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Cluster afforestation for creating diverse mountain forest structures — a review[☆]

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Abstract

A clustered arrangement of trees may be most appropriate in high elevation afforestation in order to take into account the variety of favourable and unfavourable microsite conditions and to create diverse stands with different tree species and a pattern of clusters and gaps. Long-term studies of the ecology of subalpine afforestations have shown that the young trees tend to be threatened over decades by fungal diseases, browsing ungulates, adverse climatic conditions, and snow movements. The intensity, duration and scale of the threats, however, varies greatly according to tree species and microsites.

Based on these ecological findings, favourable and unfavourable microsites are described. An adapted system of clustered afforestation (in German: *Rottenpflanzung*) has been developed and tested. On favourable microsites, 'small collectives' were densely planted with 20–30 trees of one species on the assumption that the crowns of the trees within these small collectives would close within 5–10 years. Three to six small collectives were arranged in such a distance that they would merge into a larger tree 'cluster' (in German: *Rotte*) after a few decades. The distance between the tree clusters was kept large enough to ensure they remained separate throughout stand development. Such stands of clusters and gaps are expected to be, when mature, more resistant to high winds and heavy snow loads and less threatened by insects than uniform stands. They should be able to contain extensive inner margins permanently, and to be pervaded by light and warmth. Cluster planting on favourable sites can be used to minimise seedling mortality and is therefore the best strategy for afforestation at higher elevations.

Keywords: Afforestation; Mountain forest; Stand structure; Microsite; Subalpine zone; Ecology; Timberline

1. Introduction

Since the middle of the nineteenth century large areas of the Alps have been replanted in order to restore the devastated forests and to improve the protection they provide against natural hazards. Thanks to this enormous effort we now have a much larger forest area in the mountains and better safety (Brassel and Braendli, 1999). However, the reforestation of the most extreme sites, e.g. of avalanche or torrent catchments, has often failed. Forest regeneration has proved to be a very delicate and slow process. Even after the afforestations had been established successfully the problems were not solved. Many stands originating from afforestations became homogeneous and are considered to be susceptible to breakdowns through wind, snow or insect attack (Ott et al., 1997). It was imperative that ways and means of preventing afforestation failure and of avoiding future problems with stand resistance should be found.

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This paper summarises what we have learned from long-term studies about the ecological conditions of afforestation at high elevations. Drawing on these findings, a system of clustered afforestation was thought most appropriate, and was developed and tested. This cluster afforestation is intended to increase tree survival and create diverse future stands.

2. Ecology of high elevation afforestation

2.1. Case study Stillberg: the high elevation afforestation experiment

The ecological afforestation experiment, Stillberg, was initiated in the 1950s in order to investigate the ecology of high elevation afforestation. It is on a NE-facing avalanche catchment between 2080 and 2230 m above sea level. In 1975, approximately 100 000 seedlings of three tree species, cembran pine (*Pinus cembra* L.), mugo pine (*Pinus mugo* Turra), and European larch (*Larix decidua* Miller), were planted on the site. The experimental area was divided into 4052 square plots of 3.5 m × 3.5 m. Twenty-five trees were planted in each square, with one species per plot. The three species were arranged in a regular pattern over the whole area.

Prior to planting, various site factors (e.g. elevation, slope, exposition, global radiation, mean date of snow disappearance, soil type and vegetation type) were determined for each square plot. The survival of all trees has been monitored annually since 1975. In a permanent sub-sample, tree height, damage type and degree, and the causes of mortality have also been recorded annually. The harsh conditions resulted in high seedling mortality rates and in slow growth. Within the first 20 years after plantation, the mortality of cembran pine amounted to 83.3%, that of mugo pine was 62.2%, and that of larch was 27.8%. The mean tree height reached only 70 cm for cembran pine and 80 cm for the other species (Senn, 1999). The performance of the evenly spaced trees has been analysed in response to the variation in microsite conditions, and a vast variety of types of mechanical, climatic and biotic damage and disease have been identified as the causes of the poor performance (Häsler, 1982; Schönenberger, 1985; Schönenberger and Frey, 1988; Schönenberger et al., 1994; Senn et al., 1994; Senn, 1999). These results from Stillberg were used by Schönenberger et al. (1990) to create an afforestation manual for the subalpine area of the Alps.

2.2. Review of the ecological principles behind high elevation afforestation

From these long-term studies important ecological principles can be concluded. The climatic conditions for subalpine afforestation generally involve relatively cold and short summers, and winters with deep and long-lasting snow cover. In summer, the planted seedlings are usually adversely affected by the short growing season that results in slow development and growth (Häsler, 1982). In winter and spring, significant snow movement can have a negative impact, often causing mechanical damage to stems and branches (Patten and Knight, 1994). Long-lasting snow cover increases the susceptibility of tree seedlings to parasitic fungal attack, which is one of the most important mortality agents for young trees in the subalpine zone in the Alps and on mountains in southern Norway (Roll-Hansen et al., 1992; Senn et al., 1994; Senn, 1999).

Within the subalpine environment, however, every irregularity in the slope surface causes extensive small-scale variation in the environmental conditions (Turner et al., 1982). Snow deposition, snow movement, radiation, temperature, wind, avalanche frequency, vegetation, and soil types have been found to change in a fine mosaic-like pattern according to the surface structure. This variation between microsites is reflected in the diverse performance pattern of afforestations (Schönenberger et al., 1994; Senn et al., 1994; Senn, 1999).

For the planning of a site-adapted afforestation, it is first of all important to find out which are the unfavourable microsites within this fine spatial mosaic, where afforestation would not be worthwhile or even be impossible. After that the most favourable sites where afforestation is considered most promising should be identified. The transitional zones between these sites may be afforested if specific measures to improve conditions are taken, such as removing raw humus, fixing the snow cover with poles, or using container seedlings (Schönenberger and Frey, 1988).

Unfavourable microsites for planted seedlings can be characterised as having long duration of snow cover, extensive snow movement, cold temperatures, dense competing vegetation and high winds. In winter the depth and duration of snow cover varies greatly between the microsites depending mainly on exposure to high winds and avalanche activity (Rychetnik, 1987). Senn (1999) reported the survival rate of the trees to be closely correlated with the date of snow cover disappearance. Sites on which the snow cover remains until late in the season turned out to be virtually nonreforestable. On sites with early snow disappearance (i.e. during the first half of May), 46–80% of the young trees survived during the first 19 years, while on sites where the snow cover remained after June 10 only 0.5–30% survived, depending on the tree species. In such places the growing season was too short for the young trees to complete their growth cycle. Further, snow moulds (*Phacidium infestans* Karsten, *Herpotrichia* spp., *Gremmeniella abietina* (Lagerberg) Morelet and *Ascocalyx laricina* (Ettlinger) Schläpfer) are notorious for being favoured by long snow cover and causing great losses in the evergreen pine species (Roll-Hansen et al., 1992; Senn, 1999). The pattern of snow cover disappearance in spring is, therefore, the most reliable indicator for assessing the microsite quality and hence the prospective success of an afforestation.

Snow movements, such as snow settling, creeping, gliding, and avalanches generally have little impact on young trees whose stems are still flexible. Their influence, however, increases as the trees get taller. Our experience shows that often apparently successful afforestations may collapse completely after 30–50 years due to snow movement, when the trees reach a stem diameter of more than 10 cm (Schönenberger, 1978). Potentially dangerous snow movement must, therefore, be reduced prior to afforestation through terracing, staking, three-legged supports, or temporary avalanche defence structures. Without such measures, these threatened sites cannot be afforested. Any action that increases the surface roughness is advantageous (Leuenberger, 1989).

Slopes with northern aspect are cold sites and lack solar energy. They are characterised by typical plant associations with *Empetrum hermaphroditum* and *Hylocomium splendens* (Kuoch, 1970) and by a thick surface layer of raw humus since the biological activity is low (Blaser, 1980). Due to low temperatures and poor nutrient status, the young trees grow very slowly, and are thus exposed to higher risks of damage and mortality over an extended period. In June and July, for example, east-exposed sites get approximately twice as much solar radiation as north-exposed sites with a comparable inclination (Häsler, 1982; Schönenberger, 1985).

In dense vegetation, the young trees suffer from lack of light. In such places, tall forbs and grass compete with the seedlings until the trees are large enough to overcome this hindrance. Tall vegetation generally coincides with moist patches in depressions with long-lasting snow cover (Schönenberger and Frey, 1988).

Sites exposed to high winds are often snow-free in winter and the soil may freeze to a considerable depth (Turner, 1988). At snow-free places there is sometimes a risk of frost drought, as the young trees are not protected by snow (Schönenberger, 1978).

On generally depressed terrain, such as gullies, several of these negative effects are usually found to be accumulated.

Favourable microsites are usually found on locally higher terrain, such as ridges, edges of slopes, shoulders, rock buttresses, and around tree trunks. These sites tend to have little snow, relatively short snow cover, usually only insignificant snow movement, and sparse vegetation. In the subalpine zone natural regeneration, particularly of Norway spruce and cembran pine, is concentrated in such places (Schönenberger et al., 1990). Here the young trees naturally form discrete collectives. Such densely growing communities are more successful than solitary trees, and may be taken as models for afforestation (Schönenberger, 1978). In summary: the rougher the topography, the greater the number of favourable microsites that can be exploited for afforestation. The surface roughness can be increased through mechanical measures such as terracing, and also through an irregular pattern of planting.

3. Cluster afforestation

3.1. Expected advantages of cluster afforestation

Based on our knowledge of the ecological conditions summarised in the previous section, a system of cluster afforestation was developed in contrast to the traditional procedure. In the past, afforestations were commonly planted in regular patterns over a given area, regardless of the microsite variation. Natural selection often caused great losses on slopes with unfavourable microsites (Senn, 1999), or the afforestations tended to turn into homogeneous stands (Brassel and Braendli, 1999).

Two different situations have to be considered. In the first, the terrain to be reforested is structured; in the second it is smooth and unstructured. In structured terrain the variety of favourable and unfavourable microsites must be taken into account. The microsites favourable for the early stages of the afforestation should be exploited. This is best achieved through relatively dense, clustered planting. Unfavourable sites should be left unplanted. This discrimination between microsites will lead to an irregular, varied arrangement of scattered afforestation clusters.

On slopes with an even, smooth surface there is little variation in microsites. Planted stands with a regular arrangement of planted trees tend to become single-storeyed, uniform, and short-crowned at an early stage. Such dense stands tend to be closed and dark, with virtually no ground vegetation or forest seedling regeneration. From the pole stage onwards, such uniform stands become vulnerable to snow pressure, windthrow, and insect attack (Ott et al., 1997). In forests of this type, extensive sections may collapse. Once gaps are created, the rest of the stand is greatly endangered.

In contrast, natural mountain forests, particularly Norway spruce and cembran pine forests, ideally have a cluster-like structure (Kuoch, 1972). In these forests a smaller number of trees often form a distinct cluster with a common canopy reaching to the ground (Ott et al., 1997). In afforestations it is advantageous to establish tree clusters at the time of planting and not only through tending operations later on.

The system of cluster afforestation is based on the following hypothetical considerations about how tree clusters function. The clustered arrangement of trees may have a number of advantages in the growing and mature stands. In the early stages of afforestation development, tree losses are expected to be lower than in conventional, evenly spaced afforestations since only the best microsites are planted, while unfavourable locations such as gullies, depressions or patches with well-established tall forbs are not planted at all. Despite the denser plant spacing, the number of seedlings required per unit area is not larger in clustered than in regular planting arrangements. Rapid generation of a favourable within-stand microclimate is favoured, since the trees are densely planted and, as they are located on the best sites only, they perform better. Less stand tending (thinning) is needed, as only a fraction of the total area must be cared for. The exclusion of high risk sites from planting may reduce the incidence of fungal infection because snow fungi cannot develop here. In addition, the trees on the margin of a small collective may be able to protect those in the centre from browsing damage and antler fraying. The seedlings may protect each other from wind and winter desiccation, and as the surface roughness increases with further tree growth, greater separation of trees and snow can be expected, as was found in a study of natural tree islands (Schönenberger, 1978).

At a later stage of stand development, tree clusters enhance the structural variety in mountain forests. Due to extensive internal edges with green branches reaching to the ground, the diversity of site conditions will tend to be higher than in homogeneous stands. Light, solar energy, and precipitation penetrate in a mosaic-like pattern, thus supporting a variety in soil conditions for ground vegetation and natural regeneration, as well as providing diverse habitats for birds, browsing game, and insects. Stands originating from cluster afforestations tend to become more open, multilayered, and nonuniform, and consequently more resistant to snow pressure, wind and insect attack than those from regular afforestation (Ott et al., 1997). As a result, the canopy does not have to bear the full weight of trapped snow-loads since the snow can be blown into the spaces between the clusters, and local breakdown does not automatically result in the collapse of the entire stand. Winds also attenuate within a clustered stand, and the risk of extensive windthrow may be reduced. In a cluster pattern, regeneration measures can be undertaken with minimal risk since the trees are assumed as more storm-resistant. If necessary, whole tree clusters can be removed to promote regeneration without endangering the stability of the stand.

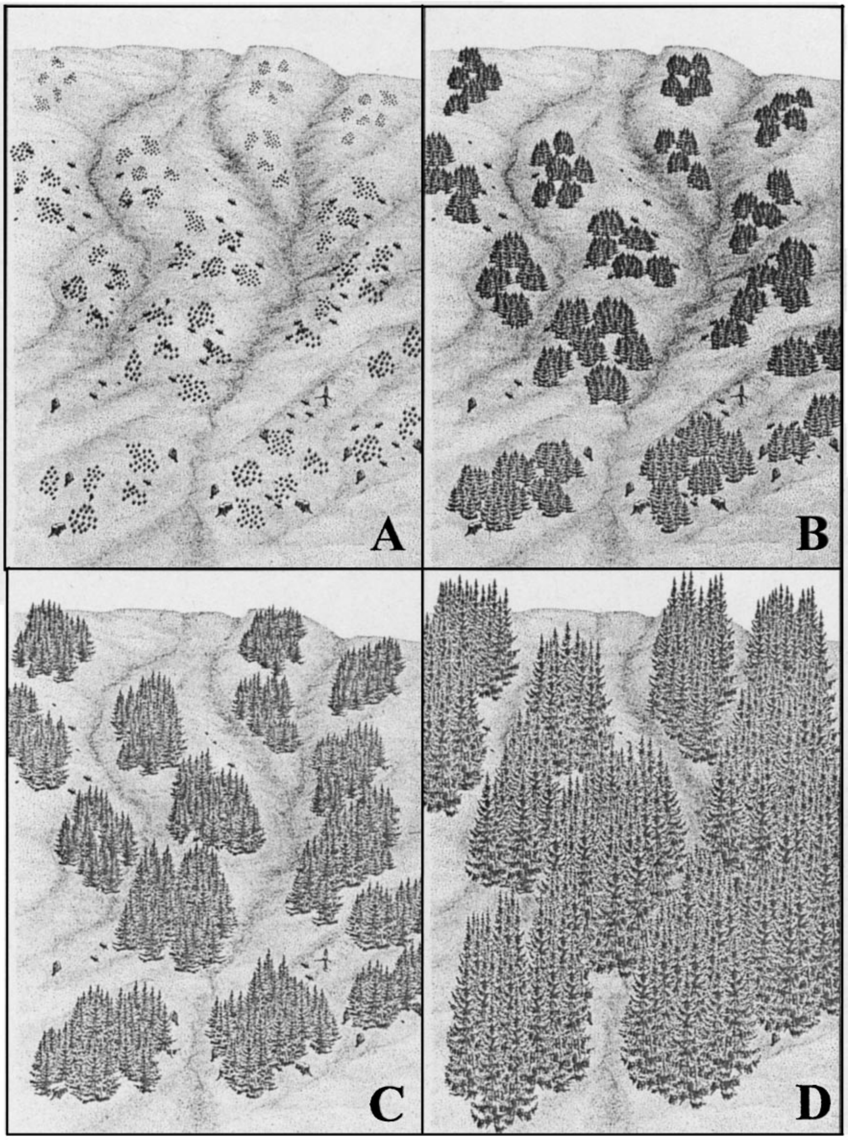

Fig. 1. A hypothetical development of a cluster afforestation with Norway spruce. (A) At the time of planting: ‘‘small collectives’’ of 20–30 seedlings, 2–4 m diameter and 2–3 m distant, seedling spacing 50–100 cm; (B) Five to ten years later, when seedling crowns close within the still separate ‘‘small collectives’’; (C) Two to three decades later, when the ‘‘small collectives’’ will merge to form the final ‘‘clusters’’; (D) Mature stand: the ‘‘clusters’’ remain distinct and touch each other only in places. The ‘‘small collectives’’ are no longer visible.

3.2. Guidelines for cluster afforestation

In afforestations clustering can be achieved by planting 20–30 seedlings in ‘‘small collectives’’ only 2–4 m in diameter, so that they do not cover the whole area (Fig. 1A). They must not be larger because otherwise they lose the character of collectives and tend to break down in the middle (Fillbrandt, 1998). Seedlings planted near the timberline should be spaced very closely, i.e. 50–100 cm apart; at lower elevations, the plants may be more widely spaced since growth and survival are better. Ideally crown closure within the small collectives should occur soon after planting, and the advantages of the cluster structure should become apparent within 5–10 years (Fig. 1B). The number of seedlings may gradually decrease due to juvenile mortality and competition. The small collectives should mainly be planted on rises, around tree stumps or on spurs. Gullies, depressions, or wet spots should not be planted.

Three to six temporary small collectives are arranged at distances as little as 2–3 m apart. They will then merge after 20–30 years to form a larger, permanent unit, a 'cluster' (in German: *Rotte*, Fig. 1C). From first planting, the distance between the final clusters must be large enough for them to remain discrete once the trees are fully grown. A suitable distance may be 7–10 m, equal to at least twice the branch extension of an adult tree. The size of a cluster should therefore be related to the expected tree height, which is dependent on elevation. The diameter of the cluster should be between half and the whole length of a mature tree. The cluster should be round to oval in shape, with the long axis parallel to the slope or to the direction of the prevailing wind. At high elevations, therefore, a width of 8–15 m and a length of 10–15 m is suitable; in mountain forests at lower elevations, the dimensions must be 5–10 m larger. Dimensions of the clusters should be governed by the desired stand structure after 100 years growth (Fig. 1D).

Only one tree species should be used within each cluster, but it is desirable to vary the species among the clusters. Cembran pine and Norway spruce are particularly suitable. On sites without risk of erosion or weed infestation, spaces of cluster size may be left unplanted for later afforestation or natural regeneration. On problematic sites, for instance, where protection against erosion is necessary, the gaps should be planted with pioneer shrubs and trees. The size, shape, and composition of the clusters should not be fixed but rather flexible and matched to the terrain.

3.3. Case study Mustair: A cluster afforestation trial

In 1984 a cluster afforestation experiment was started on a steep slope near Mustair, at the high elevation of 1800–2400 m a.s.l. close to the timberline. A forest fire in 1983 had destroyed the previous spruce-larch-cembran pine stand. Each small collective consisted of 20 or 30 seedlings planted 70 cm apart, giving it a diameter of 3–5 m (Fig. 2). Between three and six small collectives were placed at a distance of 2–4 m, thus composing a cluster. Each cluster was approximately 10 m wide and 10–20 m long. The distance between clusters was 5–10 m. Each cluster contained one of the following tree species: *Pinus cembra* L., *Pinus mugo* Turra, *Larix decidua* Mill., and *Picea abies* Karst. A total of 2000 seedlings (15–25 cm high) were planted. In the larger areas between the clusters, shrubby species (green alder *Alnus viridis* de Candolle, the prostrate form of mugo pine *Pinus mugo* Turra, and birch *Betula pendula* Roth) were planted.

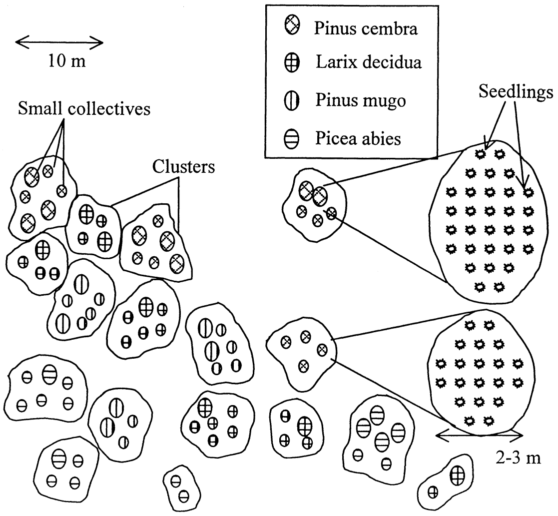

Fig. 2. Map of the cluster afforestation trial Mustair. 17 "clusters", each composed of 2–6 "small collectives", containing 20 or 30 seedlings each.

With this arrangement, the area covered by the small collectives was only 4% of the total area of 0.72 ha. It is estimated that the final clusters will cover 30% of the total area, whereas shrubs and unplanted gaps will account for 70%.

The afforestation was assessed in 1997, 13 years after plantation, and preliminary conclusions about the performance of the seedlings and small collectives drawn. However, it was still too early to comment on the relationship between small collectives and the performance of the clusters. The trees were still rather short: the cembran pine and Norway spruce were about 1 m, and larch and mugo pine about 1.7 m high (Table 1).

The influence of the position of a seedling, (i.e. whether it was growing at the outer margin of the

Table 1
Influence of tree position in the small collectives on different tree parameters after 13 years (1997)[a]

	Pinus cembra		*Pinus mugo*		*Picea abies*		*Larix decidua*	
	Margin	Centre	Margin	Centre	Margin	Centre	Margin	Centre
Mean tree height cm	110	96	163	174	**110**	**101**	180	176
Mean increment 1995–1997 cm	69	69	72	70	44	44	**41**	**33**
Trees damaged by snow pressure (%)	–	–	17	25	0	1	**15**	**18**
Trees damaged by fraying ungulates (%)	–	–	**34**	**1**	0	1	**11**	**3**

[a] Significant differences ($P < 0.05$) between margin and centre trees in bold. Block design analysis of variance, clusters as blocks, small collectives as plots within blocks.

small collective or in the centre), on several tree parameters was analysed (Table 1). No significant differences in the tree heights of the marginal and central trees of the small collectives were found except for Norway spruce, where the marginal trees were taller than the central ones. For larch growing in the centre, stem bending resulting from snow pressure was significantly worse than for marginal trees, whereas for the other species the tree position had no influence on the stem bending. Mugo pine and larch at the margins were significantly more damaged by fraying ungulates (roe and red deer) than central trees, which suggests that the majority of the trees were less accessible to browsing ungulates. Several observations in winter and spring revealed that the snow cover varied considerably between the small collectives and the gaps. The small collectives (especially of spruce) became snow free earlier in spring because the snow melted around the edges and accumulated in the gaps between them. We can conclude that the chosen arrangement of small collectives (as described above) was suitable for spruce, but too narrow and numerous for the fast-growing larch and mugo pine and too widely spaced for the slowly growing cembran pine. It was not difficult to set up the cluster arrangement, and the workers were easily able to follow the guidelines, to find and make selective use of the favourable microsites and to apply the appropriate spacing between the seedlings, small collectives and clusters.

4. Conclusion

This paper draws on observations, experience and results from more than 30 years research on the afforestation experiments at Stillberg and from the 15 years of the cluster afforestation trial at Mustair. From these we conclude that, during the juvenile phase, the system of cluster afforestation has shown many advantages over uniform planting systems. Structural diversity in terms of tree species, snow distribution, microsite variation was increased. Central seedlings were effectively protected from browsing. Small clusters were snow free earlier than the gaps between. This approach avoided excessive waste of seedlings and costs less than traditional methods of afforestation. However, it needs to be fine-tuned for different tree species. Although it is too early to draw any conclusions about the process of amalgamation of the small collectives into the final clusters and to what extent the cluster arrangement can prevent the formation of uniform thickets, pole and adult stands, initial results look promising.

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