INFLUENCE OF FOREST ON SNOW AVALANCHE HAZARD – NORWEGIAN CHALLENGES

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ABSTRACT: Forested areas are less prone to snow avalanches, due to the trees' influence on snow accumulation, snow pack layering, energy balance and the armoring effect of the trees. Crown cover, tree dimensions and forest density influence the protection effect of the forest. A plan for preserving forest – and re-establishing forest after logging or after forest fires, avalanches or landslides, can potentially reduce avalanche danger.

Many places in the European Alps and in North America protection forest is recognized as a mitigation method against natural hazards. In Norway the effect of forest is less studied. Regulations in forest harvest due to avalanche protection are uncommon, creating a challenge when it comes to hazard zoning. This paper sheds light on some of the Norwegian conditions and challenges.

1. INTRODUCTION

Avalanche hazard zoning is many places done from terrain features and climate data alone, even though vegetation is a variable well known to potentially reduce avalanche hazard. However, forest and vegetation in a slope can change rapidly due to natural or human disturbances; it is therefore a challenge to include this factor in hazard zoning and land use planning.

During the last half century, the forest in Norway has changed in two ways: 1) Large scale plantation of the north American Sitka spruce (*Picea sitchensis*), Norway Spruce *(Picea Abies)* and the hybrid *Picea x Lutzii* in original pine and birch areas in the Norwegian fjord districts around the years 1950-1975 has resulted in large stands of mature forest. 2) The timber line towards the mountain has risen due to among other factors reduced grassing and less fire wood logging.

We argue that this has reduced avalanche danger in many areas in Norway compared to the situation for example around year 1900. Many of Norway's biggest avalanche accidents happened in the late 1800's, and several of these avalanche paths and starting zones are now completely forested. According to Øyen (2012) the forested area is expected to continue rising in the next few decades. *Picea Sitchensis* covers around 500 000 daa (decare) in Norway, and large stands of this spruce are now mature and ready for harvest, making the topic protection forest highly relevant.

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Guidelines for protection forests exist for countries in the Alps as well as in North America (Weir, 2002; Bauerhansl et al., 2010). In Norway however the forest's influence on natural hazards is a less studied topic and guidelines from other countries need adjustment to take Norwegian conditions into account. The fact that there is no legislation in Norway that regulates forest logging on the background of natural hazard potential constitutes an extra challenge.

2. EFFECT OF FOREST

2.1 Starting zone

Forest affects the quality of snow cover on the ground in several ways, mainly due to its effect on the microclimate. Forested areas have generally less snow on the ground than open space areas (according to Weir (2002) snow cover is reduced by 30 %), fewer faceted grains, less layering and experiences less creep in the snow pack (Frey and Salm, 1990). Net energy loss is lower in forests than in open areas, reducing the existence of surface hoar as well as the development of faceted grains deep in the snowpack which often represent weak layers. Also, dripping water or snow falling from the canopy may damage surface hoar in the forest. These effects are mainly influenced by the forest's crown cover (i.e. Gubler and Rychetnik, 1991, Bauerhansl et al. 2010). Forest also protects the snowpack from wind, reducing snow drift and resulting layering.

Apart from producing a snow pack less prone to snow avalanching, trees also act as *mechanical reinforcement*, holding the snow in place in a similar way as human built steel supporting structures. The effect is largely dependent on number of stems per area.

2.2 Runout zone

The effect of forest in the path or in the runout zone is less documented than forest in starting zones, and a more difficult task to evaluate in hazard zoning.

Recent research (Anderson and McClung 2012) indicates that mature forest retards avalanche motion and shortens avalanche runout. Their data set shows that 44 out of 45 avalanches which met forest in their path ran shorter than to the beta-point.

However, the size and speed of the avalanche is likely to be largely significant for such retardation, as well as the trees' ability to withstand the pressure, varying with species, dimensions and density. Gubler and Rychetnik (1991) found that dry avalanches will run through forest if the original fracture height is more than 1 m and that trees with stems of up to 30 cm diameter can be destroyed by avalanches that have run less than 30 m.

3. EVALUATION OF FOREST EFFECT IN HAZARD ZONING

It is clear that forest reduces avalanche hazard. However, to what degree?

Protection effect of a forest depends on among other factors (i.e. Bauerhansl et al. 2010):

- Crown cover
- Tree species
- Tree height
- Tree diameter
- Stem number/area
- Gap length and width
- Deadwood and stumps

The height of the trees is essential for the forest to be of significance. As a rule of thumb, trees must be 1.5 to 2 times higher than the maximum snow height in the area to be effective (Frey, 1978). This means that minimum height of the trees in a protection forest varies with altitude and climate. Snow depth is therefore an important variable in evaluation of forest effect.

The crown cover of the trees is of main importance (i.e. Gubler and Rychetnik 1991, Bauerhansl et al. 2010) when it comes to changing the microclimate in forested areas, and evergreen coniferous forest is the most effective for avalanche protection. Gubler and Rychetnik (1991) found that spruce effectively reduces the formation of weak layers. Bauerhansl et al. (2010) summarize different European guidelines and conclude that an evergreen crown cover (ECC) of 50 % or a total crown cover (TCC) of 70 % can prevent significant avalanche formation.

In Norway, the planted spruce stands in the fjord districts are very dense, letting almost no light through the canopy. The crown cover is likely to be around 90 %. Most planted spruce stands in Norway are now 50-60 years old and are around 25 m high, with stems of diameters around 30 cm. We regard most spruce stands in the fjord districts of Norway to satisfy the foreign specifications for protection forest.

Birch (*Betula Pubescens*) is the most common deciduous species and has an open canopy in winter time. The higher altitude forest consists of the smaller Arctic birch (*Betula Pubescens ssp. Czerepanovii*). At its climatic border, these trees will often regenerate by suckers. The result is stems in small groups - the stem density for grown forest may be quite high in smaller areas but the gap with is uncertain. This type of tree is not as high as spruce and their stems are easily bent by snowload or even avalanches. Their effect as protection forest is therefore questionable, especially in years of extreme snow height. Birch is however a very common species in Norway, and is often a factor when evaluating avalanche hazard for mountain cabins etc and should therefore be studied closer.

There are also considerable areas of mixed forest in Norway. This type of forest is less studied and TCC, dimensions and stem number/area should be further examined for evaluation of their protective effect.

Pfister (1997) and Bebi (1999) developed methods for evaluating the probability for avalanche release in forests (0-100%) and found that a protection forest should have a probability for avalanche release less than 50 %. In Norway, minimum values for yearly avalanche probability exist for new buildings of different types (maximum probabilities ranging from 1/100 per year to 1/5000 per year). If forest is to be used in practice as a protective measure, specific values for forest qualities satisfying the different maximum annual probabilities should be developed.

4. AVALANCHE HAZARD EVALUATION AND FOREST MANAGEMENT PRACTICE IN NORWAY

The term protection forest juridically exists in Norway, however, the so called protection forest border towards the mountain is mainly created to protect the lower altitude forest from harsh mountain climate, not to protect objects like houses or roads from avalanche hazard.

In the fjord districts flatter areas are rare, and farms are typically distributed one by one along the fjords. Uphill the farmhouse there are steep forested areas, divided years ago into sectors belonging to the different farmers. The sector above one farm sometimes belongs to a neighboring farm. This makes it a challenge to take forest into account in avalanche zoning work due to the difficulty in enforcing the necessary restrictions on forest management.

The authors know of one example from the 70's when tree logging ended up in building of protection measures in the logged areas as a compensation for the lost forest protection from avalanches (Kringstadlia, Molde, NGI Project No. 784013). Studies showed that a snow avalanche released and moved half of a house into the sea back in the 18 hundreds. At this time, the area was probably deforested by grassing and extensive foresting due to timber export to Europe.

Figure 1 illustrates a typical logging area in the fjord districts of Norway. The recently logged area (ring) is situated just downslope an open area where avalanches are likely to release.

Figure 1 Typical clear cut logging of spruce stands. Logging may have enlarged starting and entrainment zone.

A few years back an avalanche hit and destroyed parts of the remaining plantation. The retarding effect of the remaining forest is an unknown factor, but a further deforestation could possibly increase the avalanche hazard in the area. Hazard evaluation is difficult in such areas.

5. FOREST HARVESTING IN PROTECTION FORESTS

Avalanche hazard is often neglected in forest logging. We suggest the following steps when assessing forest harvesting. Each step includes detailed professional knowledge and evaluation.

a) Identify if terrain favors avalanching.
b) Identify if climate favors avalanching
c) Identify consequence: any object threatened?
d) Identify if forest have the qualities required to be effective as avalanche protection
e) If protection forest – develop and follow a harvest and management plan for protection forest – or build protection measures.

Logging in a protective forest is a question of balance between different interests, such as economical interests, biodiversity and natural hazard considerations.

Conventional clear cut logging is effective and economical in a short perspective but obviously not the ideal harvesting system when it comes to avalanche protection as it creates continuous open space. McClung (2001) found that 10 000 clearcuts in British Colombia where affected by avalanches. Therefore, to maintain forest with protective effects, harvest methods could be developed that reduce the size of clearcuts, leave strips of forest across contours and in gullies, and leave certain amounts of stumps and deadwood behind (Weir, 2002).

In many countries in Europe 50 m is set as a standard value for maximum open downslope length in protection forest (Bauerhansl et al. 2010). Gubler and Rychetnik (1991) found that slabs starting in openings larger than 30-60 m would destroy the forest immediately downslope the opening.

One harvest method could be to log horizontal strips thin enough so that avalanches are not allowed to develop enough speed to damage and run through downslope forest. An obvious question would be when it is justifiable to cut the neighboring (upslope or downslope) strip of forest. If replanted, a logged area will probably reestablish protective effects after around 20 years. According to the Norwegian Forest Act, a harvested area should be replanted within 3-5 years after logging. However in 1 of 5 cases the logging areas at the west coast are turned back to grass land or changed to other types of land use (Øyen 2012).

5.1 Maintenance of protective forest

A forest will change throughout the years either by its natural life cycle, by fires, natural hazards or by human harvest. Also a healthy forest with a high density of stems needs regeneration and care to function as a long term protection forest, and should not be left unharvested. According to a national report from Austria, there is a high need for regeneration in 2/3 of the Austrian protection forest, and only 59 % of the protection forest is assumed to be stable (Patek et al., 2010).

If the forest's main value is to protect against avalanches, after logging one could consider replanting a mixed forest, with TCC of more than 70 %. Such forests probably favor continuous regeneration and will require less future management than a dense spruce forest.

6. CONCLUSIONS

If meeting certain qualities when it comes to density and dimensions, forest can be an effective measure against snow avalanches. Due to lack of guidelines and legislation within this field, regulated protection forest is in practice non-existing in Norway. Clear cut logging is wide spread, potentially creating new release and entrainment areas. Large-scale harvesting of mature spruce forest now enforces more focus on the forest's protective effects and enlightens the need for standard guidelines, harvest and management plans and juridical regulation.

6.1 Further work

A closer study on Norwegian conditions is needed, especially when it comes to the effects of birch and mixed forest on avalanche and other types of natural hazards. Harvest plans should be optimized. Further studies will be done in cooperation with Norwegian Water Resources and Energy Directorate (NVE), aiming for Norwegian guidelines for protection forest for all types of gravity mass flows.

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