PERSISTENT WEAK LAYERS ACROSS THE ALPS: CORRELATION WITH SHIFT IN TREE SPECIES FREQUENCY AND THE UNDERRATED INFLUENCE OF ABSOLUTE HUMIDITY

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ABSTRACT: The snow layering frequently differs within a mountain range due to the change of climatological conditions. Especially, the frequency and characteristics of deep persistent weak layers in most winters in the Alps strongly vary within a beeline of less than 50km. In this context, we discuss the correlation of tree species distribution and the probability of deep persistent weak layers through the Alps. Secondly, we point out that in season 2016/2017 the initial conditions for forming a deep persistent weak layer across different regions in the Eastern Alps were similar but depth hoar only formed in the regions with the continental climate/vegetation type. Therefore, we propose that the total energy of the air as a merge of absolute humidity and air temperature measured by weather stations should be integrated by equivalent potential temperature in avalanche forecasting products, respectively in weather station charts.

KEYWORDS: persistent weak layer, vegetation type, stone pine, equivalent potential temperature

1. INTRODUCTION

The output of this paper is addressed to winter-recreating practitioners. We state clearly that we are not working in adequate scientific practice. Thus, it can also be perceived as sparkling idea for accurate scientific research in the future.

Prevention of avalanche fatalities is the main target of snow research. With regard to recreational avalanche fatalities, the regularly provided avalanche forecast represents the base of trip planning and avalanche hazard assessment. Despite the fact that many countries offer high quality forecasts, there are still numerous parts in the world where precise information on avalanche hazard does not exist. Due to continuously changing skiing habits of backcountry skiers, these regions are visited year by year more often for skitouring trips as well as locals of these areas are getting progressively more into favor of recreating in snowy mountainous terrain.

To assess avalanche hazard completely by oneself during such trips, knowledge and some experience about snow & avalanches is essential. In past years, the five European Avalanche Problems (APs) as well as the nine American Avalanche Problem Types (APTs) have become well known within the backcountry skiing communities. Even in countries with provided avalanche forecasts, users tend to rate the avalanche problems more relevant than the danger level (Engeset et al., 2018). The APs/APTs obviously represent a good framework for practitioners to manage nearly every threat an avalanche can provide. All of these show relatively easy identifiable danger signs on the snow-surface – e.g. wind signs, amount of new snow, gliding cracks, soaking water in the snowpack – except the old snow problem/persistent weak layers (PWL). Sometimes they can give signals by whumpfs, shooting cracks and naturally triggered avalanches but most of the time an existing deep persistent weak layer (DPWL) is noticed too late, maybe after triggering an avalanche. Techel et al. (2014) combined regional PWL frequency, recreational winter activity and avalanche accidents in the Swiss Alps. They clearly stated that the avalanche risk for most recreationists is higher in the case of PWLs.

Digging snowpits and performing stability tests to investigate the potential presence of PWLs represent the best opportunities to get a picture of local snowpack structure, especially while travelling through unknown terrain without forecast. But even if snowpits are implemented in every day of a skitouring trip, getting an appropriate picture of snowpack stability and weak layer distribution is a long process. Unfortunately, the trip is mostly more or less over when the picture of the snowpack stability is getting sharp enough to apply *good* risk management.

Therefore, we present a simple tool for practitioners which can give a quick, first overview of how the snowpack stability presumably could be before travelling through mountain ranges in countries without avalanche forecast.

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2. BACKGROUND

Deep persistent weak layers within the snowpack form frequently in continental climates. These climates are characterized by less precipitation, lower temperatures and longer lasting high pressure systems. Reminiscing to our years of storm and stress, the avalanche forecasts in Europe were not provided in the quality we receive nowadays. In particular, information to PWLs was on a very low level compared with today's info. Due to this fact, distinction of vegetation types of continental and maritime climate was a first indicator of what to expect within the snowpack. In detail, in the Alps the presence of the so-called “continental stone pine and larch” forest type at the subalpine zone and the timberline and the absence of the beech in lower elevation levels in the same region were the first indicators for being more aware of DPWLs for us.

In a first part, we want to proof if there is a real correlation of the forest type and the probability of DPWLs through the Alps. Secondly, we give an outlook if an option exists to be more aware of DPWLs with a shift in vegetation types/tree species during a trip in other mountain ranges in the world.

After that, we discuss a separated idea of integrating the equivalent potential temperature in avalanche warning products by switching to weak layer distribution in winter 2016/17.

3. METHODS

To assess the distribution of individual tree species, we used tree species distribution maps along the European Alps, especially of Tyrol and Switzerland. The maps of Brändli (1998, Figure 2-4) – showing the percentage of one tree species in the forests in the in Switzerland – turned out to be the best for that purpose.

To allocate the regions with a high frequency of the PWL-problem we used the output of Techel & Winkler (2015, Fig. 5), of operational avalanche warning service products (Austrian Avalanche Warning Services, 2010-2018) and winter precipitation/temperature maps (Marty et al., 2010). This refers to a schematic overview (Fig. 1) of regions with the highest probability of PWLs.

4. RESULTS

The distribution of the Swiss stone pine (Fig. 4) shows two core areas within Switzerland: more or less the Canton of Valais and the Canton of Grisons. Brändli (1998) specified that the existence of Swiss stone pines in the other regions is inconsiderable. It is the typical conifer of the continental climate in the Alps.

In contrast, the European beech (Fig. 2) favors all regions within Switzerland except Valais and Grisons. According to Brändli, the beech prefers sub-maritime climate and is totally missing in the regions with low precipitation among Europe although it can be found in the subalpine zone up to 1800m. So the higher average elevation of the areas with more continental climate is not the decisive factor for the growth rate of beeches.

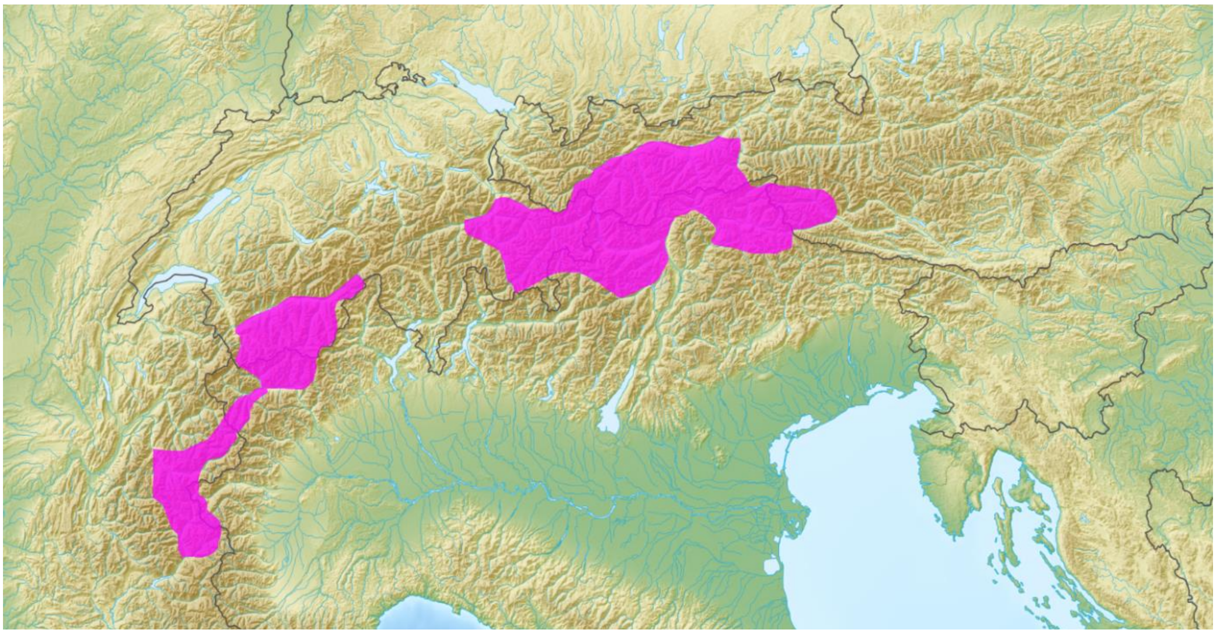

Figure 1: Schematic overview of regions in the Alps with a generally unfavorable snowpack structure, respectively a high probability of deep persistent weak layers

The silver fir prefers humid (Fig. 3) and temperate climate and shows a similar distribution to the beech.

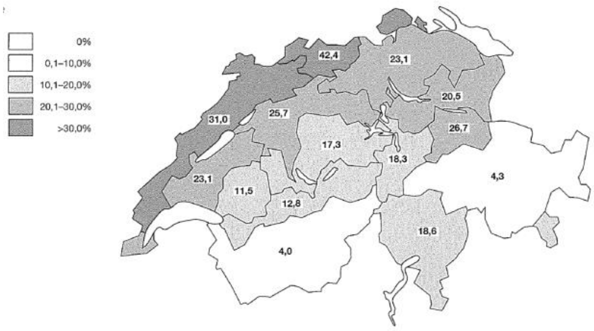

Figure 2: Percentage of *Fagus sylvatica* (European beech) to all trees in economic regions in Switzerland (Brändli, 1998)

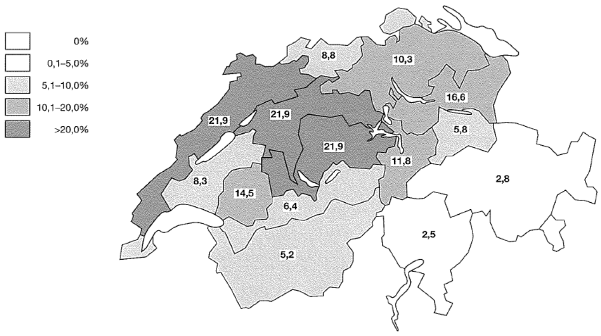

Figure 3: Percentage of *Abies alba* (silver fir) in economic regions of Switzerland (Brändli, 1998)

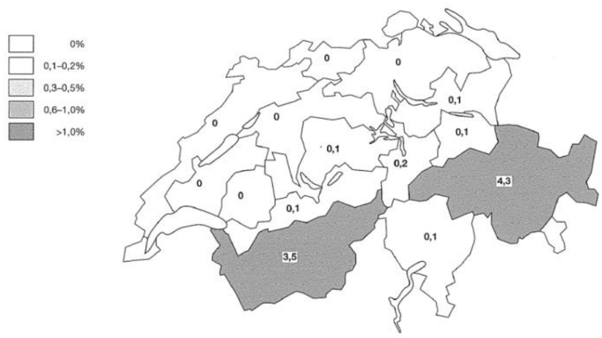

Figure 4: Percentage of *Pinus cembra* (Swiss stone pine) in economic regions in Switzerland (Brändli, 1998)

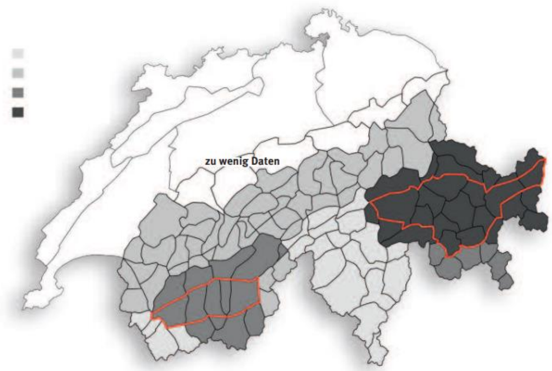

Figure 5: Snowpack structure from generally favorable (light grey) to generally unfavorable (black) in four classes in the Swiss Alps. Lack of data in white (non-alpine) regions. (Techel & Winkler, 2015)

5. DISCUSSION

Combining the provided maps, a correlation between tree species frequency and the probability of PWLs becomes clear: The main distribution area of the Swiss stone pine matches remarkable good to the regions with the mostly unfavorable snowpack structure, respectively to the formation of facets or depth hoar at the basis of the snowpack. On the other side, the beech is a rare tree in the woods of these regions. They favor more humid climate. The beech and the silver fir are mostly missing in the forests where the Swiss stone pine is the dominating tree of the subalpine zone.

As the Swiss stone pine is known to prefer continental climatological conditions with colder winters and lesser precipitation (Brändli, 1998), it is an indicator species for a high probability of faceted weak layers deep in the snowpack. Not by the observation of single trees or the general range of the species but by being the most common or even the only conifer at the subalpine zone. It represents the leading tree species at the timberline in these regions.

6. INFLUENCE OF ABSOLUTE AIR HUMIDITY: CASE STUDY WINTER 2016-17

Separated from the tree species-DPWL-concept we emphasize an idea according to DPWLs born in winter 2016/17. Field observations from this winter imply that the temperature gradient within the snowpack depends – more than frequently assumed – on the absolute air humidity and its influence to the snow-surface temperature.

This assumption is based on similar initial conditions for faceting in December 2016 according to snow heights in a cross-section from Allgäu Alps to the southern Ötztal and Stubai Alps in elevation levels up to 2500m (Fig. 4 & 5). A high pressure dominated December with excellent conditions for kinetic metamorphosis followed to the first snowfalls of the season. After more than a month of excellent faceting conditions, storms starting at January 4th, hit the Alps regularly and brought fresh snow.

Despite an almost identical snowpack thickness with 10-20cm in elevations of about 2000m-2300m in northern aspects until midwinter and the same amount of days with clear skies, the weak layer metamorphism close to the ground differed widely between the Northern Alps and the inner-alpine regions. While depth hoar and mostly even faceted crystals could not be found in the northern areas such as the Allgäu Alps (Fig. 6a), the snowpack was massively prone to avalanche triggering because of the formation of such weak layers with remarkably large depth hoar crystals in the Ötztal and Stubai Alps in January and February 2017 (Fig. 6b).

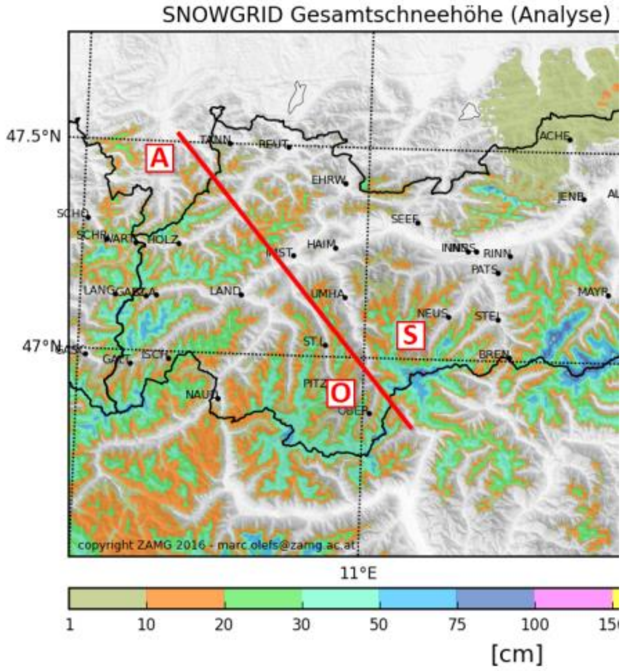

Figure 4: Snowgrid shows similar snow heights in same elevations in a cross section from the Allgäu Alps (A) to southern Ötztal (O) & Stubai (S) Alps in December 2016

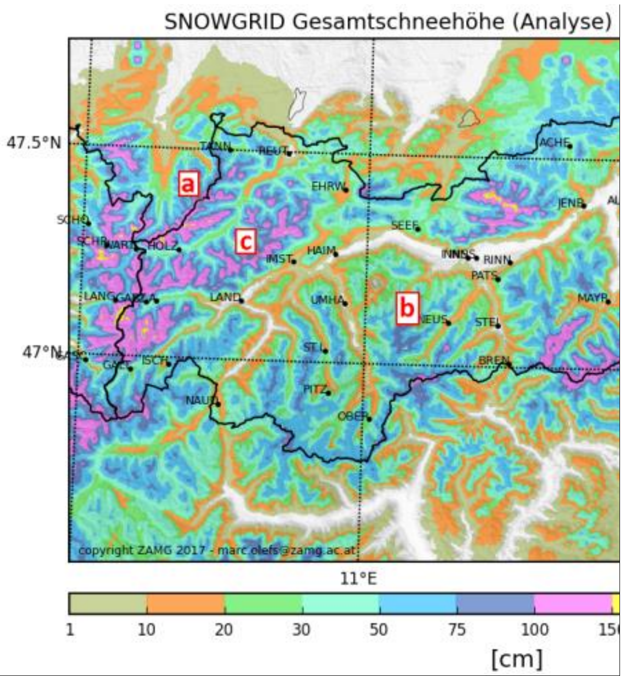

Figure 5: In February 2017 snow heights follow the common pattern of decreasing from the Allgäu Alps to the Ötztal & Stubai Alps. A, b, c mark the observation sites of Fig. 6

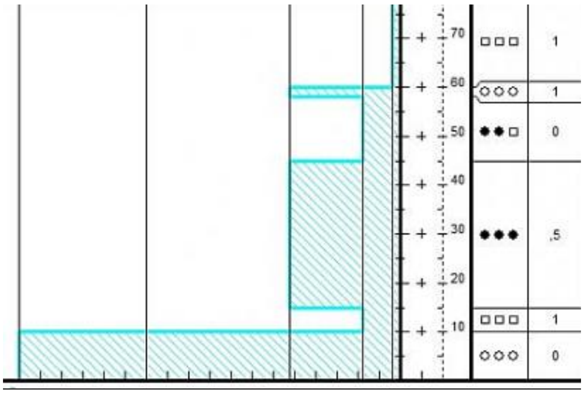

Figure 6 (a): While the snowpack basis in the Allgäu Alps of mid-February 2017 at northern aspects around 2200m consisted of +/- 10cm very hard melt-freeze crust, depth hoar was always missing…

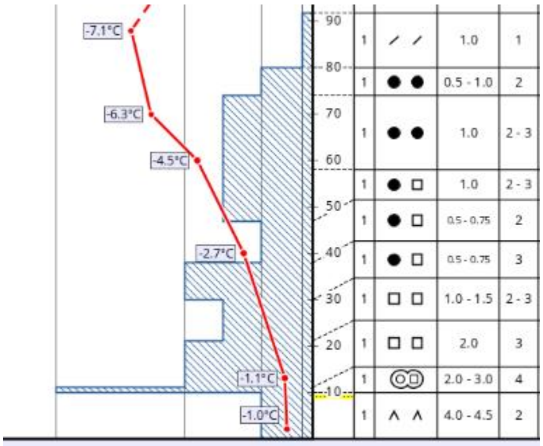

Figure 6 (b): … snow-profiles in the Ötztal and Stubai Alps in similar aspect/elevation sites. showed approximately 10cm of remarkable big depth hoar crystals under a thin melt-freeze crust.

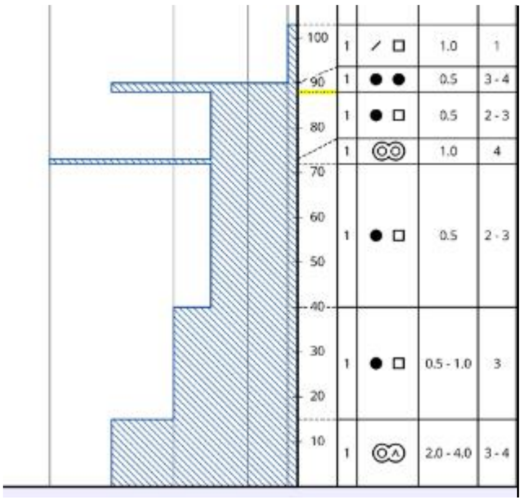

Figure 6 (c): In the transition zone from sub-maritime to continental climate the snow profiles of the Lechtal Alps showed a melt-freeze crust with slightly notes of depth hoar formation.

Table 1: Mean dew-point temperatures after last snowfall on 15th November 2016 until first snowfalls in early January 2017 assorted from Northern Alps to inneralpine-regions.

Weather station	mean dew-point
Strengen-Dawinalpe (1910m)	-6,14°C
Reutte Hahnenkamm (1884m)	-8,34°C
Innsbruck-Seegrube (1921m)	-7,98°C
Kühtai-Längental (1918m)	-9,08°C
Obergurgl (1936m)	-9,02°C
Gschnitz-Gallreideschrofen (1910m)	-10,8°C

The absolute humidity, respectively the dew point, is decreasing on average to the core of the mountain range (Table 1) and thus direxctly influences snow-surface temperature by sublimation. The cooling of the snow surface according to sublimation was presumably the most important parameter for kinetic metamorphosis in the winter under review.

7. CONCLUSIONS

In former times, when avalanche warning products were not as accurate as nowadays or even didn't exist, the tree species frequency was an indicator for practitioners to be more aware of PWLs in the Alps. Set on the fact that DPWLs emerge mostly in areas where beeches are missing and Swiss stone pines form the timberline. Nowadays, the avalanche forecasts in the Alps provide such a high quality that the correlation of the vegetation to the common found snowpack-structure is a nice-to-know but is not useful anymore. In other words: Risk management can be done with better tools now.

However, a shift in vegetation type while travelling through mountain ranges from maritime to continental climate and a previous look to climatological maps in combination with vegetation and/or tree distribution maps can continuously be used to get a first picture of DPWLs probability in a mountain range. This is based on the fact of the usual vegetation shift within a mountain range in the same elevation zone (montane – subalpine – alpine – nival) according to longitudinal/latitudinal climatic change. Especially, when recreating in countries with a strong gradient of climatic conditions – e.g. in the Caucasus

– and missing avalanche forecasts. Of course, a vegetation shift can't stand alone for the assessment of the current avalanche hazard. It represents an additional "tool" to be more attentive and take deeper consideration of the avalanche problem which indicators are mostly hidden deep in the snowpack.

The actual correlation of vegetation types or even the frequency of individual easy-to-identify species and probability of DPWLs in mountain ranges would be an interesting subject to more accurate scientific investigation in the future.

Besides, we propose the integration of the equivalent potential temperature in weather station charts of avalanche warning services. It represents an easy-to-grasp figure for the total energy of the air – representing a merge of temperature and air humidity. Operational usage will show if the equivalent potential temperature can be useful in the assessment of persistent weak layer formation.

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REFERENCES

ARGE Austrian Avalanche Warning Services: Annual reports 2010-2018. https://lawine.tirol.gv.at/archiv/winterberichte/

Brändli, U.-B., 1998: Die häufigsten Waldbäume der Schweiz, Ergebnisse aus dem Landesforstinventar 1983-85: Verbreitung, Standort und Häufigkeit von 30 Baumarten. Berichte der Eidgenössischen Forschungsanstalt für Wald, Schnee und Landschaft 342

Caudullo, G., Welk, E., San-Miguel-Ayanz, J., 2017: Chorological maps for the main European woody species. Data in Brief 12, 662-666. DOI: doi.org/10.1016/j.dib.2017.05.007

Engeset, R. V., Pfuhl, G., Landrø, M., Mannberg, A., and Hetland, A., 2018: Communicating public avalanche warnings – what works? Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2018-183, in review

Mayer, H., 1983: Waldgebiete der Alpen. Tuexenia - Mitteilungen der Floristisch-soziologischen Arbeitsgemeinschaft – NS_3: 307 - 318

Marty, C., Skaugen, T., Pecho, J., López-Moreno, J., Jonas, T., 2010: ETC-AAC Technical Paper on "Impacts of changing climate on Europe's snow and ice" Chapter 1: Ice and snow regions in Europe. In: Voigt, T., Füssel, H., Gärtner-Roer, I., Huggel, C., Marty, C.,Zemp, M., 2010 (eds.): Impacts of climate change on snow, ice, and permafrost in Europe: Observed trends, future projections, and socioeconomic relevance. ETC/ACC Technical Paper 2010/13. European Topic Centre on Air and Climate Change (ETC/ACC), European Environment Agency (EEA)

Olefs, M., Schöner, W., Suklitsch, M., Wittmann, C., Niedermoser, B., Neururer, A., Wurzer, A., 2013: SNOWGRID – A new operational snow cover model in Austria, Proceedings of the International Snow Science Workshop Grenoble – Chamonix Mont-Blanc, France. http://arc.lib.montana.edu/snow-science/item/1785

Techel, F., Zweifel, B., Winkler, K., 2014: Avalanche risk in backcountry terrain based on usage frequency and accident data. Natural Hazards and Earth System Science, 2(8), 5113-5138. https://doi.org/10.5194/nhessd-2-5113-2014

Techel, F., Winkler, K., 2015: Fürchtet den Altschnee. Bergundsteigen 1/15

Ulber, M., Gugerli, F., Bozic, G., 2004: EUFORGEN Technical Guidelines for genetic conservation and use for Swiss stone pine (Pinus cembra). International Plant Genetic Resources Institute, Rome, Italy

von Wuehlisch, G., 2008: EUFORGEN Technical Guidelines for genetic conservation and use for European beech (Fagus sylvatica). Biodiversity International, Rome, Italy

Wolf, H., 2003: EUFORGEN Technical Guidelines for genetic conservation and use for silver fir (Abies alba). International Plant Genetic Resources Institute, Rome, Italy