

# Natural dynamics in subalpine avalanche protection forests in the Swiss Alps

Krumm, F.<sup>1</sup>, Bebi, P.<sup>1</sup>, Panayotov, M.<sup>1,2</sup> & H. Spiecker<sup>3</sup>

<sup>1</sup> Swiss Federal Research Institute WSL (SLF), 7260, Davos

<sup>2</sup> University of Forestry, Sofia, Bulgaria

<sup>3</sup> Institute of Forest Growth IWW, Freiburg, Germany

Email: krumm@slf.ch

## Introduction

Mountain forests of the Alps fulfil important protection functions against avalanches and other natural hazards. The majority of the subalpine forests in the Swiss Alps are dominated by spruce (*Picea abies* Karst.). The protection effectivity of these forests is highly variable in space and time and depends on different circumstances such as topographical settings, predominant disturbance regimes and management history.

Structures and protection effect of mountain forests are permanently changing. After centuries of overexploitation, density of most remaining forests in the Alps were very low in the middle of the 19<sup>th</sup> century, leading to increasing concerns about their protection function (Kasthofer 1822, Landolt 1960). Since then, there is a high effort to increase and permanently maintain the protection function of mountain forests. Consequently, forest-cover and forest density drastically increased during the 20<sup>th</sup> century, generally leading to improved protection against natural hazards, but often also to a dominance of more or less even aged (~100-150 years old) protection forests characterised by high densities and monotonous structures with very low regeneration. The successful reforestation efforts and regeneration problems in even-aged forest stands supported the notion that “only maintained protection forests provide enough and sustainable protection against natural hazards”. There is, however, only little knowledge about natural dynamics of subalpine, spruce dominated forests in the Swiss Alps. The goal of a new international research project is thus to determine and analyse the relevant processes occurring in subalpine spruce dominated forests without human impact.

In this paper we give a short overview on the current state of knowledge on dynamic processes in unmanaged subalpine avalanche protection forests in the Alps and we present and discuss methodical approaches to explain the natural development of unmanaged forests in the subalpine altitudinal belt with the help of newly available inventory data series and tree-ring data.

## Dynamics of avalanche protection forests: What do we know?

Gravitational natural hazards like avalanches, rockfalls, or landslides appear more often in subalpine and alpine regions than in lower areas. According to the second Swiss National Forest Inventory (NFI), 31 % of montane or subalpine forests exhibit tracks of snow movements, 31 % of the areas have tracks of rockfall and 16 % tracks of erosion (Mahrer et al. 1988). 15% of the forests in Switzerland have a direct protection function against avalanches, rockfall or landslides. Particularly for avalanche protection, most of these forests are in the subalpine belt. Their importance for protecting human settlement and infrastructure is increasing, especially in tourist regions and along traffic and transportation routes. As a consequence, vulnerability and damage potential below protection forests is high and the Swiss government invested within the last few decades between 120 -150 million sfr per year for “protection activities in forests”. Around 60 % (70-94 million sfr/year) were used for maintaining protection forests, regeneration, repairing damages in forests, planning actions in the protection forests and building and maintaining infrastructure in protection forests (Schärer 2004).

Natural forest development is often described with four different stages (Barbour & Billings 1988, Oliver & Larson 1990, Peet 1999): (1) "Establishment": Phase of regeneration, mostly initiated by large – scale disturbances; (2) "stem exclusion": intensive competition with increasing tree – density excluding the establishment of young trees (cf. Fig. 1); (3) "Breakup": small - or large - scale breakdown, establishment of regeneration possible; (4) "Old – growth": no disturbances or management treatments since a longer period. The amount of dying trees and new establishing trees are more or less in balance.

For natural subalpine forests, the same stages can be described, but the relative importance of different stages may change with increasing elevation. Establishment can be so slow that by the time of canopy closure trees may already be dying from senescence-related causes. Consequently, the second and third stages - "stem exclusion" and "breakup" may be bypassed and one finds a stage in which both stand density and tree size slowly increase towards steady state conditions (Peet, 2000). Such complex natural forest structures with different layers, tree sizes and ages provide optimal protection against natural hazards (Ott et al. 1997, Motta & Haudemand 2000). They protect against different kinds of natural hazards in a sustainable way and exhibit a higher elasticity after disturbances such as windthrows and avalanches (Brang et al. 2006).

As a result of former over-exploitation and subsequently decreasing pressure of grazing and wood exploitation on large scales, many subalpine forest areas in the Swiss Alps differ from what would naturally be expected in such sites. Favourable growing conditions, providing enough light, warmth, nutrients and open soils have led to an increasing amount of young and dense forest patches in subalpine regions after land-use extensification (Bebi 1999, Brassel & Brändli 1999). Dense forest areas with more than 600 stems per hectare provide protection against rockfall and avalanches (Cattiau et al. 1995), but may be more susceptible against storm and snow break (Rottmann 1985) and require a longer period to regain their full protective properties following a disturbance. With silvicultural actions the heterogeneity and sustainable protection functions of such dense, homogenous forests in the stem exclusion stage can be influenced (Schönenberger & Brang 2004). However, the effect of such interferences differs highly according to site conditions and time of interventions. The costs of management interventions are generally so high, that they have to be prioritised according to risk considerations and expected natural dynamic of such forests without interventions (Bebi et al. 2004).

For the Alps, there is only little knowledge concerning the dynamics of subalpine forests in "self-thinning" (stem exclusion) phases. The existent knowledge is mostly based on work from outside the Swiss Alps (Peet & Christensen 1987, Korpel 1995, Veblen & Donnegan 2005). Results of dendroecological analysis and aerial photos from the European Alps suggest that the stem exclusion phase in subalpine forests does mostly happen in small scales (Cherubini et al. 1996, Motta et al. 2002). But there is still little knowledge about the time period needed for a change into favourable regeneration conditions and how this varies over different site conditions.

Near natural timberline the forest structures in the Alps and in other mountainous regions are getting more and more scattered (Arno & Hammerly 1985, Rochefort & Peterson 1996, Stützer 2002). With increasing elevation, transitions from open forest structures to closer forest structures are less frequent and slower (Bebi 2000, Rutherford 2006). The influence of temperature as a limiting factor becomes more significant with decreasing distance to the upper treeline. Consequently growth processes are slowing down and the regeneration processes of trees are strongly restricted in space and time (Ott et al. 1991, Körner & Paulsen 2004). Aggregated forests among the timberline exhibit several advantages concerning the concurrence, particularly because soil temperatures below single trees or tree cohorts are higher as below dense forest stands (Shanks 1956, Körner & Paulsen 2004). Furthermore larger amounts of snow related disturbances, like avalanches and snow-break, cause openings of the stand (Imbeck & Ott 1987, Walsh et al. 1994, Kajimoto et al. 2002).

Avalanches have a high impact on mountain ecosystems. They play important roles in shaping ecosystem dynamics, and may contribute to diversity at species and landscape level, can induce soil transport and different other types of disturbances (Luckman 1978, Rixen et al. 2007). However, avalanches also represent a source of danger to human settlements and infrastructures (Fuchs et al. 2004). Primarily subalpine forests are affected by avalanche disturbances, and in dependence of the steepness of a slope and weather conditions, avalanches may occur several times during a winter (Latenser and Schneebeli 2002). The avalanche protection function of a forest consists of impeding the release of avalanches in the forests. The most important criteria concerning the avalanche protection function of a forest are stand density (degree of coverage) and the dimensions of gaps (Meyer-Grass & Schneebeli 1992). Factors as steepness, exposition, surface structure and the rate of evergreen trees could also have an important impact for the occurring of avalanches (Schneebeli & Bebi 2004). This function is limited close to the timberline due to larger gaps between the trees or between the cohorts of trees. The avalanche protection function is also limited against avalanches starting at least 150 meters above the timberline (Schneebeli & Bebi 2004). Natural disturbances such as windthrow or bark beetle outbreaks might change the protection functions of forests immediately (Brang 2004). Dense and homogenous protection forests are generally not more sensitive against such disturbances, but they need longer to regenerate and to reach again the full protection function.

Open forest structures near timberline and monotonous formed forests of high density are thus potentially problematic forest types concerning their sustainable protection function. With increasing areas of these two forest types that haven't been managed for several decades, it is particularly important to learn more about their natural dynamics. As different driving forces seem to be predominant in these two forest types, open questions and hypotheses for the natural dynamics of subalpine avalanche protection forests have to be differentiated according to them.

A key question in open avalanche protection forests near timberline is whether they are increasing in density due to climatic factors and land-use change. These two factors might influence the forest dynamic in different ways and are often difficult to disentangle (Gehring-Fasel et al. 2007). We hypothesise that density in subalpine forests is only increasing under certain site conditions and that on very steep slopes and on sites with frequent disturbances, the forest coverage is not changing significantly. Near timberline where mainly abiotic processes cause tree mortality, self-thinning processes and competition are factors of marginal relevance. When the canopy approaches closure, trees may die from senescence related causes. "Old-growth" and "establishment" are the two phases that mostly occur under natural conditions near timberline, since the stages "Establishment" and "Stem exclusion" are essentially a function of competition, which is minimized in stressful environments.

Dense, homogenous forests in the stem exclusion stage are more driven by competition. It is an open question what finally causes tree mortality and how long this process lasts. Is it a long - term process over several decades or a quick process following some event (e.g. extreme climate situation, fine-scale disturbance). Our hypothesis is that the major reason for dying trees in subalpine avalanche protection forests within the self-thinning phase is competition. The weakest trees have competitive disadvantages such as smaller crown, less light, nutrients and warmth compared to competitors and die first. The "dying" process is a long lasting process that might take up to 100 years. Other questions of high importance in these subalpine forests in the stem-exclusion stage are: On which scale do disturbances occur? How do different site conditions and former management history affect their natural development? How fast do disturbances and subsequent regeneration processes occur without human interventions?

### **Methodical Approaches**

To examine the development and dynamics of subalpine spruce dominated forests, two different methodological approaches on different spatial and temporal scales which are complementary to each other were chosen: (1) the analysis of inventory data from three periods of the Swiss National

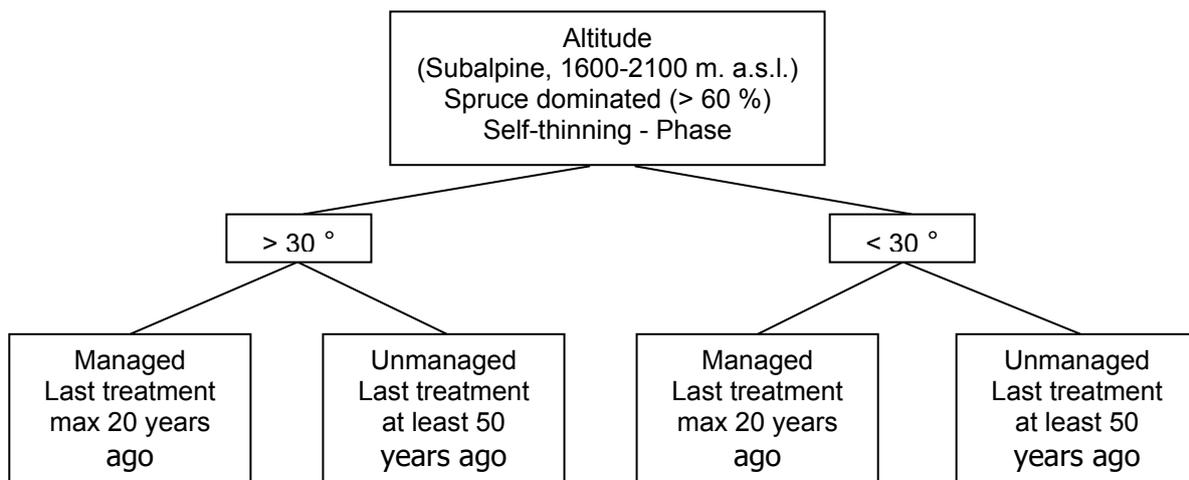
Forest Inventory and (2) the assessment and dendroecological analysis of field data on selected plots. Purposes of and differences between the two methodological approaches are summarized in table 1.

*Table 1: Comparison of the two complementary approaches to analyse the dynamics of subalpine avalanche protection forests*

<b>Analysis of NFI data</b>	<b>Dendrochronological analysis of selected forests</b>
Quantitative analysis of about 150 NFI plots with the goal of investigating differences in forest development in dependence on silvicultural management actions.	Qualitative, more detailed analysis of a selection of sites. Focus is set on "single tree-dynamics")
Focus on the last 20 years (time span of the three inventories). Comparison of different variables such as steepness, grazing, avalanches and rockfall	Investigation from the originating of the site, age of the trees – long - term development. Dynamical changes since originating.
Dying processes – examination over a larger scale.	Dying processes consideration on a high resolution.
NFI data contains information about small scale disturbances	Role of small - scale disturbance regime – small gaps, tree development in small gaps.
	Analysis and evaluation of microclimatic and regional influences

#### **Analysis of data from three complete finished Swiss National Forest Inventories.**

The Swiss Forest Inventory (NFI) obtained data from three inventory periods, NFI 1 1983-1985, NFI 2 1993-1995 and NFI3 2004-2007. On the basis of this data we identify forest areas in the whole Swiss Alps fulfilling our requested criteria of land-use and site conditions (see Fig. 1). 77 of these forests, selected from the NFI sample (1 km grid over Switzerland, for details see Brassel & Brändli, 1999) are in the self-thinning phase (stem exclusion). This selection of NFI-plots allows us to compare the development of unmanaged forest areas with comparable subalpine forests and to further analyse them with GIS and statistical methods.



*Figure 1: Selection criteria for evaluating NFI data. Number of selected forests n=77.*

The basis of our analysis is the situation during the assessment of NFI 1 with equal numbers of plots for different treatments. We then examine the development of the forests from NFI1 to NFI2 and NFI3 concerning stand density, proportion of dead trees (standing and lying) and the

dimensions of subsequent disturbances. Preliminary analysis show that various site factors exert a strong influence on structure and development of the examined subalpine forest stands. For example, sites with signs of avalanche activity have lower basal areas per hectare than sites without signs of avalanche activity (Fig. 2).

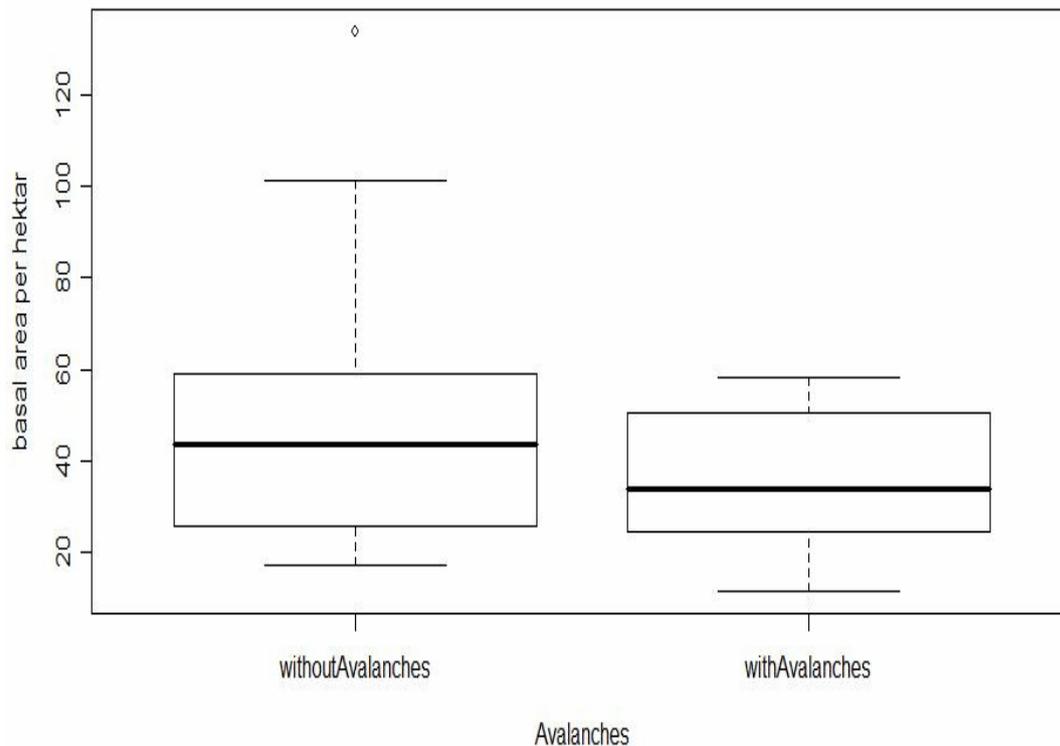


Figure 2: Basal area per hectare in unmanaged (at least for 50 years) forests. Without the influence of avalanches (left) and with avalanches (right)

#### *Dendroecological analysis of selected "self-thinning" plots in the Swiss Alps*

Based on the NFI data and the criteria described above, we locate representative plots for the Swiss Alps and study them with dendrochronological methods concerning stand structure, stand dynamics, history and age structure. Additional parameters, such as the stand density index, the degree of coverage, exposure, steepness of the slope, altitude, crown height, tree height and the diameter in 1.3 m, will be included as co-variables in the analysis.

In each plot we select areas of 22 \* 22 meters, where every tree with a diameter  $\geq 10$  cm, (dead and alive, standing and lying) will be cored twice. In order to determine the age of the trees (e.g. obtain as many year rings as possible), we take one core from the bottom, from downside the tree. The second core is taken from a height of 1.3 m parallel to the slope and provides information about year ring widths excluding reaction wood for getting information about the competition and dynamics of every single tree. Additionally we assess the structure of the whole site by exhibiting 10\*10 meters plots. In 5 such 10\*10 plots we measure diameters of every tree  $> 6$  cm, count the regeneration and put them into different age classes.

The year ring widths will be measured in the Laboratory of the Institute of Forest Growth in Freiburg (Germany) and we will analyse the year ring samples with standard methods (Stokes & Smiley 1968) concerning the age structure and the dynamic of the forests. The effects of disturbances will be related to differences in growth to the forest structure by using statistical analysis.

## Outlook

Our research questions and hypotheses concern dense subalpine forests, and open forests near timberline. These are different forest types that require different methodical approaches. The two described methods enable us to get quantitative information about the requested forests over the whole Swiss Alps. We are also able to examine forests within the stem exclusion-stage on a high resolution and on small scales. The dendroecological method allows us to reconstruct the history and the dynamics of every single stand.

## References

- Arno, S., Hammerly, R.P. (1985): Timberline-Mountain and Arctic Forest Frontiers. 304p.
- Barbour, M. G., Billings W.D. (1988): North American Terrestrial Vegetation. Cambridge University Press, New York, Port Chester, Melbourne, Sydney. 434p.
- Bebi, P. (1999): Erfassung von Strukturen im Gebirgswald als Beurteilungsgrundlage ausgeprägter Waldwirkungen. Dissertation.
- Bebi, P. (2000): Strukturen im Gebirgswald als Beurteilungsgrundlage ausgewählter Waldwirkungen. *Beiheft zur Schweizerischen Zeitschrift für Forstwesen 90*: 1-128.
- Bebi, P., Grêt-Regamey, A., Ryhner, J., Ammann, W. (2004): Risikobasierte Schutzwaldstrategie. Forum für Wissen 2004, Davos.
- Brang, P. (2004): Biologische Rationalisierung im Waldbau. Jahrestagung der Sektion Waldbau im Deutschen Verband Forstlicher Forschungsanstalten.
- Brang, P., Schönenberger, W., Frehner, M., Schwitter, R., Thormann, J.J., Wasser, B. (2006): Management of protection forests in the European Alps: An overview. *Forest Snow and landscape research 80*: 23-44.
- Brassel, P., Brändli, U.-B. (1999): Schweizerisches Landesforstinventar. Ergebnisse der Zweitaufnahme 1993-1995. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft. Bern, Bundesamt für Umwelt, Wald und Landschaft.
- Cattiau, V., Marie, E., Renaud, J.P. (1995): *Forêt et protection contre les chutes de rochers Ingénieries - EAI 3*: 45-54.
- Cherubini, P., Piussi, P., Schweingruber, F.H. (1996): Spatiotemporal growth dynamics and disturbances in a subalpine spruce forest in the Alps: a dendrochronological reconstruction. *Canadian Journal of forest research 26*: 991-1001.
- Fuchs, S., Bründl, M., Stötter, J. (2004): Development of avalanche risk between 1950 and 2000 in the Municipality of Davos, Switzerland. *Natural Hazards and Earth System Sciences 4*: 263-275.
- Gehrig-Fasel, J., Guisan, A., Zimmermann, N.E. (2007): Tree line shifts in the Swiss Alps: Climate change or land abandonment? *Journal of Vegetation Science 18*: 571-582.
- Imbeck, H., Ott, E. (1987): Verjüngungsökologische Untersuchungen in einem hochstaudenreichen subalpinen Fichtenwald, mit spezieller Berücksichtigung der Schneeablagerung und der Lawinenbildung. SLF, Davos.
- Kajimoto, T., Seki, T., Ikeda, S., Daimaru, H., Okamoto, T., Onodera, H. (2002): Effects of Snowfall fluctuation on tree growth and establishment of subalpine *Abies mariesii* near Upper forest-limit of Mt. Yumori, Northern Japan. *Arctic, Antarctic, and Alpine Research 34*: 191-200.
- Kasthofer, K. (1822): Bemerkungen auf einer Alpenreise. Sauerländer, Aarau.
- Körner, C., Paulsen, J. (2004): A world-wide study of high altitude treeline temperatures. *Journal of biogeography 31*: 713-732.
- Korpel, S. (1995): Die Urwälder der Westkarpaten. GustavFischer, Stuttgart, Jena, New York. 311p.
- Landolt, E. (1960): Bericht an den hohen Schweizerischen Bundesrath über die Untersuchung der Hochgebirgswaldungen in den Kantonen Tessin, Graubünden, St. Gallen und Appenzell. Orell Füssli, Zürich.

- Latenser, M., Schneebeli, M. (2002). Temporal Trend and Spatial Distribution of Avalanche Activity during the Last 50 Years in Switzerland. *Natural Hazards* 27: 201-230.
- Luckman, B. H. (1978): Geomorphic work of snow avalanches in the Canadian Rocky Mountains. *Arctic and Alpine Research* 10: 261-276.
- Mahrer, F. (1988): Schweizerisches Landesforstinventar: Ergebnisse der Erstaufnahme 1982-1986. WSL, Birmensdorf.
- Meyer-Grass, M., Schneebeli, M. (1992): Die Abhängigkeit der Waldlawinen vom Standorts-, Bestands- und Schneeverhältnissen. *Interpraevent* 92: 443-455.
- Motta, R., Haudemand, J.C. (2000): Protective Forests and Silvicultural Stability: An Ex. of Planning in the Aosta Valley. *Mountain Research and Development* 20: 180-187.
- Motta, R., Nola, P., Piussi, P. (2002): Long-term investigations in a strict forest reserve in the eastern Italian Alps: spatio-temporal origin and development in two multi-layered subalpine stands. *Journal of ecology* 90: 495-507.
- Oliver, C. D., Larson, B.C. (1990): Forest stand dynamics. Mc Graw\_Hill, New York. 520p.
- Ott, E., Frehner, M., Frey, H.U., Lüscher, P. (1997): Gebirgsnadelwälder: praxisorientierter Leitfaden für eine standortgerechte Waldbehandlung. Haupt, Bern; Stuttgart; Wien. 286p.
- Ott, E., Lüscher, F., Frehner, M., Brang, P. (1991): Verjüngungsökologische Besonderheiten im Gebirgsfichtenwald im Vergleich zur Bergwaldstufe. *Schweizerische Zeitschrift für Forstwesen* 142: 879-903.
- Peet, R. K. (2000): Forests and meadows of the Rocky Mountains. pp 75-123 in B. M.G Barbour and D.W.. Billings (Editors). North american terrestrial vegetation. 2nd edition. Cambridge University Press. 708 pp.
- Peet, R. K., Christensen, N.L. (1987): Competition and tree death. *Bioscience* 37: 586-595.
- Rixen, C., Haag, S., Kulakowski, D., Bebi, P. (2007): Natural avalanche disturbance shapes plant diversity and species composition in subalpine forest belt. *Journal of Vegetation science* 18: 735-742.
- Rochefort, R. M., Peterson, D.L. (1996): Temporal and spatial distribution of trees in subalpine meadows of mount Rainier National Park, Washington, USA. *Arctic and Alpine Research* 28: 52-59.
- Rottmann, M. (1985): Schneebruchschäden in Nadelholzbeständen: Beiträge zur Beurteilung der Schneebruchgefährdung, zur Schadensvorbeugung und zur Behandlung schneegesädigter Nadelholzbestände. Sauerländer, Frankfurt.
- Rutherford, G. N. (2006): The use of land-use statistics to investigate large-scale successional processes. Diss No. 16507, Zürich.
- Schärer, W. (2004): Der Schutzwald und seine Bedeutung in der Waldpolitik des Bundes. in Forum für Wissen 2004, Davos.
- Schneebeli, M., Bebi, P. (2004): Forest and snow and avalanche control. *forest hydrology*: 1-6.
- Schönenberger, W., Brang, P. (2004): Silviculture in mountain forests. Elsevier, Amsterdam.
- Shanks, R. E. (1956): Altitudinal and microclimatic relationship of soil temperature under natural vegetation. *Ecology* 37: 1-7.
- Stokes, M. A., Smiley, T.L. (1968): An introduction to tree ring dating. University of Chicago press, Chicago, IL.
- Stützer, A. (2002): Zwischen subalpinem Wald und alpiner Tundra. Eine Studie zu Struktur und Dynamik der Fichten-Waldgrenze auf der Saualpe (Kärnten). *Wulfenia* 9: 89-104.
- Veblen, T. T., Donnegan, J.A. (2005): Historical Range of Variability for forest vegetation of the national forest of the Colorado Front Range.
- Walsh, S. J., Butler, D.R., Allen, T.R., Malanson, G.P. (1994): Influence of Snow Patterns and Snow Avalanches on the Alpine Treeline Ecotone. *Journal of vegetation science* 5: 657-672.