incisions of water courses. The occurrence of shallow landslides on deep-seated landslides promotes their instability in addition to the main trigger mechanisms. Therefore, the forest cover may be important to mitigate the mass movement, although the forest cannot completely stabilize it.

In case of spontaneous landslides, the regolith cover (sometimes also bedrock material) displaces, because of a sudden loss of the shear resistance. The displaced material is transported outside of the area of depletion in one single (fast) mass movement process. The depositions are liquefied or disaggregated and therefore not prone to a further sliding mass transport. The depositions of the slide bodies may also be coherent lobes which do not move further, because of the slope inclination and the form of the underlying terrain. In contrast to permanent landslides, the slide bodies of spontaneous landslides do not move before and after the mass displacement event if they are not within water courses. Therefore, after the landslide hazard, there is usually no mass movement on the same place for a long time with the exception of fluvial transport of depositions in water courses or an episodic or permanent retrograde incision of the scar in case of steep slopes, which may initiate an erosion gully (Dietrich & Dunne 1978 p. 198; Iida 2004, Imaizumi et al. 2015 all cf. Saito et al. 2016 p. 5; Saito et al. 2016). The rupture of surface of spontaneous landslides may be of any depth, but they are usually shallow landslides. Therefore, the root network of the forest cover is able to prevent such slope failures.

The main problem of the ISDW approach is the assessment of the landslide activity and of the possible landslide size, which is semi-quantitative and base on the observation of characteristics of existing (old) landslides. In order to estimate the prospective intensity of spontaneous landslides, the user has to assess the depth of the mobilizable soil layer according to the classes proposed by Keusen et al. (2004 p. 16) and the possible volume of a mass displacement on base of existing landslides. However, future landslides may be larger. The activity assessments of permanent landslides on base of the descriptions may also be difficult and different between users. Slopes susceptible to landslides do not show clear imprints of older landslides in each case. Especially in forest terrain the forest cover may mask out traces of former landslide activity.

None of the guidelines refer to quantitative classifications or indicators of the landslide probability on base of observed spatio-temporal landslide densities of slope units. Especially the occurrence of shallow landslides cannot be determined with certainty from silent witnesses but requires the formation and analysis of geological-geomorphological slope units. Landslide susceptibility estimation requires the preliminary selection of appropriate terrain units (Reichenbach et al. 2018 p. 62). A sensitive main indicator of the landslide susceptibility of slope units addressed in most studies is the slope inclination (Reichenbach et al. 2018 p. 73). The probability of shallow landslide occurrence is a function of the slope inclination and shows specific function courses depending on the unit. Slope inclination thresholds of terrain susceptible to slope failures are appropriate for practical purposes of protection forest management and may be derived from unit-specific functions of landslide frequencies (Perzl et al. 2021 accepted). Only NaiS provides critical slope inclinations for some types of soil in the accompanying text also shown in SFP, but without a systematic link to the assessment procedure.

3.3.2 Landslides: protective effect-related characteristics of the forest structure

We have limited our investigation of the indicators of the protective effect of forests to the zones of origin of shallow landslides. There is no doubt that forests have an influence on surface and subsurface runoff formation in the infiltration area of landslides. However, surface, and subsurface runoff result from all land use units in the watersheds of the landslides. The share and spatial distribution of the hydrological response units and the fragmentation of woody areas influence the formation and flow of runoff considerably (Thomas et al. 2020). Therefore, the forest percent of the watershed and the location and fragmentation of woody areas may be more important than the canopy cover targets of 30 % (minimum requirement) and 50 % (ideal requirement) proposed by NaiS and SFP for forest stands.

The main quantitative forest characteristics used by the guidelines to distinguish protective from not protective forests in the zones susceptible to (shallow) slope failures are the areas (NaiS, SFP), widths (ISDW) and lengths (SFP) of gaps and blanks, the areas (NaiS, SFP), widths (NaiS) and lengths (SFP) of canopy openings or stands with secured forest regeneration, the canopy cover of the woody vegetation (all guidelines) and the absence or canopy cover of large-sized timber (Table 22-1).

The size of canopy openings (gaps and blanks) with and without forest regeneration

NaiS, SFP and ISDW assume that the probability of landslide occurrence in forests depends on the size of gaps and blanks. NaiS and SFP differ critical values for canopy openings with and without a sufficient ("secured") forest regeneration. GSM-N and GSM-S do not refer to the sizes of canopy openings like cuttings. Table 332-1 shows the targets respectively the critical gap dimensions proposed by NaiS, SFP and ISDW and the linking operators.

Table 332-1: Shallow landslides – gap and blank size targets (critical dimensions)

	Gaps and blanks without secured regeneration							Gaps with secured regeneration – young growth						
Dimension	NaiS minimum	NaiS ideal	SFP minimum	SFP ideal	GSM-N	GSM-S	ISDW	NaiS minimum	NaiS ideal	SFP minimum	SFP ideal	GSM-N	GSM-S	ISDW
Area [m²]	≤ 600	≤ 400	< 600	< 400	- - -	- - -	- - -	≤ 1200	≤ 800	< 1200	< 800	- - -	- - -	- - -
	- - -	- - -	AND	AND	- - -	- - -	- - -	(AND)	(AND)	AND	AND	- - -	- - -	- - -
Length [m]	- - -	- - -	< 20	< 15	- - -	- - -	- - -	- - -	- - -	< 25	< 20	- - -	- - -	- - -
Width [m]	- - -	- - -	- - -	- - -	- - -	- - -	≤ 25*	(≤ 20)	(≤ 20)	- - -	- - -	- - -	- - -	- - -

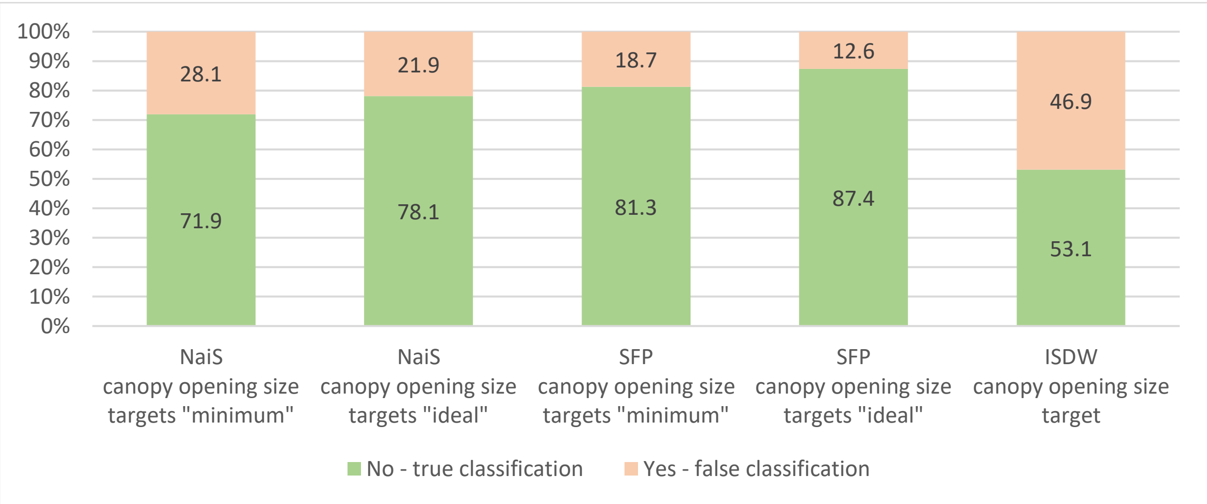
In brackets: criteria may only refer to areas larger than 1200 (800) m² on subalpine sites.
* Recommendation for a high or medium landslide susceptibility of the site.

The gap and blank size targets of NaiS and SFP are similar, but not identical. According to NaiS, canopy openings of the tree layer (canopy of saw-sized timber) should be limited to 600 m² (minimum requirements) or 400 m² (ideal requirements) at the most if there is no regeneration. In these cases, NaiS does not consider the length of the canopy opening. According to SFP, a canopy opening should be less than 600 (400) m² and the length should be less than 20 (15) m. Therefore, SFP is more restrictive than NaiS. NaiS and SFP propose similar conditions in case of areas with secured regeneration, but with larger critical areas of 800 and 1200 m², and SFP with larger gap lengths. Furthermore, NaiS limits the dimension of cuttings to widths of 20 m. However, this "and"-condition may only refer to openings larger than 800 (1200) m² on subalpine sites; the notes concerning the gap width are not clear. Hence, we did not consider this NaiS-criterion shown in brackets in Table 332-1.

ISDW does not differ situations with and without forest regeneration. The recommended width of canopy openings is 25 m at the most in case of a high or medium landslide susceptibility.

SFP gives no information whether to compare the length criteria with the plan or the inclined length of a canopy opening. We calculated the inclined lengths of the samples, since the wording may refer to the inclined length. We considered gaps with planar lengths and widths ≥ 10 m and gaps and areas with young growth ≥ 100 m² in frequency statistics. Figure 332-1 shows the results of the binary classification of the samples according to the canopy opening size targets with (gaps, blanks) and without young growth (N = 278). Figure 332-2 and Figure 332-3 present the classification results of canopy openings without regeneration (N = 103) and with regeneration (N = 175) for each indicator separately.

Figure 332-1: Landslide initiation – validity of canopy opening size targets



The canopy opening limits (or critical values of clear-cut sizes) of NaiS show an acceptable false classification rate (Figure 332-1). The true classification rate of SFP is about 9 percent points higher than the true classification rate of NaiS. This results from combining area and length targets by an "and"-condition. The "minimum" and the "ideal" requirements of NaiS and SFP do not show considerable differences of the classification results. As with the formation of snow avalanches, the differentiation into a minimum target and an ideal target does not result in any significant differences in the protective effect. The gap width indicator used by ISDW shows a considerably high false classification rate of about 47 %. This indicates that the critical width is set too large, or that the width is a much less suitable indicator of the protective effect than the area or the length of the canopy opening.

Figure 332-2 shows that the critical lengths of canopy openings without forest regeneration used by SFP result in smaller false classification rates than the critical areas used by NaiS and SFP. Both, the critical lengths and areas used by NaiS and SFP show considerable better results than the critical gap width proposed by ISDW.

However, in case of canopy openings with forest regeneration and young growth stands the performance of the proposed critical areas and lengths is lower than in case of openings without regeneration (Figure 332-3).

Figure 332-2: Landslide initiation – validity of canopy opening size targets without forest regeneration

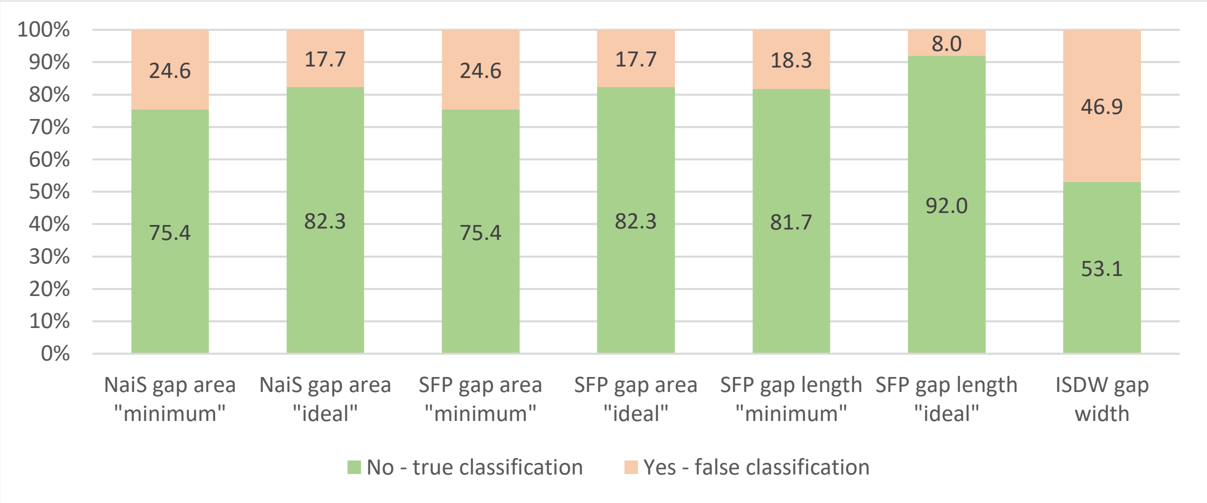
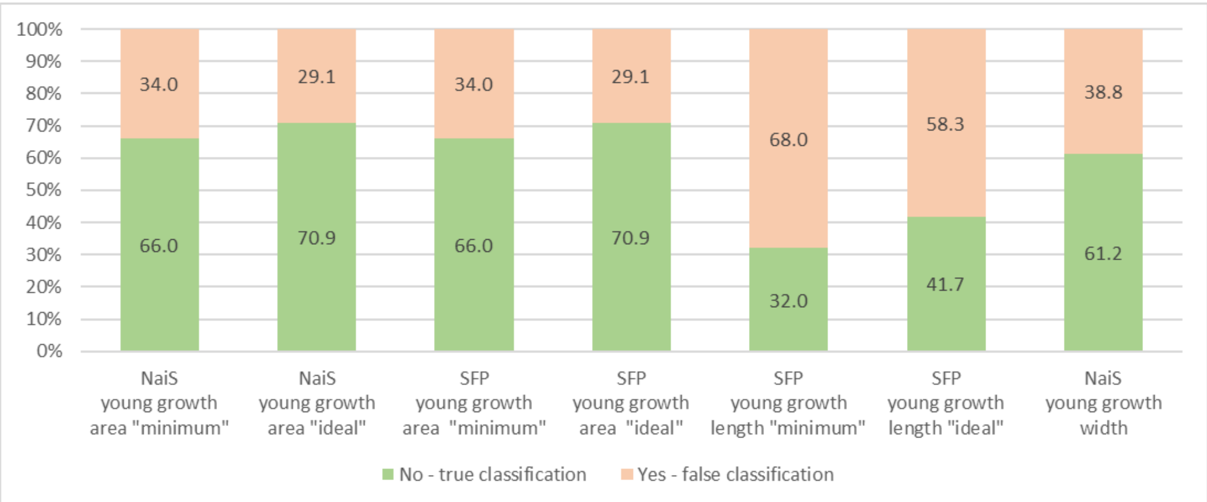


Figure 332-3: Landslide initiation – validity of canopy opening size targets with forest regeneration



Especially the critical lengths of areas with forest regeneration are not able to discriminate low and high protective effects of the woody vegetation. They show high false classification rates of about 60 % (ideal requirements) and 70 % (minimum requirements). Slopes with young growth should still be stable in case of larger openings than slopes without young growth. But in fact, the presence of young growth does not increase the critical area and length of openings to that extent assumed by NaiS and SFP. Another reason for that may also be, that some sites with low woody plants such as Alpine bushes (Alnus alnobetula) are more susceptible to slope failure because of a higher soil moisture than sites without low woody vegetation. Rice & Pillsbury (1982 p. 307) mentioned a similar effect in statistical landslide susceptibility modelling since the crown cover of dominant trees was positively correlated to slope instability. Rice & Pillsbury (1982) also explained that by correlation of the crown cover to high moisture conditions and additionally by the weight load of the forest cover. However, the weight load is neglectable in case of young growth areas. The load of the trees does not affect the slope stability negatively in each case, and the influence of the tree load is rather small (Beinsteiner 1988, Medicus 2009 p. 19). The critical lengths of openings without regeneration proposed by SFP are small and only 5 m shorter than those for areas with regeneration. Despite this, the length of the young growth areas can show the tendency to slope failure much less well than the length of gaps without regeneration. Therefore, the discriminative power of gap lengths may be limited in case of slopes with high susceptibility to slope failure.

It is frequently pointed out in literature that clear-cutting promotes slope failures. Croft & Adams (1950 cf. Swanston 1974 p. 9) addressed timber harvesting as a main promotor of shallow landslides triggered by combined heavy rain and snowmelt. Dyrness (1967) observed that 78 % of the landslides in forests are associated to logging or road building directly. Swanston (1974) alleged that logging operations are major contributors of mass movements due to the destruction of roots and of the surface vegetation cover. Robison et al. (1999) observed that debris flows initiating in mature forests show shorter runout lengths than debris flows initiated in clear-cuts and young forests. This is because of higher landslide density and erosion volumes in stands that have been harvested in the previous 9 years, as compared to older forests (Robison et al. 1999 p. 108). Montgomery et al. (2000) found that forest clearing increases the regional landslide frequency. Most of the slope failures occurred 3 to 5 years after cutting triggered mainly by 24 hours rainfall with a recurrence interval smaller than 4 years. Rickli (2001) determined a dependency of landslide density in forests on forest conditions and found highest densities in young growth and deteriorated or disintegrated forest. May (2002) observed that the average number of landslides per debris flow was highest for clear-cuts followed by roads. However, May (2002) classified stands with an average DBH less than or equal to 10 cm as clear-cuts. The mean landslide volume in clear-cuts and second-growth forests was approximately double the mean landslide volume in mature forests. Therefore, the results of May (2002) also indicate a low protective effect of young growth in line with the findings shown in Figure 332-3. Rössel (2012 pp. 72-73) calculated the densities of new landslide occurrence visible on orthophotos representing two time-intervals (1972-1985, 2001-2012) in the "Au" and "Schnepfau" regions of this study (Figure 22-1). The landslide occurrence density within forest use areas was highest in clear-cuts, in sawtimber forest with a canopy cover smaller than 35 % and in young growth forests including pole timber forests. Saito et al. (2016) found that rainfall intensity-duration thresholds declined after clear-cutting to half of those of non-clear-cut areas in forests. The remaining roots in five years old harvested spruce forests provided 40 % of the soil reinforcement of the undisturbed forest (Vergani et al. 2016). 15 years old clear-cuts in spruce forests show no soil reinforcement by roots of the harvested trees (Vergani et al. 2016). Roots of natural regeneration and shrubs 15 years after clear-cutting may provide 30 % of the reinforcement of the original forest stand (Vergani et al. 2016). Therefore, natural regeneration may not completely replace the effects of the remaining roots of old growth trees on fresh cutting sites, which also explains the results shown in Figure 332-2 and Figure 332-3.

Although the influence of clearcutting on landslide occurrence is addresses frequently in literature, only few authors provide information about the critical size of canopy openings like clear-cuts. There are many guidelines on erosion control, but they do not deliver quantitative information on this. Most recommendations and legal size-restrictions of clear-cuts are quite higher than the areas proposed by the guidelines. O'Loughlin (2005 cf. Amishev et al. 2013 p.62) propose small-coup clear-felling of 1 ha at the most on unstable terrain to substantially maintain the protective effect of forests. Moos (2014) identified the canopy cover, the length of gaps and the distance to the next tree as forest characteristics with influence on landslide susceptibility. The results indicate that a gap length larger than 20 m is critical especially on slopes steeper than 36°. The gap widths on the landslide sites did not show significant differences to the control group. However, an explanatory power of the gap length could only be ascertained in one of the two study areas.

The results of this study and scientific literature do not give a clear answer of whether the area, the length, or the width of canopy openings in the stand better explains the occurrence of landslides. Landslide occurrence seems to be more related to the length of canopy openings in flow direction than to widths.

However, the classification results react more to the size than to the type of the dimensions of a canopy opening. Figure 332-4 shows that a reduction of the critical gap width by only 5 m from 25 to 20 m lowers the false classification rate from about 47 % to 34 %, and a further reduction to 15 m results in a false classification rate of about 15 %. The rate of change of the false classification rate is 3.2 % per meter critical gap width. An enlargement of the critical gap length from 20 to 30 m responses with an increase of the false classification rate to about 33 % with a rate of change of 1.4 % per meter critical gap length. Notice that the critical gap length refers to the inclined slope length calculated on base of the slope inclination at the slide scar. If the planar length is used, the true classification deteriorates from 81.7 % to 77.7 % for example in case of a critical gap length of 20 m ("minimum requirement" of SFP).

Figure 332-4: Landslide initiation – effects of the reduction of the critical gap width and of the enlargement of the critical gap length

According to our experiences in the field, it is more difficult to measure the gap length than the gap width, and gap area mappings differ considerably. The results and literature also indicate that young growth is not fully able to substitute the root reinforcement of mature forests. Therefore, even with existing regeneration, much larger openings are not justified.

Canopy cover

Table 332-2 shows the critical values of the canopy cover proposed by the guidelines. The recommendations of NaiS and SFP are identical and refer to the canopy cover of pole- and sawtimber trees. Young growth is not considered. The critical canopy covers recommended by GSM-N, GSM-S and ISDW are similar. All of them refer to the total canopy cover of woody vegetation including young growth.

Table 332-2: Shallow landslides – critical canopy covers in the zone of origin

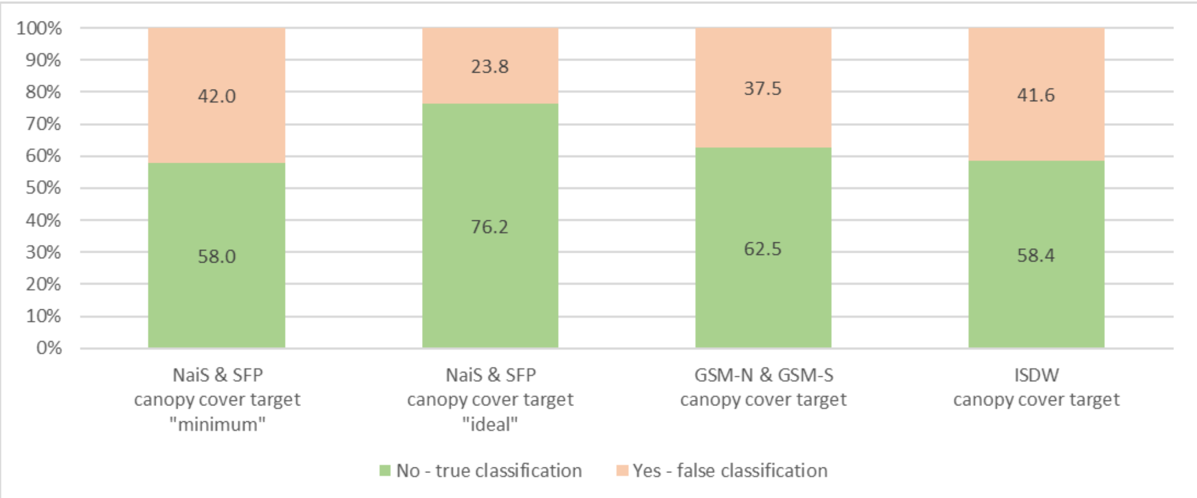
Dimension	NaiS minimum	NaiS ideal	SFP minimum	SFP ideal	GSM-N	GSM-S	ISDW
canopy cover of the tree layer (pole- and saw-timber h > 10 m) (CCPT10)	< 40 %	< 60 %	< 40 %	< 60 %	- - -	- - -	- - -
canopy cover of the woody vegetation without dwarf shrubs (CCPW)	- - -	- - -	- - -	- - -	≤ 70 %	≤ 70 %	< 65 %*
* This critical value refers to a high landslide susceptibility							

In order to compare the guidelines, we fixed a high basic landslide susceptibility for all samples in the study regions without consideration of the slope conditions. Landslide susceptibility modelling for Austria of Perzl et al. (2017 b, 2019 c) indicates that the study region is dominated by slopes with above-average susceptibility to landslides. The percentages of canopy cover include canopy openings like gaps. As the CCPT10 values are from the nDSM only, we excluded samples with a temporal mismatch caused by landslides in evaluation of the targets proposed by NaiS and SFP.

As with the gap sizes, there is hardly any other quantitative information in the literature on critical or protective canopy covers than presented by the guidelines. Statistics presented by Moos (2014 p. 20) shows a canopy cover of about 60 % as an upper limit of landslide occurrence in forests. However, in the study region and in Austria we also frequently observed landslide initiation in forests with a full canopy cover.

Figure 332-5 shows that the "minimum requirements" proposed by NaiS and SFP result in considerable false classifications. On the contrary, the "ideal" requirements show a quite lower and acceptable amount of false classifications. The critical canopy covers recommended by GSM-N, GSM-S and ISDW also do not show satisfying results. The classification results point out that the canopy cover of pole- and sawtimber trees is better suited for estimating the protective effect of the forest than the total canopy cover. The protective effect of young forests is limited as root systems are not deep enough to stabilize the soil. We observed landslide initiation also in case of dense young forests, which indicates that dimensions and depths of roots are a crucial factors to provide protection by forests. The approach of NaiS and SFP to set larger critical gaps in case of existing regeneration, but not to consider the canopy cover of young growth, is inconsistent.

Figure 332-5: Landslide initiation – validity of the canopy cover targets



Absence and canopy cover of large sized timber

In order to reduce landslide initiation in forests, SFP and ISDW recommend low occurrence of large-sized timber trees on sites susceptible to slope failures. According to SFP, there should be no large diameter trees (DBH > 47.5 cm). ISDW recommends a canopy cover smaller than 25 %. That is not plausible, since mature and old growth trees have stronger and deeper roots than younger trees. Obviously, these targets aim on the reduction of large-woody debris transfer and deposition in gullies and water courses. Large-woody debris may be a source of hydrologic hazards (Braudrick et al. 1997, Mazzorana et al. 2009, Rudolf-Miklau & Hübl 2010, Rudolf-Miklau et al. 2011; Ruiz-Villanueva et al. 2014, Badoux et al. 2015, Comiti et al. 2016, Lucía et al. 2015 all cf. Cislaghi et al. 2018). The expensive removal of large-woody deposits is common practice in water course and forest management in Europe (Wohl 2017 cf. Cislaghi et al. 2018). In European countries, the damaging effect of woody sediments in water courses is rather emphasized, whereas international literature also addresses the positive effects of woody-debris on debris flows and torrential floods due to bank protection, braking effects and early bed load deposition (Perzl & Huber 2015 p. 21). NaiS also refers to the hazard potential of woody debris, but the proportion of large-sized timber is not a part of the assessment criteria.

Since the restriction of the amount of large-sized timber proposed by SFP and ISDW may not directly refer to slope stabilizing, the consideration of the critical values is not oriented to the protective effect against landslides. However, neither SFP nor ISDW differ geomorphologic situations where large-woody debris entrance into water courses generates a mobilizable hazard source or not. Therefore, the evaluation of the assessment procedures includes this criterion.

Figure 332-6 shows that an absence or small amount of large-sized timber on sites susceptible to shallow landslides do not explain the slope failures.

Figure 332-6: Landslide initiation – validity of the large-sized timber targets

The rates of false classifications are considerable and extraordinary with the ISDW criterion. The extraordinary high rate of false classifications of the ISDW criterion may not be plausible on the first sight, since a higher amount of mature and old-growth trees with a deep and adapted root system positively influence the slope stability. However, the stands with a canopy cover of large-size trees < 25 % show also a significantly lower canopy cover of the tree layer than other stands of the sample. Therefore, they fit the large-sized tree target, but the canopy cover is not protective. This results in a high number of misclassifications. On the contrary, stands with no large-sized trees are more frequently closed stands with a smaller proportion of examples in the landslide sample.

Therefore, the proportion of false classifications due to the SFP criterion is lower. The results indicate a high explanatory power of the canopy cover of the tree layer, but no discriminative power of a low amount of large-sized timber.

Combination of protective-effect related forest characteristics

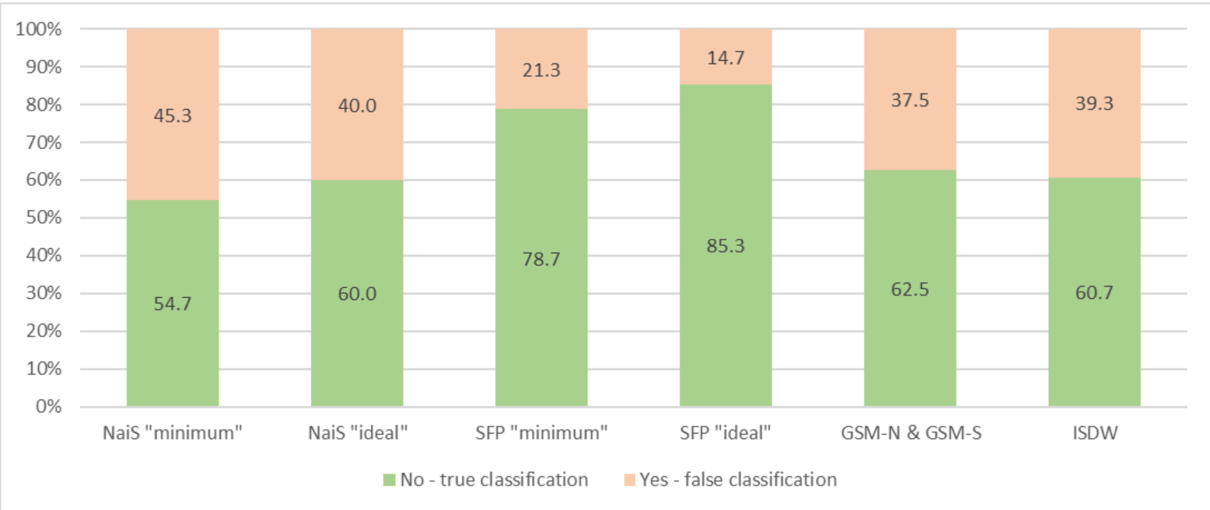
As NaiS and SFP do not describe how to combine the indicators and some information required by ISDW is missing in the landslide sample, the combination of the criteria indicating the protective effect of the forest is also based on assumptions and simplifications.

Our assumptions for NaiS and SFP are identical to the assessment procedure for snow avalanches: the canopy cover targets are only valid for stockings without a clearly delimitable gap or blank; the gap targets refer to gaps and blanks without consideration of the canopy cover (within and around the gap). In case of samples without a gap or blank, which match the canopy cover targets of SFP, the decisive criterion is the absence of large-sized timber trees.

GSM-N and GSM-S do not need a combination of forest characteristics since they refer only to one quantitative indicator.

According to the ISDW combination matrix, the protective effect of forest is first determined with the critical values for the total canopy cover and the canopy cover of large-sized timber. Secondary, if the gap width is critical, the result of the combination matrix is lowered to "no" or to a "medium" protective effect. Figure 332-7 is again limited to the question of a high (sufficient) or not high (medium or low) protective effect.

Figure 332-7: Landslide initiation – validity of the combined targets of forest characteristics



The rate of false classifications of the NaiS concept is similar to the snow avalanche concept and considerably high. There is also no remarkable difference between the "minimum" and the "ideal" requirements on the forest structure.

The quite better performance of the SFP-concept results from the combination of gap area and gap length restrictions using an "and"-condition. Therefore, the requirements on the forest structure are more restrictive.

GSM-N, GSM-S and ISDW show similar classification results. The results of the simple approaches of GSM-N and GSM-S with just one indicator of the protective effect of forests do not differ from the more complex concept of ISDW and just small from NaiS. However, forest management guidelines should provide information on critical sizes of clear-cuts.

ISDW suffers from the critical gap width and the critical cover of large-sized timber. The setting of the critical gap width is slightly too high, but with a high impact on the classification results. The worse classification results regarding the amount of large-sized timber do not fully reflect in the results, as this indicator is secondary in SFP and ISDW. A reduction of the amount of large-sized timber in forests may not enhance the protective effect against landslide initiation. As the entrance of large woody debris to water courses from hillslopes is low (Cislaghi et al. 2018), the amount of large sized timber may only be important in the inner gorges. However, a complete absence of large-sized timber trees in landslide protection forests as proposed by SFP may be in contrast to other targets like rockfall protection and biodiversity.

3.4 Rockfall: hazard potential indicators and targets of forest structure

3.4.1 Rockfall: hazard potential indicators

In case of rockfall hazards the main function of forests is to stop or to mitigate rockfall propagation in the transit or deposition zone. Effects of forests in rockfall starting zones are ambiguous (Jahn 1988, Rickli et al. 2004, Kalberer 2007). Source areas of rockfall are mostly very steep and rocky. Therefore, the mitigation of rockfall initiation by silvicultural measures is limited to the removal of unstable trees. Such trees are not always clearly identifiable, and this measure is both, expensive and dangerous for lumberjacks carrying out the work and the properties located below.

As the assessment of the rockfall protection effect of forests requires the identification of rockfall sources (starting zones) and of the potential transit zones, all guidelines provide indicators to differ hazard zones with different capability of forests to mitigate a rockfall hazard. A comparison of the guidelines reveals considerable differences in interpretation of terrain, where a protective function should be allocated to forest. All guidelines start from determination of rockfall zones by expert and provide quantitative and semi-quantitative indicators to a different extent (Table 341-1).

Table 341-1: Rockfall: hazard potential indicators and limits of the protective function of forest

	NaiS & SFP	GSM-N	GSM-S	ISDW
Indicators of rockfall sources				
Slope inclination	> 30°	≥ 25°	- - -	- - -
Sources				
cliffs H > 20 m	- - -	✓	- - -	- - -
outcropping rocks 1 m > H > 20 m (?)	- - -	✓	- - -	- - -
block depositions	- - -	✓	- - -	- - -
Indicators of transit zones				
Slope inclination	> 30°	≥ 25°	- - -	- - -
Indicators of deposition zones				
Slope inclination	< 30°	< 25°	- - -	- - -
Limits of protection				
Total volume of rockfall masses	- - -	> 500 m³	- - -	- - -
Volume of the maximum single block	≥ 5 m³	> 5 m³	> 1 m³	- - -
Capacity of slopes to slow down rockfall				
Length of the zone covered by forest	- - -	≥ 200 m	≥ 200 m	- - -
Slope inclination (slope)				
low capacity	- - -	- - -	- - -	slope > 39°
medium capacity	- - -	- - -	- - -	28°< slope ≤ 39°
high capacity	- - -	- - -	- - -	slope ≤ 28°
Mean diameter of blocks				
High capacity	- - -	- - -	- - -	< 20 cm
Medium to low capacity	- - -	- - -	- - -	≥ 20 cm
Surface roughness	- - -	- - -	- - -	✓
H = height of the cliff or fall height of rockfall; **?** = Boolean operators may show a misprint in the original				

The guidelines do not focus on the identification of potential rockfall hazard zones since this is only possible by spatial modelling. They mix the task of protective function mapping with an assessment of where and to what extent the forest might be able to absorb rockfall. This is called the "protective role" of forest in GSM-N and GSM-S. Therefore, the guidelines also provide limits of protection in the form of rockfall and single block volumes.

Table 341-1 shows the difficulties to differ rockfall source areas and transit zones as addressed in chapter 3.1.6, because NaiS, SFP and GSM-N recommend the same values of the slope inclination for rockfall sources and transit zones.

The lower slope limits of rockfall source areas proposed by NaiS (30°) and GSM-N (25°) are low in relation to observational based data published in literature. Perzl et al. (2017 c) show that rockfall initiation is rare in Austria on slopes not steeper than 36° by comparison of source slope frequencies and total terrain slope frequencies. Heim (1932 p. 7) already mentioned a lower limit of 35° of slopes prone to rockfall initiation.

GSM-N allocates different protective capabilities to forest depending on the cliff height. However, the range of the cliff height for outcropping rocks presented in the flowchart on page 35 of the guideline is not possible, as the same cliff cannot be smaller than 1 m and larger than 20 m. We also assume a misprint at this point like on page 203 of the guideline.

The proposed maximum single block volumes that might be stopped or slowed down by the forest also differ considerably. NaiS (SFP) and GSM-N refer to a block of 5 m³, GSM-S to 1 m³. The statements in literature about this vary considerably, and it is not possible to give a generally valid limit, since that is depending on many factors.

GSM-N and GSM-S also exclude a protective effect of the forest, if the length of the transit zone covered by forest is smaller than 200 m. A high influence of the length of the transit zone covered by forest on the rockfall mitigation capacity is plausible. However, it is not possible to define a minimum slope length covered by forest, below which forests do not have a relevant protective effect (Zürcher 2010 p. 13).

The concept of ISDW is completely different from the other guidelines. The concept does not exclude a protective function of the forest because of block volumes or slope lengths, but allocates different rockfall mitigation capacities to forest sites in the hazard zone depending on slope inclination, surface roughness and the mean block diameter. Hence, the concept is not designed to assess the protective effect in relation to a protection target, but to point on forest sites, where the forest is more or less important to slow down rockfall propagation. The concept assumes a high deceleration of the rocks on slopes with an inclination smaller than 28° for example. Therefore, a lower density of the forest may fit the hazard-related requirements. However, also the length of slope units determines the rockfall mitigation capacity, and there is no clear evidence for this approach based on data.

The greatest uncertainty in all these approaches is that it is difficult even for experts to predict the mass and block size of a rockfall event. Small rockfall deposits do not mean that large block volumes cannot be mobilized and vice versa. Therefore, all concepts are from limited reliability and practical usability for forest function mapping and risk assessment.

A common feature of all guidelines is that they do not explicitly define a protection target regarding rockfall. In case of avalanche and landslide initiation, the protection target concerning forest conditions is simple and obvious. Forests shall prevent hazard initiation. As the protective effect of forests concerning rockfall is limited, the definition of a protection target is difficult. The objective of NaiS, SFP and ISDW seems to be an effective forest on each site within the potential hazard zone. Indicators proposed by GSM-N and GSM-S rather refer to the total protective effect of the forested area between the rockfall source areas and the assets to be protected. Targets on the basal area of forest presented by GSM-N indicate that the forest in transit areas should be able to stop 35 % of all blocks with a diameter of 1 m³ and 60 % of all blocks with a diameter of 0.5 m³ by a forested zone of 500 m. These targets do not guarantee safety for human assets and may require additional technical measures in each case. However, there are no instructions in GSM-N and GSM-S on how to deal with the variability of forests addressed as "effect of the forest stand texture" in chapter 3.1.6.

3.4.2 Rockfall: protective effect-related characteristics of forest structure

Table 342-1 shows the protective-effect related characteristic of the forest structure recommended by the guidelines. The presentation is limited to high basic hazard susceptibility in case of the ISDW concept and to a high level of the protective effect in case of GSM-S and ISDW. The table shows considerable differences of concepts and indicators.

Table 342-1: Rockfall: protective effect-related characteristics of the forest structure proposed by sylvicultural guidelines (without indicators of stability)

	NaiS & SFP "minimum"	NaiS & SFP "ideal"	GSM-N	GSM-S	ISDW
Starting zone	- - -	- - -	gap length ≤ 20 m	- - -	same values as in the transit zone
Transit zone	stem density	stem density	stem density	stem density & basal area	stem density & young growth
Block diameter < 40 cm	≥ 400/ha DBH > 12 cm	≥ 600/ha DBH > 12 cm	- - -	- - -	- - -
Block diameter 40-60 cm	≥ 300/ha DBH > 24 cm	≥ 400/ha DBH > 24 cm	- - -	- - -	- - -
Block diameter 60-180 cm	≥ 150/ha DBH > 34 cm	≥ 200/ha DBH > 34 cm	- - -	- - -	- - -
- - -	- - -	- - -	≥ 796/ha DBH > 20 cm	> 350/ha DBH > 17.5 cm and > 25m²/ha	> 400/ha DBH > 20 cm and CCPY ≥ 15 %
- - -	gap length	gap length	gap length	gap length	gap length
- - -	< 20 m (in the deposition zone too)	< 20 m (in the deposition zone too)	if coppice < 20 m if high forest < 40 m	- - -	≤ 20 m
Length of the zone covered by forest	- - -	- - -	> 200 m	> 200 m	- - -
Deposition zone	stem density	stem density	all criteria	all criteria	all criteria
	≥ 400/ha DBH > 12 cm	≥ 600/ha DBH > 12 cm	same as in the transit zone	same values as in the transit zone	same values as in the transit zone

All guidelines refer to the stem density, but with different indications of the effective tree diameters and the required number of stems per hectare. In NaiS and SFP the critical tree diameters and stem densities vary depending on the block sizes. Therefore, results are sensitive to estimations of probable block sizes. According to the concept of Gsteiger (1989), a forest, which is adapted to the largest block diameter, may not be able to stop all smaller blocks.

The critical stem densities proposed by GSM-N, GSM-S and ISDW do not consider the block size. However, GSM-N and GSMS exclude or limit a protective function and therefore also a protective effect of forest in case of blocks larger than 5 (1) m³ in the assessment procedure of the protective role of forest. This kind of exclusion may underestimate the contribution of forest to rockfall protection, as the same rockfall sources also may mobilize smaller blocks.

All guidelines except GSM-S consider the gap length, but not a cumulative gap length at slope scale as proposed by Zürcher (2010) and Rammer et al. (2015). However, NaiS and ISDW are not designed for the slope scale, as the intended use of both systems is silvicultural controlling on plot and stands scales.

GSM-N and GSM-S refer to the length of the zone covered by forest, which is an indicator on slope scale. But the gap length is not considered on slope scale, and the critical values of the stem density may refer to averages on slope scale or to the stand scale. There are no clear instructions to deal with this in the guidelines. As GSM-N provides no flowchart, the combination of the indicators presented in Table 342-1 in order to assess protective effects is not defined.

The problems of scale and data make it difficult to evaluate the concepts quantitatively. Kalberer (2011 p. 31) for example found a high rockfall risk reduction by forest in a study area, although the forest did not fulfil the requirements according to NaiS. According to Kalberer (2011 p. 31) this is an effect of the length of the slope covered by forest. However, not only the slope length like in GSM-N and GSM-S influences the protective effect, but also the cumulative gap length and density of the forest.

Dupire et al. (2016) presented a dimensionless hazard risk reduction factor, which was also used by Scheidl et al. (2020) on base of the travel angle in relation to the mean critical energy slope for non-forested rockfall terrain profiles in order to express the effect of forests on rockfall. We compared the average hazard reduction factors of 32 rockfall hazard events, which match or do not match the minimum and ideal stem density requirements of NaiS (and SFP) for hazards with block diameters smaller than 40 cm. We did not exclude hazard events with larger blocks, since this information was not in the data delivery and the block sizes of a rockfall hazard event usually vary considerably. Therefore, the maximum block does not indicate the total protective effect.

Figure 342-1: Rockfall - average hazard reduction factors grouped by targets of stem density

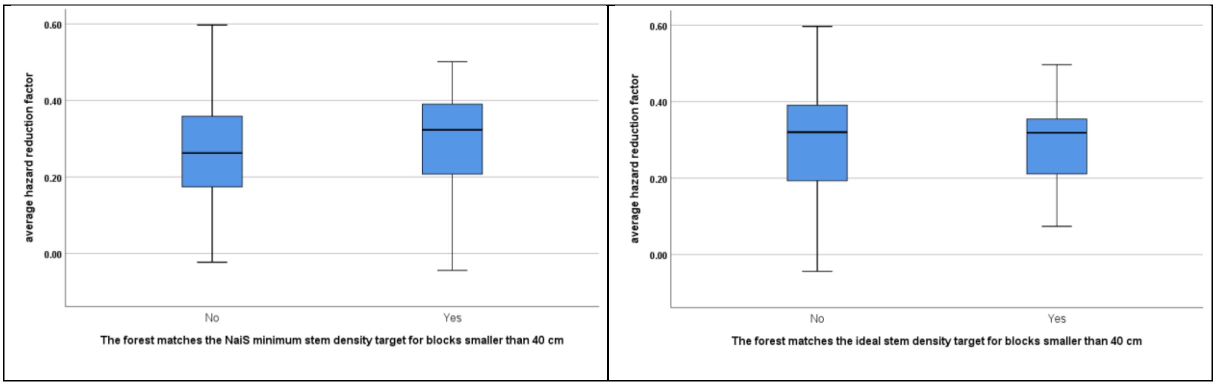


Figure 342-1 L shows that the median (and mean) of the average hazard reduction factors of non-destructive rockfalls, which match the minimum requirements of NaiS, is slightly higher than of forests with smaller average stem densities along the hazard zone. However, the differences of the groups are statistically not significant.

Findings of Scheidl et al. (2020) indicate protective stem densities in the frame of the guidelines. The hazard reduction factor of forests compliant or not compliant to the ideal requirements of NaiS (Figure 342-1 R) are at the level of forests, which match the minimum requirements. Like the results concerning snow avalanche and landslide initiation in forests, the findings do not indicate a higher level of protection due to the "ideal" requirements. Average values of the stand density weighted by the length of forest stand sections do not separate forests of different protective effects on base of the proposed targets. The results and literature indicate that there is a strong influence of the terrain on rockfall runout length. The length of the forest units and cumulative density measures are more appropriate than the indicators proposed by the guidelines.

4. SYNTHESIS AND CONCLUSIONS

The issue of this study is the evaluation and the comparison of the hazard-related criteria and targets to assess the object-protective functions and effects of forests proposed by different national guidelines for protection forest management. The study aims to clarify the concepts and to separate appropriate and valid methods from concepts that cannot be recommended. We focused on the hazard-related targets of the forest structure, which may prevent natural-hazard initiation or reduce the impact of hazard processes. To this end, it is also necessary to consider the indicators of the protective function of the forest depended on site characteristics.

The term "protective function" refers to the task of a forest (woody vegetation) to protect something of value like human settlements and infrastructures from the impacts and damage by adverse climate, or cultural and natural hazards. A protection forest is a forest with a protective function as its primary task in relation to other public interests in forest management (Brang et al. 2001).

The degree of preventing damage by forests that hazards or adverse climate would otherwise cause to the assets is the protective effect of the forest. Hazard risk analysis and prioritization of mitigation measures require the assessment of the protective effect of forests based on the forest function in combination with an analysis of the ecological stability of the forest.

We limited analysis to snow avalanche, shallow-seated slope failure and rockfall, and included the following guidelines: The Swiss guideline NaiS (Frehner et al. 2005) also available in English (Frehner et al. 2007), the Italian (Valle d'Aosta/Piedmont) guideline SFP (Berretti et al. 2006), the French guidelines GSM-N (northern French Alps, Gauquelin & Courbaud 2006) and GSM-S (southern French Alps, Ladier et al. 2012), and the Austrian guideline ISDW (BFW 2006).

We checked the guidelines for appropriate spatial scales, logical consistency, plausibility, operationality and applicability of the proposed assessment rules and criteria. We also compared the hazard-related targets proposed by the guidelines with knowledge from literature.

The methodical core of the study is the comparison of the protective effect-related characteristics of the forest structure proposed in the guidelines with the pre-event forest characteristics of real hazard events. In the potential starting zones of natural hazards, forest should prevent hazard initiation. Hence, the proportion of observed hazard initiations on terrain of forest use which do not match the proposed targets of the forest structure are true classifications (true positives) and should be considerably higher than the proportion of hazard initiations in forests compliant to the targets of a guideline (false classifications).

The evidence of this simple comparison may be biased by the total proportions of forest stands that meet or do not meet the targets. The comparisons on base of hazard samples are also biased by the fact that high targets of forest characteristics like the canopy cover percent or the stem density automatically lead to a higher proportion of correct classifications. It is therefore necessary to consider these distortions.

We compiled a dataset of about 300 snow avalanche formations in forests provided by SLF and BFW and a dataset of 555 shallow landslide initiations in forests to compare forest characteristics on hazard sites and critical stand characteristics proposed by the guidelines.

We also used an available sample of 32 non-destructive rockfall hazard events in forests with information about average runout lengths and fall heights of single blocks as well as on average stem densities and basal areas weighted by stand unit slope lengths along the hazard zones from the Alpine Space RockTheAlps (RTA) project.

NaiS and SFP

NaiS is explicitly not made for forest function mapping and refers to additional diagnostics necessary to assess the achievement of protection targets. The structure of SFP is similar to NaiS. The hazard-related targets of SFP are identical to NaiS, or moderate modifications. However, small modifications of the targets and the assessment procedures result in different conclusions on the protective effect of forests. Therefore, for example, SFP shows a considerably lower rate of false classifications concerning landslide initiation in forests than NaiS. However, this does not indicate an optimized system, but is due to more strict critical values.

The main function of NaiS is the controlling of the silvicultural measures in protection forests on plot or on stand scale in order to evaluate target achievements of protection forest management and furthermore of the forest policy. NaiS provides two levels of hazard-related targets, (1) the "minimum" and the (2) "ideal" requirements on the density and structure of the forest.

The hazard-related targets are presented in combination with indications of the basic hazard susceptibility, but without a linkage to protection targets (assets at risk) and without a clear separation of indicators of the protective function and of targets to maintain the protective effect.

The targets of NaiS and SFP are presented in tables without a description or a flowchart how to link the targets to quantify the protective effect.

NaiS provides a glossary. The descriptions in the glossary do not include measurement instructions, which are crucial to apply technical guidelines in practice.

GSM-N

GSM-N provides flowcharts to identify the protective function ("role") of forests. Although GSM-N refers to risk assessment and to a classification of assets, the procedures do not include a classification of the protective function on base of the importance and vulnerability of the human infrastructures to be protected. The social and economic importance of human infrastructures determine the direct object-protective function of forests and furthermore the protection targets, which may require different demands on forest conditions and management.

The issue of hazard potential or forest function assessment is also mixed to varying degrees with indicators of the protective effect by using the term "rôle de protection", which is ambiguous and should not be used. This concept excludes a protective function and therefore also a protective effect of the forest in case of extraordinary block sizes for example. However, the concept does not consider that smaller blocks also may be mobilized from the same rockfall sources. It is therefore not fully justified to exclude a protective function or "role" of the forest on base of the GSM-N criteria, even if the protective effect is limited in case of extraordinary hazard events or sparse woody vegetation.

Like NaiS and SFP, the criteria to assess the protective effects of forests are listed in tables without any instructions how to combine them or how to consider cumulative effects of forest stands on slope scale. The criteria might be linked by restrictive "and" conditions. But there are no instructions about this, and this is not appropriate for each category of hazard and hazard zone. Concerning rockfall, the concept mixes forest characteristics of the stand and of the slope scale.

GSM-S

In GSM-S, the protective function of the forest results from the combination of the hazard classification and the ranking of the human infrastructure within the potential hazard zones by a combination matrix. The concept to map and classify the protective functions of forests clearly differs the protective function from the protective effect in form of a simplified risk-based approach, whereas the GSM-N approach mixes functions and effects which may result in inappropriate assessments.

A drawback of the GSM-S approach is that the probability and the expected intensity of the natural hazard (in case of not protective forests in future, but without consideration of current forest conditions) is considered in very general terms. Therefore, the GSM-S approach may assign a high relevance of the protective functions of forests to hazard zones, where forest maintenance or afforestation is not the most effective measure of hazard mitigation, for example within active starting zones of avalanches.

The procedures of GSM-S to assess the protective effects of the current forest are presented in form of clear flowcharts. Just like GSM-N, GSM-S refers to the protective effect as "rôle de protection", and in some cases a protective effect of the forest is also excluded without plausible reasons. GSM-S also refers to the future protective effect of the forest under consideration of forest development and stability. The priority of silvicultural measures results from the current and the future protective effects of forests. However, we could not figure out how the future protective effect of the forest is derived and linked to priorities given by the damage potential (forest function).

ISDW

ISDW was developed for the same purpose as NaiS, the evaluation of silvicultural measures in protection forests on plot or stand scale. ISDW is an internal guideline of the Austrian forest authorities, only used in the frame of funding to support the rural development by the European Agricultural Fund for Rural Development 2007-2013. The guideline was not published, because responsible editors and forest practitioners were aware that the assessment of the protective effects of forests still involves considerable uncertainty. However, without a definition of targets concerning forest characteristics, an evaluation of protection forest policy is not possible. Forestry practitioners have rejected such guidelines and target-settings as too inflexible and not adaptable to the manifold situations in forests, a discussion which has also taken place in Switzerland.

Like NaiS, the guideline was explicitly not developed to map and classify the object-protective functions of the forests. The guideline assumes that there is an object-protective function identified by forest authorities.

The assessment procedure consists of the following steps: (1) assessment of the basic hazard susceptibility to different hazard categories without consideration of the forest conditions; (2) assessment of the protective effects of the forest depending on the basic hazard susceptibility and forest characteristics; (3) classification of the forest texture; (4) assessment of inhibiting factors of a sustainable forest growth and (5) overall assessment of sustainable protection by the forest.

The superior principle of spatial organization of ISDW is not a differentiation into starting, transit and deposition zones, since such a classification is often not clearly possible in the forests. For each hazard category there is an evaluation matrix for the basic hazard susceptibility and the protective effect of the forest. The guideline does not use flowcharts like GSM-N and GSM-S. However, the matrix combination of site and forest characteristics leads the users to a clear result.

The basic hazard susceptibility refers to the probability of hazard initiation in case of snow avalanches and landslides. The basic hazard susceptibility of rockfall considers the capability of a (stand or forest) section in the rockfall path to hamper rockfall propagation without a forest cover. This is different from GSM-N and GSM-S, since both of these systems refer to forest characteristics on stand and on slope scale without any clear allocation for example of stand densities to the slope or to a single stand in the slope.

The assessment of the protective effect of the forest is based on the current conditions of forest. The level of the protective effect refers to a section of forest under consideration like in the NaiS approach, and not to the entire forest relevant for protection of an infrastructure. The overall assessment of target achievement is organized by an evaluation matrix to combine the lowest level of the protective effect, the forest texture, and the inhibiting factors of forest stability.

Site-specific targets of forest structure are compressed to few but generalized targets. The guideline does not provide information to assess the resistance of forests like critical values of crown lengths and height-diameter-ratios, since this is known, and such indicators do not guarantee sustainability of forest growth. The principles of protection forest management are limited to few general recommendations.

The aggregation of indicators to an ordinal benchmark of the basic hazard susceptibility is suitable for the classification of the protective function, as is also done in GSM-S ("Note d'aléa"), but in the ISDW concept without a link to the infrastructures at risk. However, this aggregation reduces the adaptability of the assessment of the protective effect to specific situations and to new findings. The evaluation matrices force site conditions into a rigid pattern, whereas assessment procedures like the flowcharts used by GSM-N and GSM-S that are primarily independent of the overall assessment of the basic hazard susceptibility allow better adaptation to specific situations.

Spatial scale-related limitations

All the guidelines do not define exactly how to form spatial evaluation units which are necessary to measure the evaluation criteria and to assess the protective functions and effects of forests. NaiS (SFP) and ISDW refer to the stand scale for snow avalanches, landslides and rockfall. GSM-N and GSM-S mix indicators of the slope and of the stand scale.

All guidelines except ISDW follow the concept to differ starting, transit and deposition zones of natural hazard processes, which sounds simple, and is suitable for channeled large avalanches and for rockfall from steep cliffs. However, this scheme is too simple for other processes and situations in relation to the manifold effects of forests. Potential and active starting and transit zones of several hazard categories are mixed spatially and overlap in steep forested terrain. The boundaries of ecological and stand structure units of forests are not clearly aligned in nature to the envelopes of potential or active starting and transit zones. The union of forest stands, and hazard zones classified by hazard categories, hazard processes, hazard activities and damage potentials usually lead to extreme fragmentations of evaluation units. This is not appropriate for forest management. Foresters will apply the criteria to units like the units ("stands") of forest management plans. However, stands of forest management plans are not inevitably suitable for the assessment of protective effects of forests. Usually, they do not take adequate account of the geomorphology of the terrain, as they focus on timber production, and since this would make them too small.

The evaluation units of protective effects of forests have to consider two main functions of forests: 1) the primary ability and therefore the function of forest is to prevent hazard initiation in potential starting zones (snow avalanches, landslides) or 2) to break down and stop the propagation of the hazard process (rockfall). The protective effect of a forest - especially in transit zones of natural hazards - results from different impacts of all stands depending on their density, structure, size and location in relation to the process intensity and propagation. An unwooded area like a clear-cut or a meadow may be completely irrelevant, if other sufficiently large and dense stands in the flow path can stop the process. This is called the effect of the forest stand texture. The guidelines give no indication of how to deal with this.

The nature of natural hazard processes, site and forest conditions require small- to medium scale considerations, since zones of hazard processes with high impacts may be small (e.g. rockfall) and the spatial variations are high. But the identification of such small and fragmented units by terrestrial mapping is hardly possible for larger areas and very costly when interpreting aerial photographs too. One method to overcome this problem is the derivation of structural characteristic of forests in a high spatial resolution from normalized digital surface models. However, it is not possible to obtain all forest and site characteristics necessary to assess the protective effects of forest from digital surface models and optical aerial images. Furthermore, the temporal mismatch problem limits the reliability of remote sensing.

The assessment of object-protective functions of forests

The guidelines are not suitable for determining the object-protective function of the forest. NaiS, SFP, GSM-N and ISDW do not include the damage potential to assets in case of not protective forest conditions to the assessment procedures. GSM-N just refers to the consideration of the hazard and damage risk situation, which is depending on the vulnerability of assets, but without consistent implementation in the assessment procedures. The GSM-S concept clearly differs the protective function from the protective effect and provides a simplified risk-based approach. However, GSM-S presents the combination matrix to assess the protective function of the forest without a link to the matrix, which defines the priority of measures on base of current and future protective effects.

But the limited suitability of the guidelines for protective function mapping is mainly due to conceptual and logical errors in the proposed procedures, and due to fuzzy and inappropriate indicators of the basic hazard susceptibility. NaiS and SFP for example link the basic susceptibility to avalanche initiation to the type of forest, which is only a suitable indicator for determining the protective effect. Some indicators used by the concepts for regional application, such as the aspect of the forest site, only indicate the susceptibility to avalanche formation on a medium to local spatial scale.

Concerning landslides, none of the guidelines refer to quantitative classifications or indicators of the landslide probability on base of observed spatio-temporal landslide densities of slope units. Especially the occurrence of shallow landslides and rockfall cannot be determined with certainty from silent witnesses but requires the formation and analysis of geological-geomorphological slope units.

The assessment of object-protective effects of forests

The procedures and indicators to assess the probability of snow avalanche and landslide formation in forests either result to a significant proportion or to an extremely low proportion of false classifications. Both may result in incorrect assessments of the risk of damage to infrastructures.

This contrast is particularly high in the case of snow avalanches. Concerning landslide initiation, the misclassification rates are higher in general than in case of snow avalanches.

A misclassification means that the procedure cannot be used to determine with certainty whether snow avalanche or landslide formation is possible. As the probability of snow avalanche formation in forests is generally low, this might not lead to considerably wrong avalanche risk assessments, but to underestimations of the protective effect of forests. As regards landslide initiation in forests, the results are more problematic.

The extremely low misclassification rates of some methods do not necessarily indicate optimized procedures, but too high critical values and requirements to forest structure. The false classification rates result from conceptual weaknesses and from some inappropriate indicators.

The "minimum" and "ideal" requirements of NaiS and SFP do not show considerable differences of the classification results. Therefore, this differentiation is not effective.

The guidelines (NaiS, SFP), which use the total canopy cover (instead of the evergreen canopy cover), and which do not use the stem density in deciduous forests, show higher false classification percentages of the susceptibility to snow avalanche formation than the other approaches. NaiS and SFP show also lower true classification rates since they use the gap length as a primary indicator. Analysis of the data and other studies indicate that the length of the canopy opening is not related to the avalanche release probability in forests and does not significantly influence the avalanche propagation.

The quite low false classification rates of GSM-S and ISDW do not indicate optimized procedures of the snow avalanche protective effect of forests, but too high critical evergreen canopy cover percentages or stem densities. ISDW's high true classification, despite the poor result in terms of critical gap widths, shows the strong the influence of sequencing in the combination of indicators.

GSM-S gives no information about the sizes of canopy openings critical to snow avalanche (and landslide) formation, although this is important for protection forest management. Additionally, GSM-S's stem density curves do not optimally differ between a "low" and "no" protective effect.

NaiS and SFP allow larger canopy openings, if there is secured regeneration on sites susceptible to slope failures. The results of the study and literature indicate that young growth is not fully able to substitute the root reinforcement of mature forests. Therefore, even with existing regeneration, much larger openings are not justified. The canopy cover of the pole- and sawtimber trees is better suited for estimating the protective effect of the forest than the total canopy cover, which is proposed by GSM-N, GSM-S and ISDW. The results of this study and scientific literature do not give a clear answer of whether the area, the length, or the width of canopy openings in the stand better explains the occurrence of landslides. A reduction of the amount of large-sized timber in forests as proposed by SFP and ISDW may not enhance the protective effect against landslide initiation.

The results and literature indicate that there is a strong influence of the terrain on rockfall runout length. The length of the forest units and cumulative density measures are more appropriate than the indicators proposed by the guidelines.

Final conclusions and recommendations

The guidelines should not be used for the assessment and mapping of the object-protective functions of forests. This task can only be solved by spatial modelling in combination with terrestrial post-processing.

The guidelines should be used with caution when assessing the protective effect of forests and subsequently when assessing hazard and damage risks, especially on forest sites close to infrastructures.

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