D.T.1.4.3 Report on "High alpine afforestation - survey and effectivity assessment"

WP1 - PRONA: New tools on Protection forest and natural hazard assessment

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Introduction

Forests serve an important role in reducing risk to people, infrastructure and resources from natural hazards including floods, debris flows, snow avalanches and rockfalls (e.g., Brang et al., 2008; Sidle and Ochiai, 2013). For the purpose of protection, European countries have managed protective forests since the early 19th century. Forests at high-altitudes are exposed to harsh growing conditions where managing these forests or establishing high-alpine afforestations is challenging and requires high expertise. High alpine afforestations are not located at a specific elevation, where the term "high elevation" refers more to a vegetation zone such as the montane, subalpine and alpine zones in the Alps. These vegetation zones can be found at different elevations based on geographic location, e.g. in the Northern Prealps the subalpine zone starts around 1200 m, while in the Central Alps the subalpine zone starts a few hundred meters higher (Figure 1).

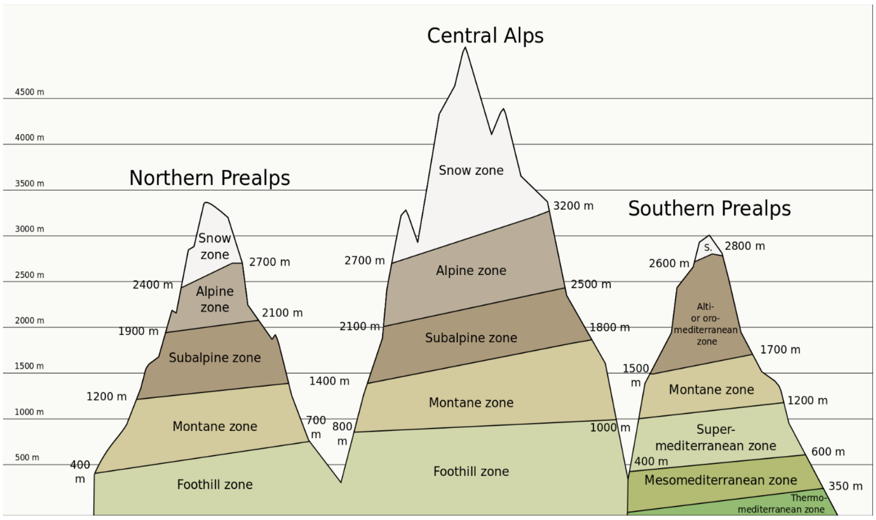

Figure 1: Vegetation zones at different elevation ranges depending on the geographic location in the Alps (Pethrus, 2012, based on Polese J.-M. and Couplan F,2008).

Legal framework

A legal framework for high alpine afforestations is not established in most alpine countries. For example, in Slovenia or Germany, high alpine afforestations are not specifically mentioned or defined in the forest law. Therefore, extra regulations or responsible authorities do not exist.

In Austria, regulations for the management of high alpine afforestations are included in the Forest Act of 1975. In this Act, “high-elevation” afforestations (“Hochlagenaufforstungen”) are defined as afforestations up to 500 m below the natural tree line. As high alpine afforestations are most often established to prevent natural hazards by torrents and avalanches, the responsibility lies with the Austrian Service for Torrent and Avalanche Control. To prevent damages by natural hazards, the authorities are obliged to establish and maintain certain measures like high alpine afforestations.

Area covered by high alpine afforestations

Austria

In 1884 the Austrian Torrent and Avalanche Control Service was established under the Federal Forest Service as “the importance of torrent defense in connection with forest preservation, forest-grazing regulation, reforestation and revegetation in mountainous regions” (Seckendorff, 1884) was becoming more important.

In Austria 20.5 % (420,000 ha) of the forest cover is categorised as forest with a protective function, of those ~15,000 ha are located in high elevation areas (Figure 2). About 3,200 afforestation sites have been established between 1906 and 2017, most of them in 1950–1960 in order to establish protection forests at high elevations (Scheidl et al., unpubl. 2020).

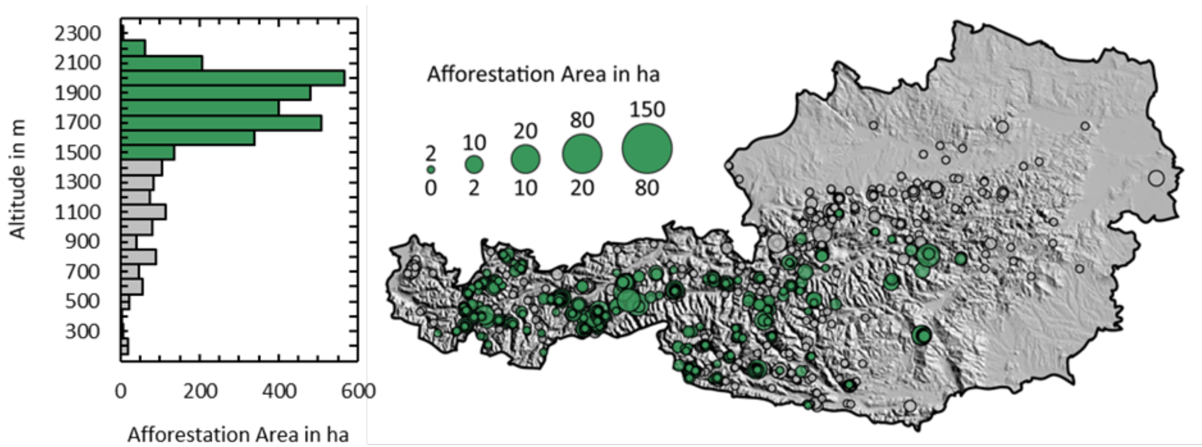

Figure 2: The map on the right shows Austrian afforestation sites at high elevations. The left diagram shows the distribution of the afforestation sites at different altitudes. More than 80%, in terms of area, are situated in subalpine or alpine altitudinal zones (Source: Austrian Torrent and Avalanche Control Service, 2016).

Slovenia

The afforestations needed and carried out in the PAR region Kranjska Gora were defined in the forest management plans. Spruce and partly larch dominated among the tree species. Particularly noteworthy is the afforestation carried out in 1960 by the PUH (Torrent and snow avalanche control company) (Figure 3). The purpose of afforestations were to decrease surface erosion and onset of natural hazards. The area afforested was only 8.8 km^2, which represents 5 % of the forest cover currently present in the PAR Kranjska Gora region (174.23 km^2). The average elevation of the afforested areas was 1188 m (min: 668 m, max: 1825 m) with an average slope angle of 36°. They used tree and shrub plantings as well as cuttings.

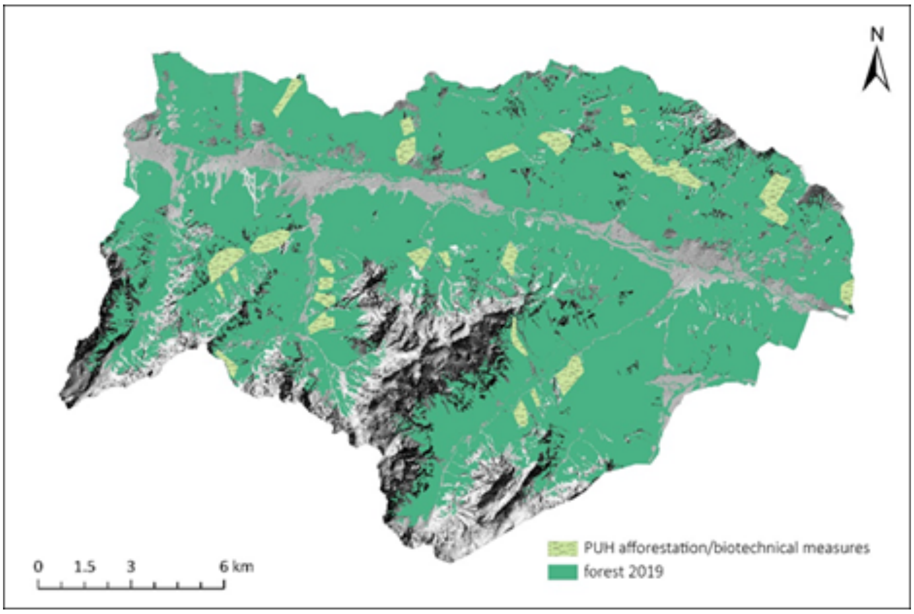

Figure 3: Afforestation done by PUH (Torrent and snow avalanche control company) around 1960 in the Slovenian PAR Kranjska Gora to reduce surface erosion and onset of natural hazards.

In the period between 2015– 2019 forest owners with professional support and supervision of the Slovenia Forest Service, carried out afforestations in the PAR region Kranjska Gora where 3.4 ha forest (0.02 % of the current forest cover) was planted. The following species were used: 53.6 % European beech (*Fagus sylvatica*), 31.4 % European larch (*Larix decidua*), 14.6 % sycamore maple (*Acer pseudoplatanus*), and 0.4 % unknown. The average elevation of the afforested areas was 987 m with an average slope angle of 28° (Figure 4).

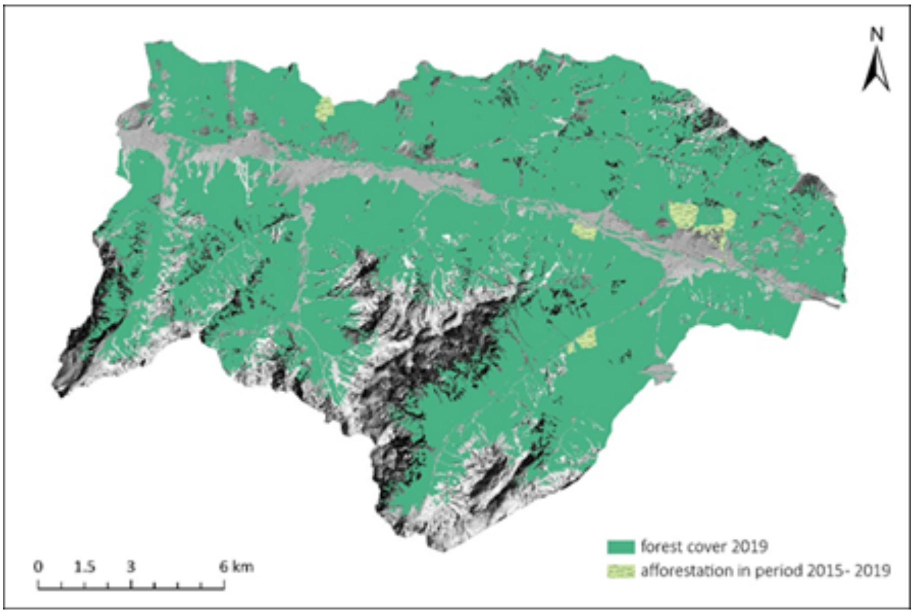

Figure 4: Afforestation done by forest owners with professional support and supervision of the Slovenia Forest Service between 2015- 2019 in the Slovenian PAR Kranjska Gora to reduce surface erosion and onset of natural hazards.

Germany

In Bavaria "high alpine" afforestations are not classified as such. Therefore, no concrete data exists. However, there are protection forests in designated redevelopment areas within the Bavarian Alps, in which afforestation and thinning are primarily carried out to maintain protective functions.

In total, 52% of the Bavarian Alps are covered by forests. This corresponds to a forest area of approximately 250,000 ha; 150,000 ha, which are classified as protection forest according to the Bavarian Forest law (2005). On June 5th, 1984, the Bavarian Government decided to implement protection measures for mountain forests. Currently there are almost 14,000 hectares reported as protection forest rehabilitation areas in Bavaria. The financial costs for establishing and maintain these forests was around 85 million Euro and after 30 years, the first forest development classes are visible. A large part of this money has been invested in afforestation in redevelopment areas. In total, approximately 13 million plants have been planted of which 8 million are Norway spruce

(*Picea abies*), European beech, silver fir (*Abies alba*) and sycamore maples, the main tree species comprising mixed mountain forests. The percentage break down of the species are Norway spruce 53%, silver fir 12%, European beech 24% and sycamore maple 11%. Within the redevelopment area, 10,000 ha are currently being planted, of which 3800 ha has been completed.

Italy

In Italy, reforestation has been a main forest policy instrument dating back to the second half of the 19th century. Romano (1987) identified two main periods: a first phase, between the second World War and the 1970s aimed at increasing hydrogeological protection and to decrease surface erosion and runoff. A second phase, started during the 1970s to present, devoted to post-disturbance restoration and productive purposes. Post-disturbance management in the Italian Alps has been traditionally applied through salvage logging operations followed by afforestation. However, due to high costs, high elevation afforestation is no longer commonly applied. Over the past few decades, Italy has initiated a change from a uniform planting system to strategies such as cluster afforestation aimed at replicating natural regeneration processes in order to ensure greater survival of seedlings (Garbarino, 2002). The second "National Inventory of Forests and Forest Carbon Pools" (INFC) shows that approximately 430,000 hectares in Italy are reforested stands of which 60.000 hectares (14%) are in the Alpine Space. More than half of the afforested areas are pure conifer stands, the remaining areas are pure broadleaved stands (12%) and mixed afforestation (33%) (INFC, 2005).

Case studies:

1. Post-fire cluster afforestation (Monte Zerbion, Aosta Valley)

In 1990, a wildfire-affected area of 303 hectares was afforested on Monte Zerbion (Aosta Valley (AO), Italy). The area affected by the wildfire was a subalpine conifer stand comprised of European larch and Scots pine (*Pinus sylvestris*). An experimental afforestation cluster was conducted in 1994 over an area of 7 hectares, named Bois de Cheney. More than 9000 seedlings (62% bare root seedlings and 38% balled seedlings) were planted forming 19 clusters (73 micro-collectives). During the summers of 1995, 2001 and 2002 data collection on regeneration characteristics (number, species, height and apical growth) was recorded (Burtolo, 1995; Garbarino and Pividori, 2003). In 2002 the reforested area was formed by 4261 plants in 56 micro-collectives. The species composition was primarily European larch (50%), Scots pine (27%) and Norway spruce (23%). The data showed that balled plants have better growing results and lower mortality rates compared to bare root seedlings. This difference is particularly evident in the first two years, when transplant shock creates a greater stress on establishment for bare root plants, especially Scots pine (Schönenberger, 1990). Only Norway spruce had a higher mortality rate in the second period (1995-2002), likely due to the fact that this species may not be the most appropriate species used in active post-fire forest management on southern-exposed slopes (Table 1, Figure 5).

Table 1: Mortality percent rates (MR %) of the three species planted at Bois de Cheney (AO), calculated for the 1994-1995 and 1995-2002 periods and divided by nurse technique (BR = Bare Root, B = Balled) and average (M = Mean) values (modified from Garbarino 2002).

Species	European larch			Scots pine			Norway spruce			Total
Technique	BR	B	M	BR	B	M	BR	B	M	
MR % 1994-1995	49.3	9.3	35.9	96.8	3.5	60.0	13.4	4.4	9.5	42.1
MR % 1995-2002	10.6	20.4	15.2	53.4	23.9	25.3	25.0	12.1	19.1	19.1

The results of the study demonstrate that cluster afforestation is a more suitable technique in subalpine areas. Despite the high mortality rate, the reforestation was successful and all 19 clusters survived. This is also due to the use of balled plants, which has generated better results (Garbarino and Pividori, 2003).

Figure 5: A Norway spruce cluster of the Bois de Cheney afforestation 20 years after planting (2014) (Picture Garbarino M.).

2. Post-fire experimental afforestation (Del, AO)

Del is a small village located in the Aosta Valley (Italy). In 1995 a 52 ha almost pure Scots pine forest was affected by wildfire. After the event, an experimental reforestation project was developed in 2008 with the aim of testing different types of plantations. The reforestation covered only 12 ha, while 38 ha were left to natural regeneration and 2.5 ha were logged. The species used for the reforestation were European larch, Scots pine and mixed broadleaves (*Fraxinus excelsior* L., *Acer pseudoplatanus* L., *Prunus avium* L. and *Sorbus* spp.; Figure 6).

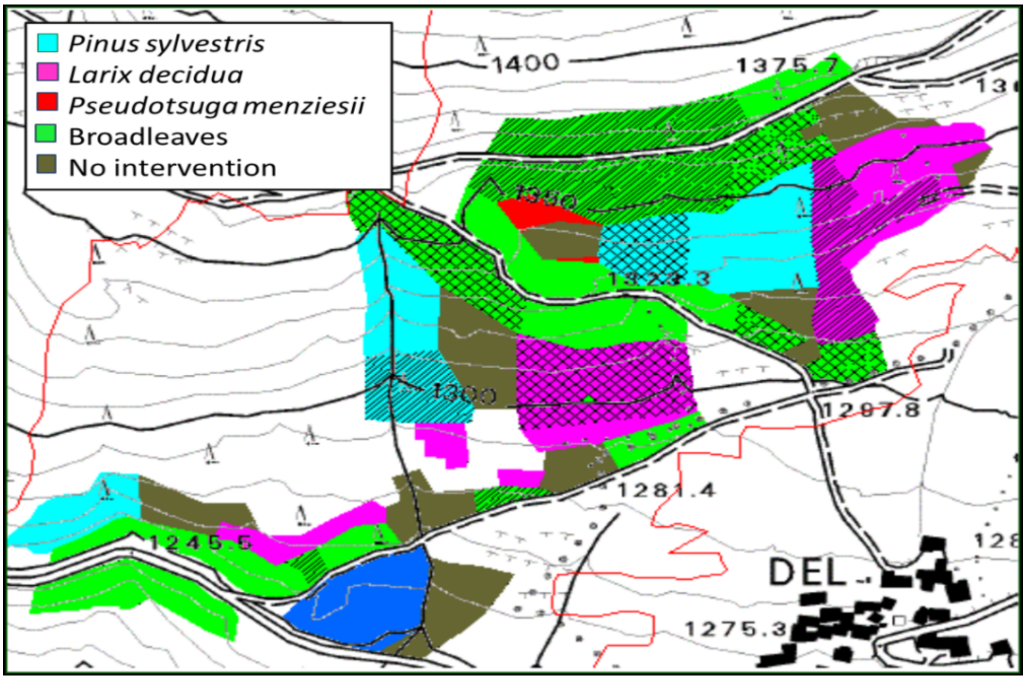

Figure 6: Experimental post-fire afforestation map used at Del (AO) (from Chapellu, 2008).

Since 2010 it was found that natural regeneration was more abundant in areas with no intervention, mainly due to the presence of deadwood (Beghin et al., 2010). The differences between managed and unmanaged areas became more pronounced with repeated sampling carried out in 2018 where all plots from 2008 were remeasured. The average regeneration density in unmanaged areas was 10,000 plants/ha, more than double compared to the one measured in the afforested areas. The lowest tree densities were found in salvage logged areas. The artificial regeneration density in the broadleaved reforested plots was approximately 250 plants/ha in 2018 (Mantero, 2018), with a high mortality rate caused by harsh environmental conditions and problems caused by the use of shelters (Chapellu, 2008). The presence of artificial regeneration proved to inhibit the development of the natural regeneration, but pine plantations were found to be more successful (Mantero, 2018).

In summary, in unmanaged areas post-disturbance regeneration performed the best in terms of density and species diversity. These results prove that human intervention through active post-disturbance management does not always lead to positive results, sometimes instead it can slow down and inhibit natural regeneration dynamics. A thorough study of ecological and site characteristics is important to ensure a fast and effective recovery of vegetation following a disturbance. An active approach should be adopted only where it is necessary and with the aim of facilitating natural dynamics (Mantero, 2018).

Reason for establishment

Afforestation in high altitudes are a nature-based solution to prevent natural hazards and resulting risks in process release zones. These measures have the advantage of low environmental impacts, relatively low investment costs and a higher adaptability to changing climate and environmental conditions. For the alpine regions, great attention was concentrated to high alpine afforestation within avalanche release zones (Figure 7), aiming at supplementing or even substituting the technical avalanche mitigation structures (Heumader, 2000; Schönenberger, 2001), or to reduce strong runoff events by increased rainfall interception and increased transpiration during dry periods (e.g., Bosch and Hewlett, 1982; Rowe and Pearce, 1994; Stednick, 1996; Bruijnzeel, 2004).

Figure 7: Examples for recently established afforestation in an avalanche release zone. Trees have not yet taken over the protective function of the mitigation measures yet (left). Photo on the right: Older afforestation where the trees took over the protective function. (Picture: BFW/WLV)

The stabilizing effect of tree roots is also a reason for the establishment of afforestations to prevent erosion or shallow landslides. This is shown in an example from the municipality Kranjska Gora were on the hillslope of the Belca torrent an afforestation had been established in 1960 (Figure 8).

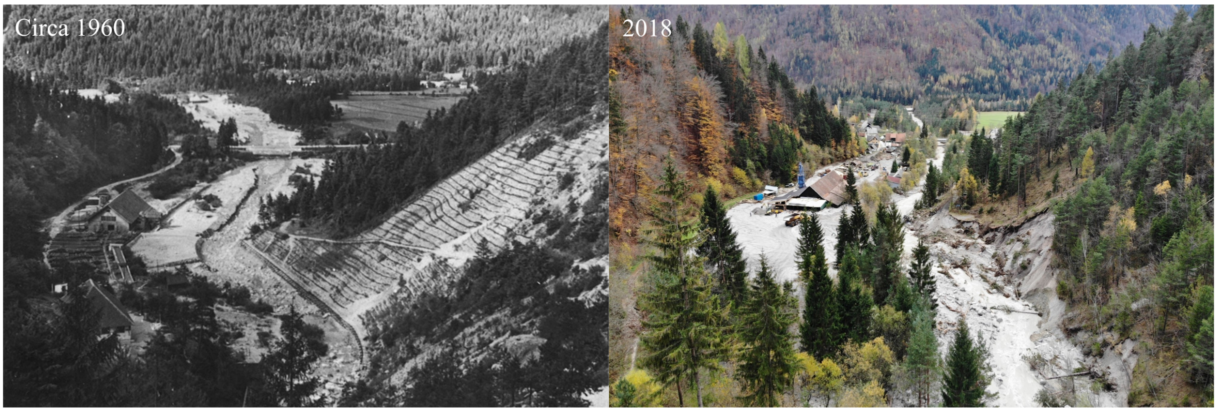

Figure 8: Surface erosion and torrent control was the main reason for the afforestation plans near Belca torrent (left). Today the afforestation areas cover mature forest of Norway spruce and Scots pine (right).

Tree species selection and their benefits

Subalpine tree species used for high alpine afforestations in the central mountain ranges:

Norway spruce and European larch are the main tree species found in the subalpine zone of the Central Alps as well as in the Prealps. For central mountain ranges, also Swiss stone pine and on some sites, Scots pine. In the lower subalpine belt, silver fir, sycamore maple, European beech and Scots pine can serve an important role (Heumader, 2000 and 2007).

Some tree species are more suitable for cluster afforestation than others, including Swiss stone pine and Norway spruce as well as European larch and mountain pine (*Pinus mugo*). Areas between the clusters can be planted with shrubs such as green alder (*Alnus viridis* de Candolle), mountain pine and silver birch (*Betula pendula).* In total it was approximated that shrubs will cover 70% and clusters 30% of the area (Schönenberger, 2001). Norway spruce seedling establishment on southern aspects is mainly limited by moisture (Brang, 1998).

Planted seedlings of mountain pine and European larch can suffer from browsing pressure and snow damage, with higher effect on marginal trees than central trees in the cluster (Schönenberger, 2001).

In a 20-year-old study of afforestation success of an area in a snow avalanche catchment, European larch (compared to mountain pine and Swiss stone pine) had the best survival rates and were on average the tallest (Brang et al., 2004).

An overview of the preventive and protective functions of high alpine afforestations and resulting targets for management is given in Table 2.

Table 2: Preventive and protective functions of high alpine afforestations and resulting targets for management (Heumader, 1996)

Positive effects of subalpine forests:	**Long-term forest composition and condition targets:**	**Comments on management of existing forest stands:**	**Comments on reforestation of unstocked areas:**
Torrents headwaters, upper catchment basin	**Processes: Flood development, formation of runoff peaks; sheet erosion, rill erosion, sometimes gully erosion**		
Reduction of runoff and flood peaks by precipitation interception in the canopy; increase of soil water storage capacities by transpiration, snow interception and snow evaporation in the canopy of wintergreen stands; slowing down of snowmelt by the shadowing effect of wintergreen trees; prevention and reduction of soil erosion by stabilizing tree roots.	High percentage of wintergreen conifers and of deep-rooting tree species with high interception rates, mixed in small stable groups of different age (femel structure).	Large-scale prohibition of livestock grazing is already quite effective.	The higher the percentage of reforested catchment area, the better the effect.
Avalanches starting zones	**Processes: Accumulation of snow layers by snowfall and wind; destructive and constructive metamorphism in the snowpack; triggering of snow slabs; triggering of loose-snow avalanches normally of no importance**		
Levelling and reducing the snowpack thickness by calming wind-shield effects and by snow interception and snow evaporation in the canopy of wintergreen stands; prevention of the formation of undisturbed layers and of sliding surfaces in the snowpack by snow lumps dropping from the trees; prevention of depth-hoar formation by the microclimate inside the forest; supporting effect of tree-trunks on the snowpack.	High percentage of winter-green tree species; mixture of small, multiple-layered, stable groups of different age (femel structure).	Potential starting zones. Preventive management is effective and advisable.	Actual starting zone: Normally only in combination with technical countermeasures as long-term, sustainable substitution of snowpack-stabilizing works.
Landslide Infiltration area	**Processes: Infiltration of precipitation, snowmelt and surface runoff**		
Increase of water-holding soil capacities by interception and transpiration of rain and snow in the canopy, slowing down of snow melt by the shadowing effect of wintergreen trees.	High percentage of winter-green tree species with high interception rates, mixed in small stable groups of different age (femel structure).	Prohibition of livestock grazing very important and quite effective. In some cases, additional draining works advisable.	Useful and advisable; most effective in combination with technical draining works.

Designing forest restoration in subalpine areas should consider all the issues regarding harsh environmental conditions such as short growing seasons, extreme cold temperatures and high wind speeds as well as deep snowpacks. Particularly important is the assessment of site environmental conditions such as identifying suitable microsites as well as consideration of species characteristics and needs. These microsites include high points such as ridges, terrain hilltops, tree stumps and logs, or sites with areas of shallow snow cover, little snow movement and sparse vegetation (Schönenberger, 2001). Snow filled valleys, avalanche channels and north facing slopes are considered unsuitable for the development of regeneration (Garbarino, 2002).

An official guideline on how to manage and monitor high alpine forests does not exist in Austria or in Slovenia. Two guidelines where forests in high altitudes are included but not mentioned specifically, are available for Germany: “Principles for forest management in the high mountains at the Bavarian State Forests” (Bavarian State Forests) and “The mountain and protective forest in the Bavarian Alps” (Bavarian Forest Administration).

Following, a summary of recommendations from current literature is given:

Planting stock

The forest stands surrounding the area where afforestation is planed indicate which tree species are growing naturally in this area. Harvesting cones from these stands provides suitable seed material. If neighbouring stands are not present, collecting seeds from stands in the same growth region and at the same altitude as the afforestation site should be utilized. For afforestation planned during the summer months, potted plants are recommended to avoid moisture loss. If drought is not a limiting factor for plant growth, bare-root transplantations, mainly pit plantings, are also recommended (Heumader et al., 2017).

Suitable microsites for regeneration

For successful high alpine afforestation, suitable microsites should provide favourable and best conditions for seedling establishment (Schönenberger, 2001).

High elevated terrain like ridges, slope edges, slope shoulders, rocky ground, and areas around tree trunks are associated with favourable microsites (Figure 9). On such sites, trees naturally form discrete collectives that become more successful as solitary trees.

In general, with higher terrain roughness, more microsites can be exploited for afforestation, which is best achieved through clustered planting (Schönenberger, 2001), except slope depressions (small snow valleys) based on the “wind-snow ecogram” according to Aulitzky (1963).

Figure 9: Suitable microsites for afforestations protected from wind (left) and sites without prolonged snow cover (right). (Pictures: Heumader)

Unsuitable microsites:

- wind exposed sites (risk of frozen soil, frost drought)
- extensive snow movement
- snow accumulation sites, prolonged duration of snow cover
- locations with lower temperatures (“cold air pools”)
- co-habitation by competing vegetation (when located in moist patches and depressions)

Duration of snow cover in the growing season has a huge effect on the mortality of young trees (Brang et al., 2004). In one study by Schönenberger (2001), on sites where snow cover remained after the 10th of July, the mortality of seedlings increased below 30%. Prolonged snow cover is also associated with a higher mortality caused by snow mold (Senn, 1999),

The effect of snow movement can be detrimental to both older trees and younger trees. Young trees tend to be flexible and may survive snow movements to a certain extent. When stem diameters exceed 10 cm they collapse under the effects of snow avalanches. Thus, technical prevention measures that increase surface roughness are advantageous (Schönenberger, 2001).

North-facing sites tend to be less suitable for afforestation, because of lower temperatures, lower solar radiation, and often poor nutrient status, which results in greater exposure and mortality. On south facing slopes afforestation should be done in March to prevent mortality due to high temperatures in the summer (Schönenberger, 2001).

Cluster afforestation

Until the last decades of 20th century, afforestations were characterized by a regular planting pattern without considering variations in microclimatic conditions (Schönenberger, 2001), thus causing high mortality rates (Senn, 1999). Furthermore, this method tends to create homogeneous stands (Brassel and Braendli, 1999), which are more sensitive to natural disturbances (e.g. wind, snow or insects, Ott et al., 1997). Afforestation with high tree numbers from a hydrological point of view offers advantages in the first few years after planting. This positive effect (reduction of surface runoff and deep infiltration) declines after a few decades by increased competition, reduced needle mass and therefore interception, unfavourable stem forms (high Height/Diameter values) and high maintenance costs (Markart. 2000).

At the beginning of 21st century, a new afforestation method, "cluster afforestation" based on natural mountain forest spatial patterns has been conceived (Schönenberger, 2001). The rationale for this method is based on forest ecological dynamics of species such as Norway spruce, European larch and Swiss stone pine, which naturally tend to form cluster-like structures called "collectives". In mountain forests, clustered stands occur naturally, with dense canopies that reach the ground. These small forest patches or clusters have been managed as stand-alone biological entities

(Garbarino and Pividori, 2003). Cluster afforestation has numerous advantages, one being that during the first years, the mortality rate is lower because planting is done only at favourable microsites with the most suitable characteristics for tree establishment (Schönenberger, 2001). Moreover, trees along the edges of each cluster protect trees growing in the cluster centre from animal damage such as browsing and fraying (Schönenberger, 2001). In the mature stage, silvicultural treatments such as thinning are less necessary, because only a part of the total area is planted. Although the density of planting is greater, less of an area is planted and the number of individuals remains similar as if they were planted in a regular pattern. Stands that evolve from clusters are multi-layered and non-uniform, and therefore more resistant to abiotic disturbance agents such as wind and snow. Moreover, biodiversity and natural regeneration are favoured by ecological conditions created by groups structure (Schönenberger, 2001).

Guidelines for cluster afforestation (Figure 10):

- Planting 20-30 seedlings in “small collectives”
- Diameter of “small collectives” should be 2-4 m
- When planting near treeline, seedling spacing should be 50-100 cm
- At lower elevations spacing should be greater
- Location of planting should be considered: small ridges, near tree stumps
- Avoid planting in gullies, depressions and wet spots
- 3-6 small collectives should be arranged in 2-3 m distances
- After canopy closure, small collectives should be structured as clusters (approx. 20-30 years after canopy closure)
- Distance between final clusters should be 7-10 m
- Diameter of the cluster is between half and the whole height of a tree
- Shape of the cluster should be oval, and the longer axis should be in parallel to the wind direction or the slope

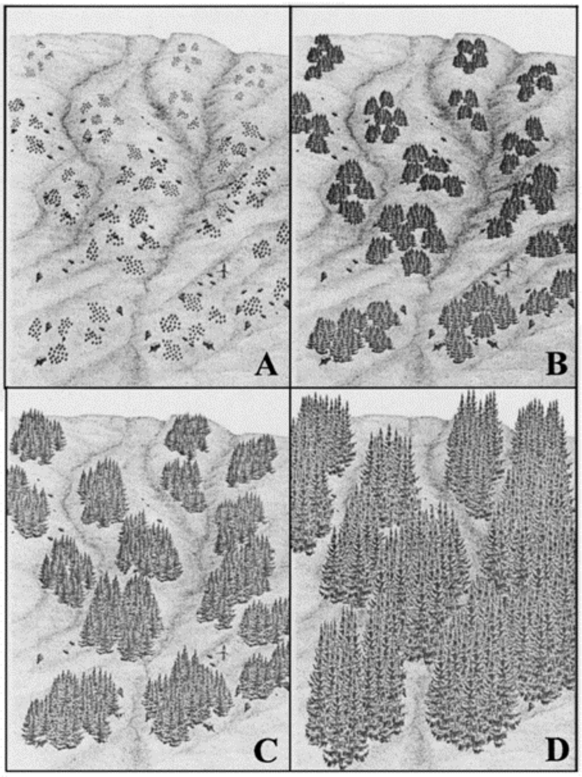

Figure 10: According to Schönenberger (2001): "A hypothetical development of a cluster afforestation with Norway spruce. (A) At the time of planting: "small collectives" of 20±30 seedlings, 2±4 m diameter and 2±3 m apart, seedling spacing 50±100 cm; (B) Five to ten years later, when seedling crowns close within the still separate "small collectives"; (C) Two to three decades later, when the "small collectives" merge to form the final "clusters"; (D) Mature stand: the "clusters" remain distinct and touch only in a few places. The "small collectives" are no longer visible."

Factors influencing success of afforestation

Evaluating and understanding the performance of saplings on different micro-sites can be done by mapping snow accumulation and melt patterns (Brang et al., 2004). Monitoring afforestation areas should be done over decades, because homogeneous afforestations often become unstable and prone to damages by natural disturbances (Brang et al., 2006). Browsing by ungulates can also be detrimental for seedling establishment (Kupferschmid and Bugmann, 2005, Markart et al., 2019).

Stands originating from afforestation often become homogenous and susceptible to wind throws and insect outbreaks. Afforestations were often planted in regular patterns, and on unfavourable microsites resulting in high mortality (Senn, 1999).

Success of high alpine afforestation is also related to the activity of different pathogenic fungi (*Gremeniella abietina*, *Phacidium infestans*, *Dothistroma septosporum*), which can be more destructive, if an afforestation area is larger rather than a smaller afforested area (Brang et al., 2004) (Figure 11).

Figure 11: Left: Phacidium infestans (Picture: Stern), right: Dothistroma septosporum (Picture: Czech and Hoch

Conclusion

Since the early 19th century, European countries are managing mountain forests for protection against natural hazards to reduce the risk from erosion processes, floods, torrents, landslides, snow avalanches and rockfall (e.g., Brang et al., 2008; Sidle and Ochiai, 2013). Protection forests that are established close to the upper treeline under harsh growing conditions have to be planted and maintained carefully (so-called high alpine afforestations). Existing literature provides guidance for planning high alpine afforestations (e.g., Aulitzky, 1963; Schönenberger, 2001), e.g.:

- Use plant material and tree species that are adapted to the location,
- choose suitable microsites (wind-protected sites with short snowcover duration), and
- plant in clusters to increase the stability.

In most countries, high alpine afforestations are not specifically defined, and because these areas are often newly established, are (up to the point of establishment) not designated as forest. This raises the important question of who is responsible to maintain these newly forested areas. High alpine afforestations are mostly managed by the forest services or institutions dealing with natural hazards. A global standard of how to establish, monitor and maintain high alpine afforestations does not exist and, therefore, the assessment of their effectivity is challenging or is only valid for a few study areas.

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