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GUIDELINES FOR HIGH ALTITUDE RESTORATION

RICHTLINIEN HOCHLAGEN-BEGRÜNUNG

DIRECTIVES POUR LA VÉGÉTALISATION EN ALTITUDE

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Foreword

The first version of the present guidelines, published in the issue Soil Bioengineering 2/2008, made an important contribution to the distribution of current knowledge with recommendations for the realization and the planning of projects and the realization of successful high altitude restoration in the alpine region. In this way, it was illustrated to planning engineers, contractors, and authorities that vegetation can also make a valuable contribution to the sustainable stabilization of constructions or other human interventions in alpine regions. Projects have been carried out, the vegetation has grown in the meantime and so has the knowledge of their consistent and site-adapted use. New research knowledge and experience gained since the first guideline published twelve years ago have been integrated in the present version with decision-making aids for the selection of suitable methods, plant materials and additives. This makes the guidelines even better adapted to implementation needs.

The preface of the first edition of these guidelines by the former president Rolf Studer is still valid. The extreme conditions in the alpine region slow down processes such as soil formation and vegetation growth. The formation of an alpine lawn therefore requires very long periods of time. In order to be able to remedy the effects of structural interventions more quickly, profound knowledge of alpine ecosystems is needed. Together with practical manual instructions, these are conveyed in the present work.

At the outset, attention is paid to a uniform language regime so that those involved can communicate accordingly. The legal framework as well as the site conditions are the basic points of any project. Good project planning is essential for smooth execution. The actors and elements of project planning are explained in detail and then serve as the planning of the preparatory work and the ecologically sensitive, target-oriented execution, which takes into account all restoration-relevant aspects. With the acceptance of a revegetation project, one assumes that the development of the vegetation is going in the right (planned) direction, taking into account any maintenance measures. With regular performance checks, this development needs to be monitored even after the acceptance of work, until the restoration target is reached. If necessary, subsequent improvements are made.

The authors, as well as the members of the association's Working Group for High Altitude Restoration (AGHB), have done a remarkable job. This reference work will certainly find its deserved place in revegetation and revitalization projects at high elevation, where a broad internal consensus exists thanks to the tireless efforts of all involved.

Giovanni De Cesare, president of the Swiss Association for Soil Bioengineering

Vorwort

Die erste Version der vorliegenden Richtlinien, herausgegeben vor zwölf Jahren im Heft Ingenieurbiologie 2/2008, leistete mit Empfehlungen für die Projektierung und Realisierung von erfolgreichen Hochlagenbegrünungen im alpinen Raum einen wichtigen Beitrag zur Verbreitung von aktuellem Wissen. Es wurde auf diese Weise den planenden Ingenieuren, den Auftraggebern sowie den Behörden veranschaulicht, dass Pflanzen auch im alpinen Raum einen wertvollen Beitrag zur nachhaltigen Stabilisierung von Bauwerken oder anderweitigen menschlichen Eingriffen leisten können. Projekte wurden ausgeführt, die Pflanzen sind in der Zwischenzeit gewachsen, und die Kenntnisse zu deren folgerichtigen und standortangepassten Einsatz ebenfalls. Neue Erkenntnisse aus der Forschung sowie die Erfahrungen, welche seit dem Erscheinen der ersten Richtlinie vor zwölf Jahren gemacht wurden, sind in der vorliegenden Version ergänzt durch Entscheidungshilfen für die Wahl der geeigneten Methoden, Pflanzenmaterialien und Zusatzstoffen. Dadurch werden die Richtlinien noch besser an die Bedürfnisse bei der Umsetzung angepasst.

Das Vorwort der ersten Ausgabe dieser Richtlinien vom damaligen Präsidenten Rolf Studer hat immer noch seine Gültigkeit. Die extremen Bedingungen im alpinen Raum führen zu einer massiven Verlangsamung von Prozessen wie Bodenbildung und Pflanzenwachstum. Die Bildung eines alpinen Rasens benötigt daher sehr lange Zeiträume. Um die Auswirkungen von baulichen Eingriffen schneller beheben zu können, braucht es fundierte Kenntnisse der alpinen Ökosysteme. Zusammen mit praktischen Handlungsanweisungen werden diese im vorliegenden Werk vermittelt.

Eingangs wird auf eine einheitliche Sprachregelung geachtet, damit die Beteiligten sich entsprechend verständigen können. Der rechtliche Rahmen sowie die Standortbedingungen sind die Grundpfeiler eines jeden Projektes. Eine gute Projektierung ist für einen reibungslosen Ablauf bei der Ausführung unerlässlich. Die Akteure und Elemente der Projektierung werden infolge eingehend dargelegt und dienen alsdann der Planung der Vorbereitungsarbeiten und der umweltschonenden, zielgerechten Ausführung, welche alle begrünungsrelevanten Aspekte berücksichtigt. Mit der Abnahme einer Begrünung geht man davon aus, dass die Entwicklung der Vegetation unter Berücksichtigung allfälliger Unterhaltsmassnahmen in die richtige (geplante) Richtung geht. Mit regelmässigen Erfolgskontrollen wird diese Entwicklung auch nach der Werkabnahme bis zum Erreichen des Begrünungsziels überwacht. Allenfalls sind Nachbesserungen erforderlich.

Die Autoren sowie die Mitglieder der Arbeitsgruppe Hochlagenbegrünung (AGHB) des Vereins haben eine bemerkenswerte Arbeit geleistet. Dieses Standardwerk findet sicherlich seinen verdienten Platz bei Begrünungs- und Revitalisierungsprojekten in Hochlagen, wo dank dem unermüdlichen Einsatz aller Beteiligten ein breiter fachinterner Konsens besteht.

Giovanni De Cesare, Präsident des Schweizerischen Vereins für Ingenieurbiologie

Avant-propos

La première version des présentes directives, publiée il y a douze ans dans le numéro 2/2008 de notre bulletin Génie biologique, a apporté une contribution importante à la diffusion des connaissances actuelles avec des recommandations pour la planification et la réalisation de projets de végétalisation en altitude dans l'arc alpin. De cette manière, il a été démontré aux ingénieurs en charge des planifications, aux maîtres d'ouvrage et aux autorités que les plantes peuvent apporter une contribution précieuse à la stabilisation durable des ouvrages ou à d'autres interventions humaines également en région alpine. Des projets ont été réalisés, les plantes ont entre-temps poussé et les connaissances nécessaires à leur engagement cohérent et adapté à la station ont également été acquises.

Les nouvelles connaissances issues de la recherche et les expériences acquises depuis la publication des premières directives il y a douze ans ont été complétées dans la présente version par des aides à la décision pour la sélection des méthodes, des matériaux végétaux et des additifs appropriés. Ainsi, les directives sont encore mieux adaptées aux besoins de la mise en œuvre.

L'avant-propos de la première édition de ces directives par le président de l'époque, Rolf Studer, est toujours valable. Les conditions extrêmes en région alpine entraînent un ralentissement massif des processus tels que la formation des sols et la croissance des plantes. La formation d'une pelouse alpine nécessite donc de très longues périodes de temps. Afin de pouvoir remédier plus rapidement aux effets des interventions structurelles, une bonne connaissance des écosystèmes alpins est nécessaire. Ces connaissances, ainsi que des instructions pratiques de mise en œuvre, sont transmises dans cet ouvrage.

Pour débuter, on veille à utiliser un langage uniforme afin que les participants puissent communiquer en conséquence. Le cadre juridique et les conditions du site sont les pierres angulaires de chaque projet. Une bonne planification des projets est essentielle pour une exécution sans heurts. Les acteurs et les éléments de la planification du projet sont expliqués en détails et servent ensuite à

planifier les travaux préparatoires et l'exécution ciblée et respectueuse de l'environnement, tenant compte de tous les aspects pertinents pour la végétalisation. L'acceptation d'un projet de végétalisation repose sur l'hypothèse que le développement de la végétation va dans la bonne direction (planifiée), en tenant compte des éventuelles mesures d'entretien. Cette évolution est suivie par des contrôles d'efficacité réguliers, également après l'acceptation des travaux, jusqu'à ce que l'objectif de végétalisation soit atteint. Des retouches peuvent éventuellement être nécessaires.
Les auteurs ainsi que les membres du Groupe de travail pour une végétalisation en altitude (Arbeitsgruppe Hochlagenbegrünung AGHB) de l'Association ont accompli un travail remarquable. Ce travail de référence trouvera certainement sa place méritée dans les projets de végétalisation et de revitalisation en altitude, où il existe, grâce aux efforts inlassables de tous les acteurs concernés, un large consensus interne.

Giovanni De Cesare, président de l'Association suisse pour le génie biologique

Abstract

Ecosystems at high elevation are sensitive habitats of protection value. Construction, improper agricultural use and winter sports can leave scars that need to be repaired by adapted revegetation measures. In addition to protecting the soil from erosion, revegetation should not only preserve the landscape's attractiveness, but also the rich biodiversity that is perfectly adapted to alpine conditions. When habitats worthy of protection with rare or endangered species are affected, restoration is also required by law.
The site conditions of alpine and subalpine zones make biological and chemical processes slow. Low temperatures, wind or soil erosion lead to very slow soil formation. The resulting low water storage capacity and nutrient availability impede plant growth. The development and establishment of the present vegetation cover is the result of very long-lasting processes. After disturbance by structural interventions or by natural events, vegetation at high elevation recovers only very gradually. In addition, most plant species at this elevation spread mainly vegetatively rather than by seeds. It is therefore extremely important to protect existing vegetation and reestablish it as best as possible. Another significant point is the aspect of soil protection: Only vegetated soil is suitably protected against impacts such as erosion and leaching.
In recent years, procedures for the restoration of site-appropriate vegetation in the Alpine region have gained further importance. The best possible results are achieved with the direct reuse of the intact vegetation cover in the form of sods, if necessary with intermediate storage. Seeding is inevitable when no or not enough sods can be peeled off. Seeds can be applied wet or dry. The seed mixture should be regional, adapted to the site, and should not contain alien species. Additives such as glue or mulch help seed germination and establishment. Often, seeds are sown in late autumn as sleeping seeds so that they germinate in spring under optimal conditions.
In order to avoid ecological and economic damage in the long term, it is worthwhile implementing high-quality restoration that provides good protection against soil erosion and takes the concerns of nature and landscape conservation into account as much as possible. These must already be included in the project planning.

Keywords
High elevation restoration, high altitude restoration site-specific, restoration, bioengineering, high elevation, high elevation, habitat, alpine, erosion, landscape value, natural value

Zusammenfassung

Ökosysteme in Hochlagen sind empfindliche und schützenswerte Lebensräume. Baumassnahmen, unsachgemässe landwirtschaftliche Nutzung und der Wintersport können Narben hinterlassen, welche durch angepasste Begrünungsmassnahmen zu beheben sind. Neben dem Schutz des Bodens vor Erosion sollen Begrünungen nicht nur die landschaftliche Attraktivität, sondern auch die reiche, perfekt an die alpinen Verhältnisse angepasste Artenvielfalt erhalten. Bei Beeinträchtigungen von schutzwürdigen Lebensräumen mit seltenen oder gefährdeten Arten wird die Wiederherstellung auch vom Gesetzgeber vorgeschrieben.
Die Standortbedingungen der alpinen und subalpinen Höhenstufen lassen biologische und chemische Prozesse nur langsam ablaufen. Tiefe Temperaturen, Wind oder Bodenerosion führen zu sehr langsamer Bodenbildung. Die dadurch geringe Wasserspeicherkapazität und Nährstoffverfügbarkeit erschweren das Pflanzenwachstum. Die Entwicklung und Etablierung der heutigen Vegetationsdecke ist das Resultat von sehr lang andauernden Prozessen. Nach einer Störung durch bauliche Eingriffe oder durch natürliche Ereignisse erholt sich die Vegetation in Hochlagen nur sehr zögerlich. Zudem breiten sich die meisten Pflanzenarten in dieser Höhenlage vorwiegend vegetativ und weniger über Samen aus. Es ist daher äusserst wichtig, die bestehende Vegetation zu schützen und bestmöglich wiederanzulegen. Ein weiterer bedeutsamer Punkt ist der Aspekt des Bodenschutzes: Nur bewachsener Boden ist gegen Einflüsse wie Erosion und Auswaschung optimal geschützt.
In den letzten Jahren haben Verfahren zur Wiederherstellung einer standortgerechten Vegetation im Alpenraum weiter an Bedeutung gewonnen. Bestmögliche Resultate erzielt man mit der direkten Wiederverwendung der intakten Pflanzendecke in Form von Soden, wenn nötig mit Zwischenlagerung. Aussaaten sind unumgänglich, wenn keine oder zu wenig Soden abgeschält werden können. Das Saatgut kann nass oder trocken aufgebracht werden. Die Samenmischung sollte regional sein, dem Standort angepasst und keine gebietsfremden Arten enthalten. Zusatzstoffe wie Kleber oder Mulch helfen bei der Keimung und Etablierung der Saat. Häufig werden Aussaaten im Spätherbst als Schlafsaat ausgebracht, damit sie im Frühjahr bei optimalen Bedingungen keimen. Um langfristig ökologischen und auch wirtschaftlichen Schaden zu vermeiden, lohnt es sich, qualitativ hochstehende Begrünungen zu realisieren, welche einen guten Erosionsschutz bieten und die Anliegen von Natur- und Landschaftsschutz grösstmöglich berücksichtigen. Diese müssen bei der Projektplanung bereits vorgesehen werden.

Keywords

Hochlagenbegrünung, standortgerecht, Renaturierung, Ingenieurbiologie, Hochlagen, Lebensraum, alpin, Erosion, Landschaftswert, Naturwert

Résumé

Les écosystèmes en altitude sont des habitats sensibles et dignes de protection. Les mesures de construction, l'exploitation agricole inappropriée et les sports d'hiver peuvent laisser des cicatrices qui peuvent être résorbés par des mesures de végétalisation appropriées. En plus de protéger le sol de l'érosion, la végétalisation doit non seulement préserver l'attrait du paysage, mais aussi la riche biodiversité parfaitement adaptée aux conditions alpines. Lorsque des habitats dignes de protection abritant des espèces rares ou menacées sont endommagés, la loi exige également leur restauration.
Les conditions des sites en stations alpines et subalpines permettent uniquement un développement plus lent des processus biologiques et chimiques. Les basses températures, le vent ou l'érosion des sols entraînent une formation très lente des sols. La faible capacité de stockage de l'eau et la disponibilité des éléments nutritifs qui en résulte entravent la croissance des plantes. Le développement et l'établissement de la couverture végétale actuelle sont le résultat de processus très durables.
Après un dérangement causé par des interventions structurelles ou des événements naturels, la végétation en haute altitude tarde à se rétablir. De plus, la plupart des espèces végétales à cette altitude se propagent principalement par voie végétative et moins par les semences. Il est extrêmement important de protéger la végétation existante et de la réintroduire de la meilleure façon possible. Un autre aspect important est la protection des sols: seul un sol végétalisé est protégé de manière optimale contre des influences telles que l'érosion et l'affouillement.
Ces dernières années, les procédures de restauration de la végétation adaptée aux stations alpines ont gagné en importance. Les meilleurs résultats possibles sont obtenus en réutilisant directement la couverture végétale intacte sous forme de mottes, si nécessaire avec un stockage intermédiaire. Les semis sont inévitables si l'on ne peut pas, ou en quantité insuffisante, préparer les mottes de gazon. Les semences peuvent être appliquées de façon humide ou sèche. Le mélange de semences doit être régional, adapté à la station et ne pas contenir d'espèces non indigènes.

Des additifs tels que la colle ou du mulch aident la graine à germer et à s'établir. Les semis sont souvent effectués à la fin de l'automne comme semis dormants afin que la germination se fasse au printemps dans des conditions optimales.
Afin d'éviter des dommages écologiques et économiques à long terme, il est intéressant de mettre en place une végétalisation de haute qualité offrant une bonne protection contre l'érosion et tenant compte autant que possible des préoccupations de la protection de la nature et du paysage. Celles-ci doivent déjà être prévues lors de la planification du projet.

Mots-clés
Végétalisation en altitude, adapté à la station, renaturation, génie biologique, stations d'altitude, habitat, alpin, érosion, valeur du paysage, valeur naturelle

1 Introduction

1.1 Authors

The Working Group for High Altitude Restoration (AGHB) has existed since 1996 as a specialist group of the Swiss Association for Bioengineering. It is committed to the promotion of site-specific and ecological restoration at high elevation. The first version of the guidelines was developed in collaboration with the Environmental Planning Research Group of the Zurich University of Applied Sciences (ZHAW) in Wädenswil, including one diploma thesis and one semester thesis each, and was supported financially and organizationally by the Swiss Federal Office for the Environment, Hazard Prevention Department.

This second, completely revised and expanded version was produced by the Mountain Ecosystems Research Group at the WSL Institute for Snow and Avalanche Research (SLF) of the Swiss Federal Institute for Forest, Snow and Landscape Research in Davos, incorporating research results from ZHAW in Wädenswil and the Forage Production and Grassland Systems Research Group of Agroscope, with the support and expert advice of the members of the AGHB.

1.2 Goal

The guidelines are intended to increase the quality of high-altitude restoration by defining standards. Permit and concession authorities are given an instrument on which they can base their assessment of projects at high elevation. This standardizes enforcement throughout Switzerland. In addition, the guidelines are intended to support all parties involved in the planning and implementation of high altitude restoration in order to efficiently achieve a long-term, ecologically satisfactory restoration success and to avoid later remediation costs due to erosion damage.

1.3 Scope of application

The present guidelines apply primarily to high elevation areas in the Swiss Alps (altitude and elevation used synonymous throughout). According to the following definition, high altitudes are areas of the subalpine, alpine and nival zones, which are located in the Swiss Alps above c. 1500 m above sea level. The guidelines take into account legal and geographical conditions in the Swiss Alpine region. However, they can also be applied to a large extent at high elevations outside of Switzerland.

1.4 Application of the guidelines (Content, structure and outline)

In order to meet the different needs, two versions have been drafted. The long, extensive version serves as a reference work, while the short version is used as a checklist at the construction site.

The present, extensive version contains detailed recommendations for practice with graphs and illustrations for all work phases from project planning and execution to handover and success checks.

The color-coded structure of the individual working steps simplifies the overview (Fig. 1). With reference to literature as well as the experience of the members of the AGHB, various possibilities are shown for the individual subject areas. Where special cases do not require an individual assessment, users will find suitable recommendations for most situations.

Figure 1: Schematic sequence of a restoration procedure. The sequence corresponds to the outline in the guidelines.

2 Definitions

The literature contains a large number of technical terms that are not always used consistently. This glossary defines the most important terms as they are used in these guidelines.

2.1 Glossary

Aggregate

A soil aggregate results from cementation of mineral components with living and dead organic matter (Nievergelt et al. 2002). Stable aggregate structures are essential building blocks for the soil matrix and the pore structure. They are the prerequisite for good water and nutrient retention capacity of the soil (Graf et al. 2017).

Biodiversity

Biodiversity includes species richness of animals, plants, fungi, and microorganisms, diversity within various species, diversity of habitats, and the interactions within and between these levels (BAFU 2017).

Climate

Climate (also called macroclimate as a distinction from microclimate) refers to the average weather and the state of the atmosphere over a longer period of time. In contrast, current phenomena are referred to as weather (Körner et al. 1989).

Climax Community

Final state of succession (see Succession). A stable, but usually dynamically oscillating and fluctuating permanent state of a self-sustaining biological system under constant climatic conditions (Schaefer 2012).

Commercial seed

Commercial seed is produced in nurseries and usually sold as a standardized mixture but can also be composed specifically for a certain area. Depending on further designation, it may contain ecotypes or cultivars of different origins. A distinction is made between ecological suitability (site-appropriate / off-site) and geographical origin (local / regional / CH / foreign). Each seed company has its own brand names.

Coverage

The coverage is the vertical projection of all above-ground parts of a plant onto the sample area as a percentage of the total area. In the case of multilayered closed vegetation, the sum of the coverage percentages can exceed 100% (Wagenitz 2003).

Cultivars
Cultivars are plants specifically selected by humans for certain characteristics, which then result in a variety with the corresponding designation. In forage production, for example, the aim is to achieve a high leaf mass and few flowering sprouts. At high elevation, cultivated forms are only used in the restoration of cultivated agricultural land (intensive grassland), while wild forms are used for near-natural revegetation.

Direct revegetation
In direct revegetation, the seeds of a donor area are harvested in a suitable way and spread on the recipient area without intermediate propagation. In this process, freshly cut grass, hay or harvested seeds can be transferred (Agridea 2015).

Direct relocation
In the case of direct relocation, the existing vegetation is carefully removed together with the upper rooted layer of soil. The sods obtained in this way are immediately reused at another site without intermediate storage (Marti et al. 2016).

Ecotypes
Ecotypes are genetic variants of a plant species resulting from natural selection, which are optimally adapted to the environmental conditions of their location in their geographical range (Dierssen 1990). They are also called wild forms, as opposed to cultivated forms. Ecotypes are seeds that have been propagated for generations without human breeding selection.

Hay flowers
Hay flowers are seeds that fall out from stored hay and are collected from the ground. Older material from harvests more than two years ago is unsuitable, as the germination capacity of seeds decreases rapidly (Sengl et al. 2014). Suitable for seeding at high elevation are hay flowers of extensive permanent meadows up to approx. 2000 m above sea level.

High altitudes (syn. high elevation)
High altitudes are areas of the subalpine, alpine and nival levels. In the Swiss Alps, the high altitudes begin above about 1500 m above sea level.

High-altitude restoration
High-altitude restoration refers to the restoration and establishment of site-appropriate vegetation at high elevation, which generally maintains itself in a permanently stable manner when used with low intensity or not at all. With the exception of a growth and development phase, it does not require any further measures compared to the previous use (Krautzer et al. 2000).

Horizon
A soil horizon is a layer in the soil that can be distinguished in structure and composition from areas above and below it and has been formed by soil formation (Kretzschmar 2017).

Invasive plant species
Neophytes are foreign plants that have been intentionally or unintentionally introduced from other areas and have been able to establish themselves in their new locations. Invasive neophytes proliferate and damage native biodiversity, can destroy infrastructure and endanger human health (Nentwig 2011).

For some of the invasive neophytes in Switzerland, a legal basis exists to prevent their spread. In Switzerland invasive neophytes that are blacklisted or watch-listed and cannot be tolerated in near-natural high-altitude restoration.

Landscape value
Landscape value takes into account the aesthetic-visual and physical-sensory as well as the ecological and cultural values of a landscape (ANU 2018).

Livestock trails
Livestock trails are trodden paths made passable by the cattle. Cow tracks often move parallel to the slope or with a slight incline (Schweizerisches Idiotikon: Treie).

Local
The plants or seeds originate from the same valley community with a maximum distance of 30 km and a maximum elevation difference of 300 m (Agridea 2015).

Macro relief
Macro relief describes large-scale terrain features such as plains, valleys, mountains, or hills (Blume et al. 2010).

Microclimate
The microclimate is influenced, among others, by slope, topography, shading, and soil properties (Wagenitz 2003), but also by the plant itself (Körner 2014). It can deviate significantly from the macroclimate at a defined site.

Micro relief
Micro relief is the term used to describe small-scale terrain forms. These can be e.g., grooves, humps, steps or ramparts, but also smaller irregularities of the surface (Blume et al. 2010).

Mycorrhiza
Mycorrhiza is a symbiosis between plants and fungi, where the fungi live on or in the plant's roots and form a fungal tissue in the soil (Mertz 2008). Arbuscular mycorrhizal fungi can be used in revegetation with herbaceous plants (Schmid et al. 2005). The plants profit from improved nutrient uptake and have better protection against root pests thanks to the fungi (Townsend et al. 2009). Root growth is stimulated. The finely branched fungal filaments stabilize the soil together with the roots and contribute significantly to aggregate formation (Graf et al. 2017). The species diversity of vascular plants also depends on the diversity of site-specific fungal species in the soil (van der Heijden et al. 1998, van der Heijden et al. 2016).

Nature value
The nature value describes the value of a landscape in terms of the occurrence of habitats, animals, and plant species worthy of protection, as well as the closeness to nature (Bühler et al. 2015).

Nurse grasses and herbs
Nurse species are optional, short-living components of the seed mixture with the aim of favoring the development of the intended site-appropriate vegetation type, but later no longer being a component of this vegetation type (Krautzer et al. 2006). In case nurse species must be used, it is recommended to use regional seeds if possible (see 6.1).

Off-site species
Species that are foreign to a site are those that do not occur spontaneously or regularly at a specific site (LUBW 2009).

Raw soil
In the case of raw soils, chemical weathering and enrichment of organic matter has hardly or not at all taken place. As a result, raw soils have no B horizon and at most a weakly developed A horizon (Kretzschmar 2017). A raw soil is rich in macropores and therefore has a low capacity for water storage (Blume et al. 2010). There are no or few plant available nutrients (Kretzschmar 2017).

Regional
Regional refers to the origin of plant material. For Switzerland, biogeografical regions have been defined, which are further subdivided into major and minor regions. These take into account floristic and faunal species occurrences (Gonseth et al. 2001). Regional seeds are obtained and spread within the boundaries of a defined region of origin.

Site
Site is determined by the sum of site factors that affect an organism. In contrast to the geographical location, the site refers to the ecological situation, i.e. the abiotic and biotic environmental conditions (Wagenitz 2003).

Site factors
Site factors are specific conditions in the terrain over certain periods of time, such as climate, relief, nutrient and water availability, or soil type, but also biotic influences by other organisms such as shading, competition, predators, or symbioses (Wagenitz 2003, Körner 2014).

Site-appropriate species
Site-appropriate species are those that occur at a particular site under the conditions prevailing there (Krautzer and Graiss 2015). Their occurrence indicates the average prevailing biotic and abiotic site factors.

Slope
The slope describes the inclination of the hillside or the angle of repose. It can be described in degrees, percentages or as a ratio. An overview of the conversion is given in chapter 3.1 under the item "Site and soil factors" (see also Figure 3). In these guidelines, percentage is used for the slope.

Sod planting
In the case of sod planting, the existing vegetation cover is carefully removed in sods, analogous to direct relocation. The sods are temporarily stored and later planted, or they are directly transferred to a new site.

Sods
Sod refers to a lifted and removed piece of the original plant cover including roots and topsoil.

Soil horizon
Soil horizons are a sequence of layers above the parent material, which differ in their properties and were formed by soil formation (Kretzschmar 2017).

Soil matrix
The soil matrix consists of the solid soil substrate without pores (Hintermaier-Erhard and Zech 1997).

Soil pores
Soil pores can be filled with water or air and represent about half of the soil volume. A distinction is made between macropores, which serve for aeration and absorption of heavy precipitation, mesopores, which store water available to plants, and micropores (Kretzschmar 2017). The micropores also store water, but this is not accessible to plant roots, unlike for fungal filaments, because the water is too strongly bound in the tiny pores (capillary force) (Schmid et al. 2005, Graf et al. 2017).

Subsoil (B-Horizon)
Subsoil is the less rooted layer below the humus in which soil formation takes place. It is 60 to 80 cm thick in deep soils, in flat soils less than 30 cm or even absent. Subsoil serves as a reservoir for water and nutrients (Umweltfachstellen-Zentralschweiz 2007).

Succession
Succession describes the sequence of interaction stages in the development of a biotic community at a site, which can lead to the final stage (climax). The species composition of the stage results from the respective site conditions and the previous history (Kreeb 1994, Willmanns 1998).

Target vegetation
The target vegetation is the vegetation that has been defined as the restoration object (or goal). Usually, the goal is to restore the original vegetation before the construction intervention. Where this is not possible (e.g., deforestation) or desirable (e.g., previous failed revegetation or usage-dependent vegetation phase), the target vegetation must be defined in advance. Foreign or nurse species are not permitted in the target vegetation according to the guidelines for high-altitude restoration.

Topsoil (A-Horizon)
Topsoil is the uppermost layer of soil, a few cm to about 30 cm thick (Umweltfachstellen-Zentralschweiz 2007). It is usually dark in color, rich in dead organic matter and living organisms, densely intergrown with roots, unsealed, and structured by aggregates. The term "humus" is generally used (Bellini 2015).

2.2 Abbreviation list

BAFU	(Bundesamt für Umwelt) – Federal Office for the Environment FOEN
BBB	(Bodenkundliche Baubegleitung) – Supervision for soil protection at construction sites
DZV	(Direktzahlungsverordnung) – Ordinance on direct payments to agriculture
K_2O	Potassium oxide
N	Nitrogen
NHG	(Bundesgesetz über den Natur- und Heimatschutz) – Federal Law about the Protection of Nature and Cultural Heritage
NHV	(Verordnung über den Natur- und Heimatschutz) Ordinance on the Protection of Nature and Cultural Heritage
P_2O_5	Phosphate
SIA	(Schweizerischer Ingenieur- und Architektenverein) Swiss Association of Engineers and Architects
SR	(Systematische Rechtssammlung des Bundesrechts) Systematic collection of federal law
UBB	(Umweltbaubegleitung) – Environmental construction supervision
VBBo	(Verordnung über die Belastungen des Bodens) – Ordinance on the pollution of the soil
WSL	(Eidg. Forschungsanstalt für Wald, Schnee und Landschaft) – Swiss Federal Institute for Forest, Snow and Landscape Research

3 Site conditions and legal context

3.1 High elevation site factors

High altitudes refer to areas in the subalpine, alpine and nival zone. An overview of the altitudinal zones in Switzerland is given by the classification according to Hess, Landolt & Hirzel, Flora der Schweiz, 1967–72 (Figure 2). The mean annual temperature is >0° C in the subalpine zone, –3° to –1° C in the alpine zone, and <–3° C in the nival zone (Eberhardt 1999). The transition from the subalpine to the alpine zone corresponds to the tree line. The alpine zone is characterized by largely closed alpine grasslands, which transition to sparse pioneer grasslands with cushion plants at the boundary with the (sub)nival zone (Ellenberg and Leuschner 2010). Depending on the geographic location, the altitudinal zones shift. In the inner alpine valleys, the boundaries are higher than at the alpine rim.

For every 100 meters of altitude, the vegetation period decreases by about one week (Krautzer et al. 2012c). At 2000 m above sea level, the vegetation period is about 100 days, at 2400 m above sea level it is still 70 days (BAFU and BAV 2013).

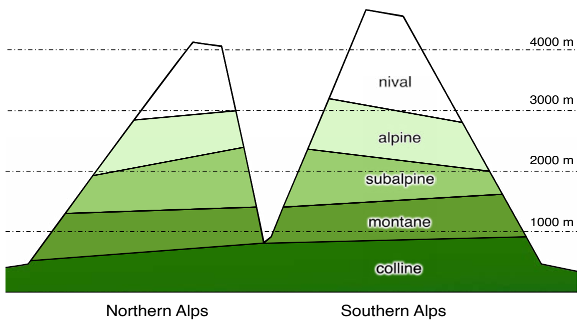

Figure 2: Altitudinal zones of Switzerland according to HESS, LANDOLT & HIRZEL, Flora der Schweiz (Hess et al. 1977)

Climatic factors

Temperature

In general, the temperature decreases 0.54° to 0.65°C per 100 meters of elevation (Laiolo and Obeso 2017), but it is strongly influenced by the respective microclimate (Ellenberg and Leuschner 2010). Minimum and maximum daily temperatures have a much higher amplitude in the Alps than in the Central Plateau. Clear nights can be very cold, however dark substrates can heat up to 80° C on sunny days (Körner 2003).
Frost and snowfall can occur throughout the year at high elevations (Ellenberg and Leuschner 2010). A snow cover in winter reduces the occurrence of ground frost. Under a 50 cm deep layer of snow, the temperature rarely drops below 0° C (Ellenberg and Leuschner 2010). In contrast,

during pre-winter periods with little snow, the ground can freeze quickly and then may remain frozen throughout the winter. Studies show that temperatures in the Alps have been rising faster than average as a result of climate warming (Meusburger and Alewell 2014), which can lead to a shift in altitudinal zones.

Solar radiation
The lower opacity of the atmosphere at higher elevation reduces the proportion of diffuse radiation, so that the intensity of direct radiation increases, and the contrasts between sunny and shady areas become stronger with increasing elevation (Körner 2003).

Precipitation
Precipitation in the Alps is relatively high at the northern and southern rim and can be up to 2500 mm/year. The inner alpine valleys are much less precipitated with 450 to 700 mm/year (Ellenberg and Leuschner 2010).

Wind
Wind has a major influence on snow distribution, snowmelt and evaporation. Exposed sites and flat areas are far more exposed to the wind than sheltered sites in valleys or hollows (Körner 2003). In winter, wind-swept sites are exposed to frost, and in summer there is a risk of drying out.

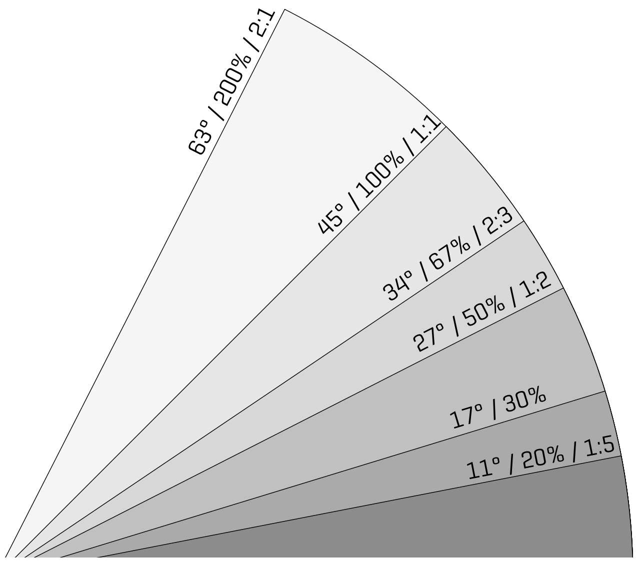

Figure 3: Selected slope angles in degrees, percentage and as ratio.

Terrain and soil factors
Relief and aspect
The small-scale changing relief of the Alps creates versatile site conditions (Figure 4). Different angles of solar radiation result in different warm spots (Krautzer and Klug 2009). Depressions have a better nutrient supply, but are generally snow-covered for longer periods (Lichtenegger 1994). Edges, knolls, and ridges exposed to the wind are poor in snow, which makes them more exposed to frost (Ellenberg and Leuschner 2010). The influence of relief can affect the microclimate far more than elevation (Ellenberg and Leuschner 2010), variation in the growing season of up to one month is possible (Scherrer and Körner 2011). However, the microclimate is not only influenced by the relief, but also by the vegetation itself (Latzin 2004).

Figure 4: Differences in relief cause different soils and plant communities to alternate in a small area (Photo: K. Edelkraut).

Erosion
During erosion, soil components are translocated by wind or water and sedimented again elsewhere (Kretzschmar 2017). Erosion at high elevation is significant and could increase due to climate change if snow lasts less long and increased heavy precipitation in summer leads to increased surface runoff (Meusburger and Alewell 2014). Erosion promotes physical weathering and increases leaching of fine soil. As a result, soil formation is influenced.

Soil formation
Soils at high elevation are relatively young and mostly shallow. Physical weathering, i.e., the mechanical disintegration of the parent material without chemical alteration of the minerals, is pronounced at high elevation. On one hand, this is due to strong erosion, on the other, frequent frost changes.

Chemical weathering and, above all, the biological activity of the microorganisms that decompose organic matter are, conversely, strongly inhibited by low temperatures. As a result, soil formation at high elevation is very slow (Ellenberg and Leuschner 2010, Kretzschmar 2017). For example, while the formation of brown soil in subalpine grasslands takes about 190 years, it takes 250 to 300 years above the treeline. The formation of a podzol can take 500 to 3000 years (D'Amico 2015).

Nutrient and water availability
Due to the slow decomposition of organic matter, a large part of the nutrients is bound to litter and humic substances where they are not available to plants (Ellenberg and Leuschner 2010). Even though the total nitrogen supply above the treeline is about the same or greater than at lower elevations, low temperatures reduce mineralization and thus the availability of nitrogen for plants. The water storage capacity of alpine soils is constrained because of their shallow depth and high share of large pores (Körner 2003).

Anthropogenic factors
Meadows and pastures below the treeline require (agricultural) use to maintain them unforested. Above the treeline, regular management prevents the emergence of prostrate shrub vegetation. Pasture management promotes the structures typical of pastures with bare patches or grass tufts. Species composition is different from that of meadows and depends on the grazing animal species and its feeding behavior.

Excessive grazing, especially with heavy animals, promotes trampling damage, and abandonment leads to woody encroachment and reforestation (Bollmann et al. 2014).

In winter sports areas, insufficient snow cover can cause damage to the turf by snow groomers and skiers (Figure 5) (Schmid and Frei 2005). On groomed natural snow slopes, the compact snow is less insulating than loose snow, so ground frost occurs under the slopes. Artificial snowmaking reduces frost and mechanical injury to vegetation by groomers because the snow layer is thicker. On the other hand, additional water and minerals are added, and in springtime snowmelt is delayed about 2 to 3 weeks, which delays the development of vegetation (Stöckli et al. 2002). The higher density of artificial snow also reduces the exchange of gases with the environment, which can lead to suffocation of plants due to the reduced oxygen supply (Newesely et al. 1994).

In summer, mountain bikers or agricultural vehicles can damage the vegetation (Raper 2005, Marion and Wimpey 2007). However, inappropriate grazing (too high stocking, too heavy animals, too wet weather) also causes degradation to the vegetation cover (Schneider et al. 2017).

Adaptation of plants to the site
Morphological adaptations
Plants at high elevation are perfectly adapted to the conditions of their location. Special growth forms enable them to significantly affect the microclimate (Latzin 2004).

Figure 5: Visible damage on an alpine pasture. When the snow cover was too low, the knolls, which typically occur on pastures, were removed by snow groomers (photo: K. Edelkraut)

Figure 6: The Glacier Buttercup is perfectly adapted to the temperatures of its habitat (photo: C. Rixen)

Figure 7: The dense turf of the Cushion Pink keeps the litter and thus the nutrients with the plant and causes higher humidity inside the cushion. Both the cushion and the espaliered growth of the Willow protect against strong winds, and the warming of the soil is used optimally (photos: M. Peters)

The most important adaptation is small size (cushion, espalier growth, rosettes). High elevation plants invest less in growth above-ground than species at lower elevation, and their leaves are often smaller and thicker. On the other hand, the relative root mass of these plants is greater. The plants store relatively more reserves than comparable lowland plants. Small size and slow growth protect them from cold, wind, and predators and help them cope with the lower nutrient supply (Ellenberg and Leuschner 2010). The plants additionally protect themselves against drying out due to special characteristics of their leaves. In some species, dense hair reduces the wind speed on the upper leaf surface and thus protects against drying out, while a leathery upper surface or curled leaves protect against evaporation (Hess et al. 2015). Thanks to these adaptations, the water balance of plants is usually intact despite wind and low water availability (Krautzer et al. 2012c). Alpine plants have a wide temperature range for photosynthesis. For most species, growth already starts at a few degrees above zero. Glacier buttercup (*Ranunculus glacialis*) even achieves photosynthesis at –5°C (Figure 6). Hibernation organs of most plants are located near the ground or in the soil to profit from the insulation of the snow cover in winter.
In summer, the cushion or espalier growth causes higher humidity and temperature directly at the plant. Similar effects on the microclimate are caused by the dense hair of some species or the dead leaves of tussock grasses (Figure 7).
In autumn, among other mechanisms, plants gain freezing tolerance through tissue drainage. On the other hand, early frost events in autumn or late frost at the beginning of summer, when plants are physiologically active, can be damaging (Ellenberg and Leuschner 2010). This can prevent flowering or seed maturation (Heuerding 2005, Stöcklin 2009).

Adaptions in reproduction

Plants at high elevation have a slow growth rate but often reach a great age. Steinger et al. (1996) estimated an age of 2000 years for clonal populations of Curvy Sedge (*Carex curvula*). In general, these plants invest more energy in their vegetative maintenance than in generative reproduction.
Clonal reproduction, especially in dominant species of alpine grassland, thus plays a major role (Ellenberg and Leuschner 2010). In tussock grasses, spontaneous self-fragmentation supports vegetative reproduction (Wilhalm, 1996 in Ellenberg and Leuschner 2010).
Alpine plants indeed produce abundant seeds (Ellenberg and Leuschner, 2010), but proportionately fewer seedlings develop from these than from species at lower elevation. Still, plants generally reach a higher age, which compensates for this disadvantage (Forbis and Doak 2004).

Figure 8: Sprouting propagule in Bistorta vivipara *and Alpine Bluegrass (photos: M. Peters)*

Seed dormancy is a widespread characteristic of alpine plants. Seeds need one or more specific triggers to germinate. Probably the most common trigger that initiates or abolishes dormancy is temperature (Fernández-Pascual et al. 2017), normally a temperature of >5°C for several days is needed to break seed dormancy (Ellenberg and Leuschner 2010). Some species respond to a certain length of daylight or have underdeveloped seedlings within the seeds, which only develop completely until environmental conditions are optimal. Seeds with impermeable coats (often legumes) require factors that roughen the coats. Most alpine species show photoblastic germination, which is probably an adaptation to the treeless habitat (Schwienbacher et al. 2011).
The seasonal development of alpine plants must be completed in about 10 to 12 weeks. Development after snowmelt to flower formation is rapid. Pollination varies; in addition to cross-pollination, some species rely on self-pollination or the formation of vegetative propagules in addition to seeds (Alpine meadow-grass – *Poa alpina,* Alpine bistort – *Polygonum viviparum*) (Figure 8).

Relevance for revegetation
Successful revegetation should consider the special features of alpine sites and small-scale differences as best as possible.
The slow growth, small size and high age of the plants demonstrates that a closed alpine grassland requires a long development period and cannot be restored within a few years by seeding.
Therefore, the avoidance of interventions, and in particular appropriate planning and implementation of protection measures, as well as the conservation and reuse of plants and soil are of great importance. The reuse of whole sods not only helps to preserve the mature plants but also favors clonal growth into adjacent open areas.
If sowing is still necessary, slow soil formation must be considered. Existing topsoil must be protected from erosion by a covering (mulch, geotextiles). If topsoil is missing or insufficient, the seedbed must be complemented with suitable organic soil conditioners. Only local plant species adapted to the site are perfectly suited to the harsh conditions at high elevation.
By choosing a suitable sowing period (e.g., late autumn sowing), the short growing season can be used to its full potential (e.g., dormant sowing).
Adapted additives improve the microclimate and reduce erosion (e.g., mulch seeding). Microreliefs form interesting niches for revegetation and should therefore be preserved or promoted. Sunny depressions favor germination and growth thanks to better nutrient influx. In shaded depressions, on the other hand, development is slowed down due to late snow melt (Lichtenegger 1994), but the water supply may be higher.

3.2 Legal basis

The federal government sets legal framework conditions for structural interventions outside building zones. Some of these concern restoration measures.

If protected habitats (e.g., bogs or dry grasslands, but also sites that are habitats of protected or rare species) are impaired, the rule applies: "avoidance ➞ protection ➞ restoration ➞ replacement" (Art. 18 para. 1ter NHG). If, after a careful weighing of interests, an intervention cannot be avoided, it must be kept as small as possible. If this is not possible, the habitat must be restored or, if necessary, replaced. These guidelines are used in the restoration process. With the exception of agricultural and forestry operations and in parks, gardens, etc., the use of animal and plant species foreign to the site or the region is subject to authorization (Art. 23 NHG). For fertilization, cutting and grazing regimes, the directives of the Direct Payments Ordinance (DZV) must also be observed. In addition to Swiss legislation, the Convention on Biological Diversity also contains provisions concerning restoration.

Enforcement
The cantons ensure appropriate and effective enforcement of the constitutional and legal mandate (Art. 26 para. 1 NCHO). In addition to the legal basis, most cantons have further guidelines that must be taken into account (e.g. UBB guidelines). The handling varies from canton to canton and must be considered in individual cases (example GR see box). Additional information can be found in the guideline "Restoration and replacement in nature and landscape conservation", which was published by the BAFU (Kägi et al. 2002).

Relevant decrees and directives
The most important articles are listed below. The current status can be found online in the Systematic Collection of Federal Law.

- Bundesgesetz vom 1. Juli 1966 über den Natur- und Heimatschutz (NHG; SR 451); Art. 18 Abs. 1, Art. 18 Abs. 1ter, Art. 23
- Verordnung vom 16. Januar 1991 über den Natur- und Heimatschutz (NHV; SR 451.1); Art. 14 Abs. 3, Art. 20, Art. 26 Abs. 1, Anhang 1
- Verordnung vom 1. Juli 1998 über Belastungen des Bodens (VBBo; SR 814.12); Art. 6, Art. 7
- Verordnung über die Direktzahlungen an die Landwirtschaft (DZV; SR 910.13); Art. 29-34 (Sömmerungsgebiet), sowie verschiedene Artikel für übrige Wiesen und Weiden
- Vom BAFU erlassene oder anerkannte Rote Listen (RL) Übereinkommen vom 5. Juni 1992 über die biologische Vielfalt (Biodiversitätskonvention; SR 0.451.43); Art. 2, Art. 8

Example of evaluation system in Grisons (ANU 2018)

Evaluation of interventions in protected habitats (scoring system)
The assessment is used by the canton of Grison to calculate residual impacts that must be compensated for after an intervention. It is therefore in the interest of the project leadf to plan the interventions as gently as possible already during the planning phase. This can be done by adapting the project (impact area, routing) or by avoiding impacts through alternative procedures.

The guideline for the assessment of the obligation to restoration contains tables for the evaluation of the individual biotopes. The score points take into account landscape and various natural values (including open land biotopes, forest communities, springs, streams and stream banks, etc.). Then the scores of the impairment as well as the replacement measures are calculated. Replacement measures must reach approximately the same score as the impairment. In exceptional cases, the difference can be compensated monetarily.

Calculation example:
A new snowmaking line is to be built on 0.8 ha through a meadow with sedges on acidic soil (14 points) (F = 1 for loss). As a compensation, a 1 ha area of ski slope a meadow with sedges on calcareous soil (19 pts.) needs to be removed (F = 0.5 for slope removal).

8'000 x 14 x 1=112'000
10'000 x 19 x 0.5=95'000

The compensation is not sufficient, the point difference is 17'000. The compensation obligation is CHF 3.00/point, totaling CHF 51'000.

With a different alignment, the pipeline could be routed through grassland with Matgrass (*Nardus stricta*) (4 points), but would impact twice the area.

16'000 x 4 x 1=64'000
10'000 x 19 x 0.5=95'000

In the second option, the compensation would be valued higher than the construction: the project lead would not have to provide replacement and would even have a point credit for later use.

4 Project planning

Good project planning is essential for smooth execution (Figure 9). This includes preparatory investigations of vegetation, soil, etc., the realistic formulation of objectives as well as the preparation and submission of planning and documentation. At the beginning of the planning stage, the involvement of stakeholders and quality assurance must be defined.

4.1 Stakeholders

Early involvement of all stakeholders avoids unnecessary misunderstandings and thus helps to save time and costs. The following interest groups and stakeholders may be involved:

- Builders, property owners, farmers
- Environmental construction supervisors, soil engineering construction supervisors
- Planners, engineering and environmental offices
- Seed and plant suppliers
- Contractors, machine operators
- Administration (nature conservation, soil protection, natural hazards, agriculture)
- Tourism, mountain railroads
- Nature conservation and environmental organizations
- Research institutions

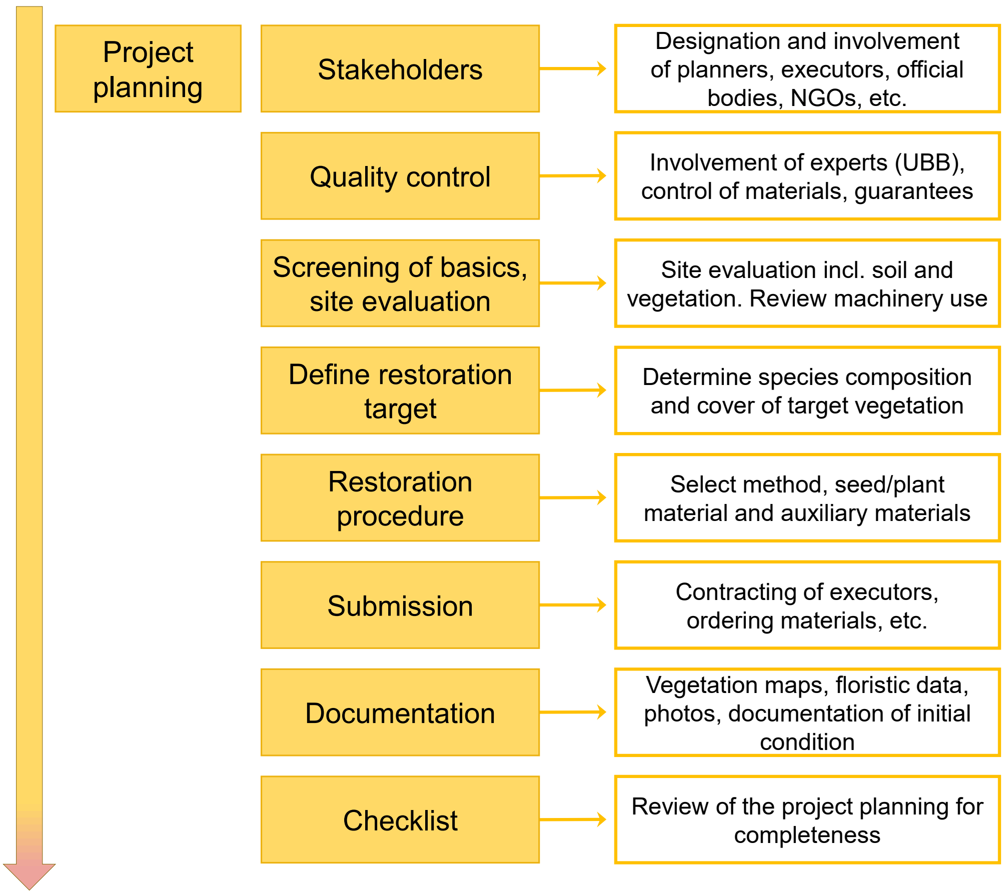

Figure 9: Summary of the project planning process.

4.2 Quality control

Involvement of external experts

During planning and construction, larger projects are closely accompanied from the beginning by specialists (mapping of vegetation and soil), as well as an environmental construction supervision / soil science construction supervision (hereinafter referred to as UBB) (BAFU and BAV 2013, Bellini 2015). Advice and early intervention by the UBB help to save costs. The UBB contributes to minimizing the impacts on nature and the landscape, ensures compliance with environmental protection legislation, checks the effectiveness of the measures introduced, and plans the restoration and revegetation.

Constant contact with the UBB during execution as well as with construction management and machine operators, helps maintain the good quality of the work carried out. The BAFU recommends that the UBB be present at the construction site several times a week (Brunner and Schmidweber 2007). Interdisciplinary cooperation between planners, authorities, construction companies, research institutes and institutions is important and should be encouraged.

Plants and seeds, additives

In addition to a certificate of origin, a seed delivery must be accompanied by a list of all the species contained in the delivery, together with their proportions in the mixture. Prior to sowing, a reserve sample is taken (Rieger 2006). Random sampling and the checking of receipts and delivery bills ensure that the seeds and additives ordered are used.

Execution

Contractors should be made aware of the correct handling of soil and turf sod. During an introductory briefing by the UBB or BBB, the direct relocation or the correct storage of the sods is demonstrated and special features (special plant species etc.) are pointed out.

After completion

After completion of the work, the process of the project needs to be reviewed and approved (see chapter 7).

Guarantees

Requirements

The SIA standards 118 "General conditions for construction work" and 318 "Gardening and landscaping" apply to guarantees if this is contractually agreed on. If no agreement is made, the Swiss Code of Obligations applies (Hürlimann 2007). The conditions are described below in accordance with the aforementioned SIA standards (SIA 2009, 2013).

In addition to the actual restoration objective, the required condition of the restoration areas at the time of handover following construction or restoration must be specified in the tender (e.g., with regard to soil loosening, humus formation, installation of cross gutters), as must be the responsibility for protection against harmful effects after acceptance. This forms the basis for any warranty claims.

Start of the complaint period

The complaint period begins upon acceptance of the restoration, which must be carried out jointly by the contractor and client within one month of completion of the work in the form of an acceptance test (Hürlimann 2007).

Scope

The extent of the damage to be repaired should be determined at the time of the tender in order to avoid ambiguities at a later stage.

Expiration of the warranty claim

The following damage will void the warranty:

- Damage caused by third parties (e.g., grazing, stepping on, driving with vehicles or fire);
- Damage caused by natural hazards;
- Damage caused by unusually heavy infestation of pests and diseases;
- Damage caused by contaminated and poisoned soils.

If the cultivation of seeds and planting are not carried out by the same contractor, the restoration company's warranty expires once the plants have become established. In the case of unsuitable timing of planting or seeding, the warranty shall expire only if the cultivation contractor issues a written rejection of warranty to the restoration company. If the cause of damage is caused by a breach of the contractor's duty of care, the warranty claim shall not expire (SIA 2009).

4.3 Site assessment

In many cases, restoration requirements are already specified in the building permit. As a basis for implementation, including the choice of seed or revegetation methods, surveys are carried out at the site before construction work begins. This includes information on existing vegetation, site factors (soil, exposure, slope, terrain, elevation), characteristic species of the respective target habitat, and species distribution.

Furthermore, the intended land use, infrastructure (access roads, machinery), etc. must be clarified.

Reviewing and completing the baseline

The data relevant to restoration should already be documented as part of the construction application. Where necessary, this information may be supplemented using relevant documents or literature (Delarze and Gonseth 2008), Internet databases (InfoFlora) or geoportals (Swisstopo). Geological and hydrogeological studies, site factors including vegetation surveys and soil investigations, information on species and protected areas, etc., and the applicable legal framework shall be reviewed and supplemented as required.

Vegetation studies

The aim of the vegetation survey is to determine the existing vegetation of the area concerned or of reference sites. This provides information on potential target communities and helps identify any obstacles to their establishment. Furthermore, potential biotopes for seed supply in the vicinity can be identified (Tischew 2006).

Clarifying previous use prior to construction work in grassland soils provides clues to the existing seed bank in the topsoil (Molder 2006).

Data should be recorded in a way that allows it to be used to define restoration targets and as a reference for subsequent success monitoring. The diversity of habitats at a small scale should be considered (Bellini 2015). A combination of the following methods are recommended.

Habitat mapping after Delarze is required for the permit process according to the NHG. For this purpose, vegetation units are assigned to a habitat type (Delarze and Gonseth 2008).

In the total species list, all species occurring in the revegetation area and its surroundings are reported without assessing their frequency of cover (Tremp 2005). The goal is a complete list. A Braun-Blanquet vegetation survey is used to estimate the cover percentages of the species present on sample areas (Braun-Blanquet 1964). For suitable plot sizes, empirical values are used (10 m^2 for species-poor pioneer grasslands, dry and wet meadows and intensive pastures, 10-25 m^2 for meadows, mountain grasslands or dwarf shrub heaths) (Tremp 2005). The size and number of sample areas depend on the heterogeneity of the perimeter and should be adapted to the circumstances.

Prior soil testing

A soil survey helps to select the appropriate target vegetation for the existing soil types and includes an assessment of erosion risk.

Heterogeneous conditions usually require small-scale mapping (Figure 10) (Bellini 2015). To ensure a representative selection of sampling for sites, attention should be paid to the site's topography as well as past and current soil-forming factors. Geological maps provide a rough indication of the parent rock. However, this may be obscured by heterogeneous deposits resulting from rockfalls and similar processes (Figure 10, left) (Baruck et al. 2016).

After large-scale soil rearrangements and mixing, it is advisable to carry out a new soil study in order to optimally adapt the revegetation to the site, particularly if site conditions have changed (Schneider et al. 2017).

Figure 10: High elevation soils are shallow and vary greatly depending on the location (photographs: K. Edelkraut).

Examination parameters

The following parameters should be recorded for site assessment (Krautzer et al. 2000, Nestroy et al. 2011):

- Thickness of the topsoil, and, where present, the subsoil;
- Features and thickness of the organic surface layer;
- Special soil characteristics (e.g., organic soil);
- Water balance (including waterlogging, slope water, or backwater)
- Erosion phenomena and susceptibility to erosion;
- Proportion of soil components that cannot support vegetation (especially stones/rocks).
- If the options allow further investigation, the following parameters provide useful additional information (Brunner et al. 1997, Nestroy et al. 2011):
- pH;
- Skeleton content;
- Grain size

Soil recycling

If surplus soil remains at the construction site and is not reused on site, its reuse or disposal must be planned at the project planning stage, taking landscape protection into account. Geogenic metals such as cadmium or selenium constrain recyclability. If such deposits or forms of soil contamination are suspected, further chemical analyses are necessary (Bellini 2015).

Erosion hazard

For slopes greater than 30%, a revegetation method with adequate erosion control must be selected (Krautzer et al. 2006). Depending on the soil composition, this value may vary.

Specify access roads, machine use and soil protection

Transportation options can influence the choice of revegetation methods. Therefore, it is essential to clarify whether and how a construction site is accessible. Excavators are used for groundwork. From a soil protection point of view, crawler excavators are preferable to wheeled excavators because they exert a lower surface pressure due to their larger contact area. Walking excavators are lighter and more agile overall. They are mainly used in steep terrain (Schiechtl and Stern 1992, Bellini 2015). Due to their special design, they can operate above the excavation pit and thus take up significantly less space than conventional excavators.
Even though soils at high elevations are often shallow, Wet soils must not be trafficked or worked on, as they are more prone to compaction. The relevant parameter for this is the suction tension, a measure of the water content of the soil pores. This can be measured using tensiometers.

In practice, however, soil moisture is often determined by touch or decided on the basis of the current weather. The suction tension as an expression of the load-bearing capacity of the soil is compared with the surface pressure and the operating weight of the machine. The application limits for construction machines can be calculated or read from the nomogram (Figure 11). In addition, measuring stations within cantonal soil monitoring networks provide information on the current soil condition.

Suction tension [cbar]=Insert weight [t] x surface pressure [kg/ cm^2] × 1.25

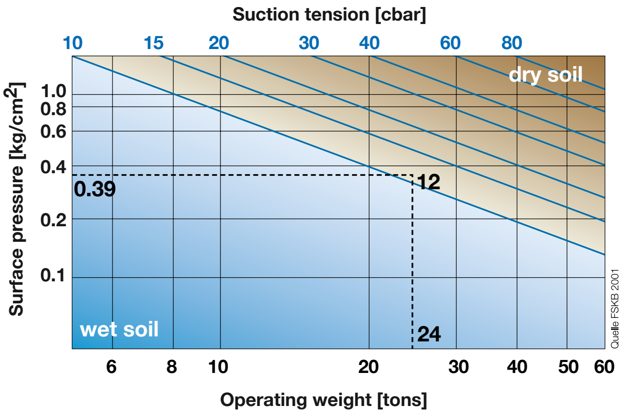

Figure 11: Determining the application limit from the nomogram: The intersection of the operating weight (vertical lines) and the surface pressure (horizontal lines) results in the suction tension (oblique lines). This corresponds to the soil moisture content above which the machine can be used directly on the soil (e.g., 24-ton excavator) (source: FSKB).

At the construction site, the following notes serve to assess soil moisture (Environmental Offices-Central Switzerland 2007):

Suction tension of:	
< 6 cbar	(Soil is wet and sticks in the excavator bucket): no driving and no earthworks.
6–10 cbar	(Soil is malleable, but does not stick to the excavator bucket): No driving, earthworks only from a base that is gentle to the soil (excavator mattress or similar) and when the soil is pourable.
> 10 cbar	(Chunks of soil break easily and freely move around in the excavator bucket): Driving and earthworks according to machine list or in consultation with UBB.

4.4 Restoration Target

The overarching goal of revegetation is site-appropriate, erosion-resistant vegetation (Marti et al. 2016). It should be close to the natural state of the area and adapted to the climatic conditions and the elevation level. The introduction of non-native vegetation should be avoided.
For a specific revegetation project, realistic, verifiable goals must be defined in the planning phase. Future land use and planting options as well as the elevation should be taken into account along with the timeframe for final success monitoring. Depending on the site, target vegetation, and revegetation technique, it may take several decades to achieve the desired species composition and coverage (Rydgren et al. 2011). The most important basis for the definition of the revegetation target is a thorough assessment. Contact with regional experts provide further information. In the absence of investigations prior to the start of construction, the species composition can be surveyed in comparable habitats in the immediate vicinity.

Table 1: Definition of revegetation targets.
Tableau 1 : Formulation d'objectifs pour la végétalisation en altitude.

Criterion	**Goals**
Aesthetics	Small structures are present The areas are integrated into the landscape The aspect of vegetation (flowering color, coloring) corresponds to that of the surrounding areas
Erosion	The degree of vegetation cover is at least 75%. There are no signs of erosion in the intervention area There are no vegetation-free areas > 400 cm^2
Naturalness	No non-native species to the region are present or predominant. The species composition corresponds to at least 3/4 of the target vegetation. The typical species of the target habitat predominate.

Table 2: Staging of the success monitoring until the restoration target is reached. The upper row (intensive) applies to seeding of intensive and low-intensity meadows and pastures as well as to sod planting, the lower row (non-intensive) applies to seeding of extensive meadows and pastures as well as alpine grassland.
Tableau 2 : Étapes du contrôle d'efficacité jusqu'à ce que l'objectif de végétalisation soit atteint. La ligne supérieure (intensive) s'applique aux semis des prairies et pâturages intensifs et de faible intensité ainsi qu'au repiquage des plaques de gazon, la ligne inférieure (extensive) s'applique aux semis des prairies et pâturages extensifs ainsi qu'aux prairies alpines.

Intensive	1 year	2–3 years	4–5 years
Non-intensive	1 year	2–3 years	8–10 years
Germination	Majority of germination has occurred, hardly any sods have died	Plants established, sods grown up	Seeding and sod established
Aesthetics		> 50% of target achieved	Target achieved

Figure 12: If old construction sites require revegetation, the vegetation target must be adapted to the site conditions. The topsoil is usually only very sparsely developed. In the case of non-native vegetation, it is advisable to sow site-appropriate seeds (photo: K. Edelkraut).

Within the timeframe specified in Table 2, restoration should meet the criteria listed in Table 1.

Time frame
The time frame varies depending on vegetation type and elevation. For sod planting and for seeding of intensive and low-intensity meadows and pastures, and at elevations below 2000 m, the goal should be reached within 5 years. In contrast, revegetation of slow-intensity meadows and pastures and alpine grasslands at higher elevations

requires a longer timeframe. A graduated success monitoring approach helps identify unfavorable developments at an early stage. Staging in accordance with Table 2 is recommended.

Species composition

In principle, the species composition of the revegetation should correspond to that of the target vegetation. Non-native species are only permissible in cultural mixtures for agriculture. Species characteristic of earlier successional stages may be appropriate if such habitats occur naturally in the surrounding area.

Target vegetation: special cases

In the case of new interventions on old construction sites or on forest clearings, the condition immediately before the intervention will not correspond to the desired target vegetation (Figure 12). The decision on which revegetation to pursue and which plant material can be reused must be made on a situational basis. If old construction sites were planted with non-native seed, the new intervention offers the opportunity to apply a site-appropriate mixture of the most local origin possible. If, on the other hand, the slope has been left to succession, efforts should be made to preserve the sods as much as possible and to supplement them with seeding. In pasture areas, no mown material is available according to the use. Where sowing is necessary and a suitable donor area is available, local meadow seed can be used for revegetation. Subsequent grazing will cause the species composition to shift back toward pasture.

Coverage

Vegetation cover should be adapted to the surrounding vegetation or the defined target vegetation. At locations below the tree line and in areas with continuous alpine grasslands, a coverage of 100% is targeted (Marti et al. 2016). If the existing surrounding vegetation naturally exhibits a lower cover, this level should also be adopted as the target for the restoration area Krautzer et al (2006)

Protection against erosion

Erosion must not be more pronounced after the intervention than before (BAFU and BAV 2013). Adequate erosion protection can generally be assumed at vegetation cover levels above approx. 70% (Krautzer et al. 2011). Higher species diversity in revegetation leads to improved erosion protection results (Martin et al. 2010). The target vegetation cover should be achieved as soon as possible. In the case of sowing, experience has shown that the vegetation is not stable enough to provide sufficient erosion protection until the second growing season. Even the sowing of nurse species does not necessarily provide faster erosion control (Graiss and Krautzer 2011). Until then, tools such as mulch combined with adhesives or geotextiles should be used to prevent erosion (Krautzer et al. 2011). In difficult conditions, cross beams, slope grates, or log cribwalls provide additional erosion protection for extended periods (Florineth 2014, Ammann 2017). Stones, root wads, or surface textures can also contribute to erosion control. In areas where there is a risk of slipping, sods are secured with wooden pegs. The planted vegetation blocks must establish firm root contact with the soil. The edges of the sods must be protected as good as possible from erosion or drying out by mounting them as close as possible to ground level.

Aesthetics / Tourism

Climate scenarios indicate a significant reduction in winter snow cover in the Alps (Gobiet et al. 2014), which increases the importance of summer tourism. Among summer guests, there is a trend towards nature-based hiking vacations. These guests seek unspoiled natural landscapes (Fleischhacker et al. 2012, Schützinger 2015). For this reason as well, construction-related interventions should become as visually unobtrusive as possible and integrate optimally into the surrounding landscape (Heuerding 2005). The relief should look as natural as possible within the constraints of the construction project. Neither visible scars nor inappropriate, landscape-incongruent revegetation should remain evident (Schmid and Frei 2005).

4.5 Selecting restoration methods

A wide range of seeds and seedlings are available for restoration, as well as various methods and additives. Most of them can be combined. In some cases, they are interdependent (Figure 13).

The following overview (Figure 13) lists the possible processes and possible combinations or dependencies between plant material, processes and additives. The numbers in the header refer to the respective chapters in which the processes and materials are described in more detail. A further overview (Figure 14) serves as support for the selection of the appropriate revegetation method, the plant and seed material and the recommended additives.

Based on the information from the preliminary studies and the available resources, the optimal revegetation method is selected to meet the revegetation goals. The gentler the use of available resources, the faster the revegetation goal will be achieved. The gentlest method is direct relocation.
If this is not possible, it is nevertheless important to save all existing plant material and to plant the remaining sod, if necessary in combination with sowing.

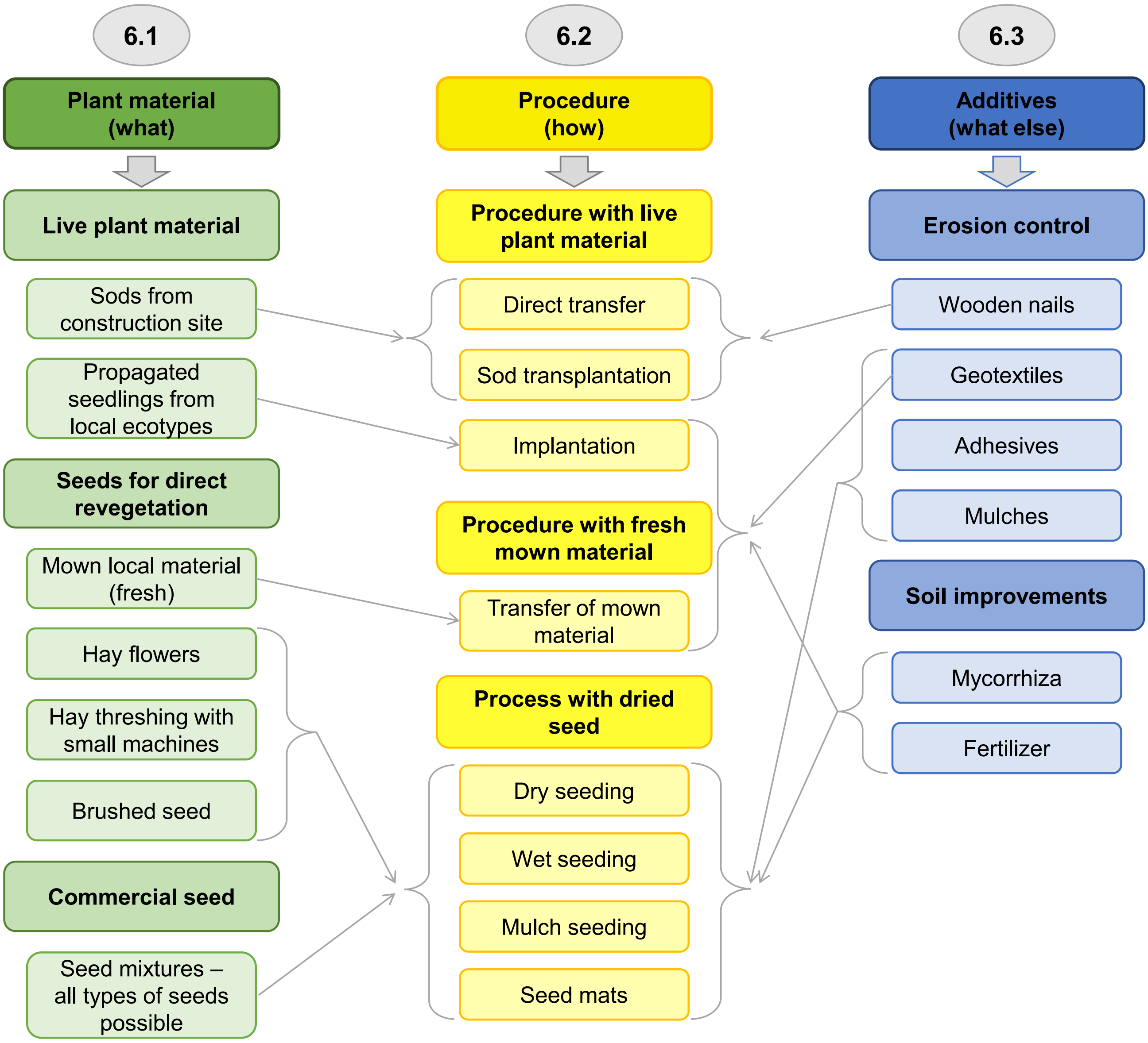

Figure 13: Overview of the methods, the possible plant and seed material as well as the additives and their combination. The individual methods or materials are described in chapters 6.2, 6.3, and 6.4 according to the numbers above the columns.

If seeds are needed, they must be site-specific. Local seed is ideal, but this requires suitable donor areas or the necessary lead time for targeted propagation. If local seed is not available, regional or CH-ecotype seed may be used. The choice of additives depends mainly on the soil condition, erosion risk and the revegetation method. In general, sod contains sufficient topsoil, so additional soil amendments are usually not required. Where topsoil is severely impacted or even absent and seeding is planned, soil improvement measures such as the placement of organic material to improve structure may be considered.
If mycorrhizal fungi are added to the seed, they can support nutrient and water uptake by the seedlings. However, these must be adapted to the site conditions of the intervention area.
Seedings at high elevation should be protected from wind erosion using mulches and an organic adhesive. Mulches also provide some erosion control against wash-off during rainfall.

The following overview (Figure 14) is intended to provide guidelines to select a restoration method. Special cases are not considered here. Explanations of the questions in the gray boxes can be found in the associated Table 3.

4.6 Tender

If the tender for the overall construction project includes a separated lot for restoration, further qualitative award criteria should be defined in addition to the costs (relevant project specific references, qualifications and training of the personnel involved, machines used, requirements for the seed and plant material).
The delegation of contracts to subcontractors shall be regulated in the tender. Deadline requirements are specified in the tender documents and in the contract between the contractor and the client. The specific weather conditions at high altitudes must be considered (snowing, access, frost, weather-related interruptions, etc.).

4.7 Documentation

Plan and map basis

The intervention perimeter should be recorded in a plan for tendering, execution, and documentation purposes. This also allows the size of the area to be estimated (e.g., to determine the amount of seed required). In addition, photographs of individual interventions serve as documentation for the report.

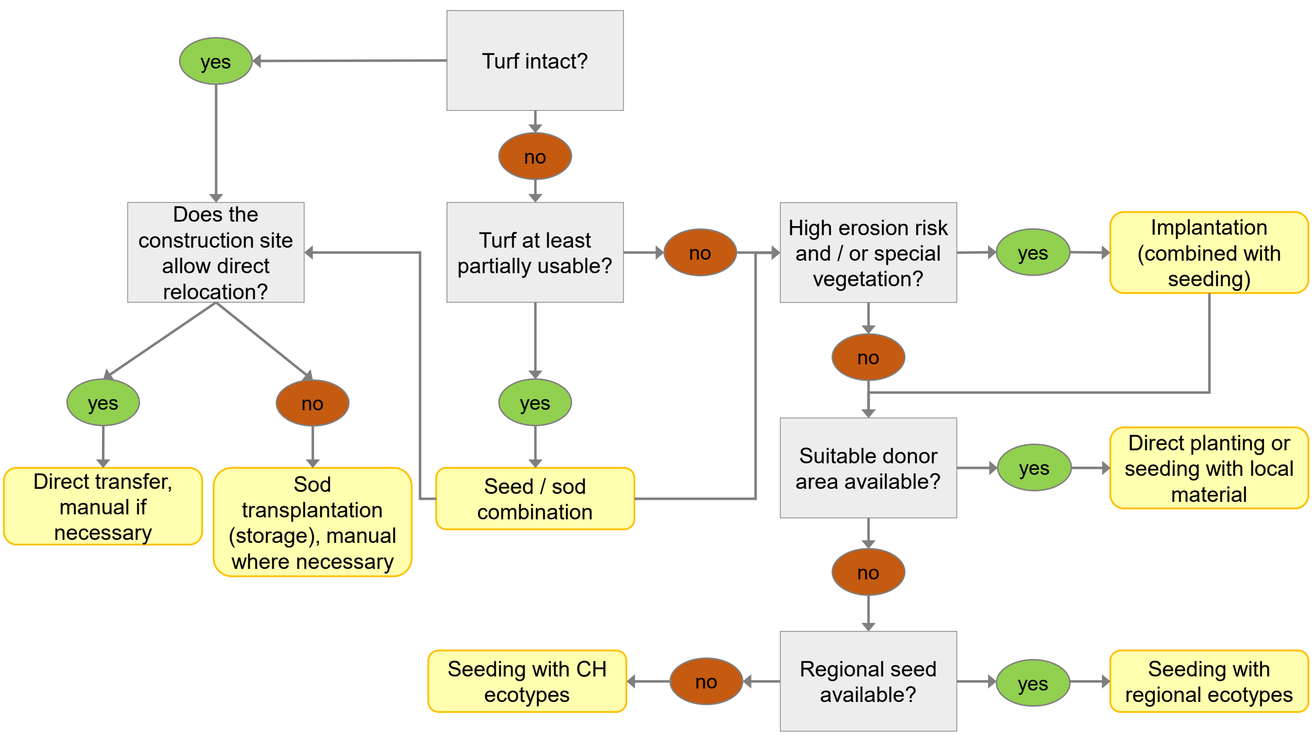

Figure 14: Selection scheme for restoration methods. The explanations for the gray boxes can be found in Table 3 below.

Table 3: Explanations of the questions (square boxes) in the selection scheme | Tableau 3 : Explications aux questions (boxes carrées) dans le schéma de sélection.

Turf intact?	Grass sods are very important for restoration in terms of species composition, origin and age. Whenever possible, these should be separated during removal. If necessary, manual assistance may be beneficial.
Does the construction site allow for direct relocation?	If the organization of the construction site allows the sods to be reused immediately elsewhere, intermediate storage is not necessary. The number of relocations is reduced.
Turf at least partially usable?	If sufficient sod cannot be obtained for restoration, the existing sod will be distributed in a mosaic pattern and, if necessary, supplemented by seeding using the seed-sod combination method.
High erosion hazard and/or special vegetation?	If little or no topsoil remains on an erosion-prone area, implantation may be the best method (Urbanska 1997, Rixen and Schmid 2016). This is also true if, for example, dwarf shrubs are desired. In most cases, implantation is supplemented with seeding. If sods are present, they can be used as a supplement, but may need to be secured (wooden nails).
Suitable donor area available?	For seeding with local seed, a donor area suitable for the site and located as close as possible is required. This applies to direct application of freshly cut mown material, as well as to collection methods (such as brush harvesting or hay threshing). A suitable mowed meadow nearby is also needed for hay flowers. The hay must be stored separately.
Regional seed available?	If it is not possible to obtain local seed directly, commercially produced seed must be used. Regional seeds are preferable to seed of other origins. If sufficient time is available, seed from defined origins can be produced to order by specialized propagation companies. Ecotypes should be preferred over cultivated forms.

Written documentation

The minimum documentation requirements are defined in the construction permit. For the success control, it is recommended that the aspects of aesthetics, erosion, and nature/landscape be assessed according to the guidelines for high altitude revegetation as defined in chapter 4.4. Supplementary detailed vegetation surveys as well as estimates of revegetation cover help in the formulation of any necessary remedial measures. The documentation in the field is supplemented by meaningful photographs (initial condition, during the construction phase, during and after revegetation). The final report describes the project, the measures taken, and a preliminary assessment of the success of the revegetation.

Responsibility

The client is responsible for the documentation. As a rule, this task is delegated to the UBB or another qualified specialist. Any interim reports and the final report must normally be submitted to the approving authority.

4.8 Checklist

The following checklist is used to check whether the planning has been carried out completely. At the same time, it includes items relating to preparations at the construction site.

- ❑ An on-site inspection has been conducted with the relevant stakeholders.
- ❑ The relevant stakeholders have been informed about the restoration objectives.
- ❑ Training for construction site personnel has been scheduled.
- ❑ Weather conditions were taken into account when scheduling the work.
- ❑ Access (access routes, times, frequencies, approved means of transport) have been checked.
- ❑ Soil protection has been taken into account in the planning of soil works and temporary storage (in coordination with the UBB).
- ❑ Suitable machines and equipment are selected, taking into account the physical properties of the soil and soil moisture.
- ❑ A list of the machines is prepared for the UBB (Bellini 2015).

5 Preparatory work

In this context, the term "construction" is used for all activities within the scope of a construction project, from the construction site setup to the completion of the **structure/facility** and the restoration of the occupied areas. Only the aspects of a construction project that are relevant to revegetation are discussed below (Figure 15). During an initial site visit with the contractor, the work relevant to soils and vegetation is discussed and the areas affected are defined. If protected species are present, it must be clarified how their populations can be secured (transplanting, seed collection). For the best possible securing of plant material, the possibility of obtaining sod and storing and replanting it must be discussed. Alternatively, later seeding should be optimally prepared by **documenting** the existing areas (species lists of the most important, habitat-determining species) and **arranging procurement** of the appropriate seed (whether commercial seed or own seed extraction in the area). If construction has already begun and there is no information on the initial condition of the affected areas, neighboring areas can be examined as a reference. Independent seed collection must be well timed, as seeds from alpine plants quickly lose their germination capacity.

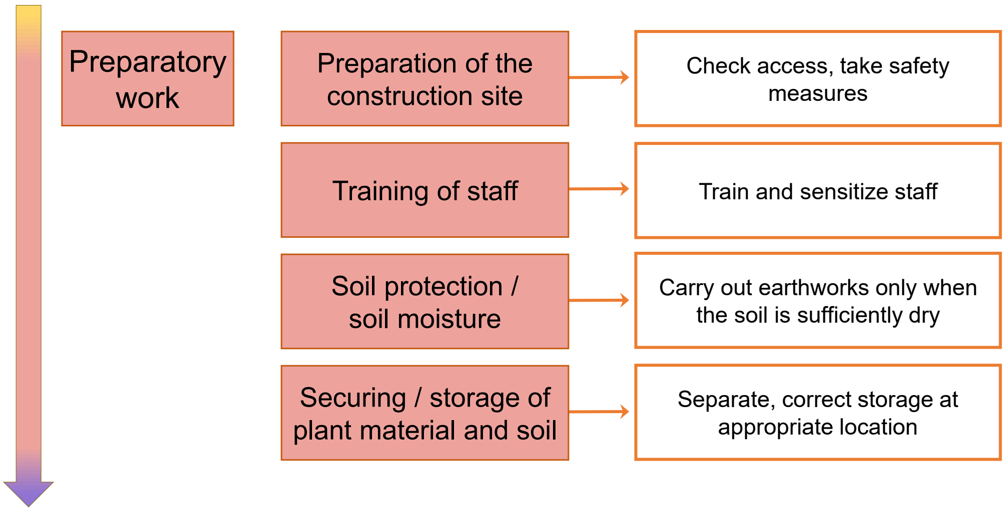

Figure 15: Content overview sequence of preparatory work.

Figure 16: Formwork panels secure the construction site and prevent material from sliding into the areas below (photo: M. Peters).

5.1 Site preparation
During preparation, it is checked whether the planned access roads are clear, the machines are available as planned and the necessary precautions for soil protection have been taken. This includes staking out the construction area and marking sensitive areas (special flora, etc.) that must not be affected by construction machinery. Temporary dams, formwork panels, or covers can prevent the slipping or erosion of soil or stones (Figure 16) (Schiechtl and Stern 1992).

Training of staff by UBB
Construction workers must be trained by UBB or other experienced specialists in the proper handling of topsoil and soil protection measures. In order to ensure the greatest possible care in the handling of topsoil and plant material, those involved should be made aware of the importance of intact sods for rapid and ecologically superior revegetation success (Bellini 2015).

5.2 Soil protection / soil moisture
Topsoil and subsoil must be carefully separated (Bellini 2015). Soil-relevant work may only be carried out when the soil is sufficiently dry. Checking the current soil moisture influences the decision as to which soil protection measures are necessary. Some cantons operate measuring stations for soil moisture and offer the information online. However, when using this information, the heterogeneity of soils must be considered. Information on assessing soil moisture can be found in chapter 4.3. When the soil is frozen, it is possible to drive over it, but not to excavate or move it.

5.3 Securing / storage of plant material and soil
In order to avoid delays during the earthworks, the securing of the turf sods and the suitable stockpile locations should be clarified in advance. The stockpiles are located so that they are within reach of the excavator, but without obstructing access roads or transport routes.

Securing seeds and individual plants
Local seed collection begins as early as possible. In practice, collection continues during the construction work in the area of the construction site. Information on collecting and seed harvesting can be found in chapter 6.2. If there are individual plants worthy of special protection in the construction site area, they are either transplanted directly to suitable locations or excavated and temporary stored/planted. They must be protected from desiccation.

Securing sods
The turf sods present at the site must be secured (Krautzer et al. 2000, Schmid and Frei 2005). For this purpose, pieces of the vegetation cover including soil and roots are cut. This is done by hand or with a grading bucket (Figure 17). The sods must be handled carefully, ideally, they are peeled off like a “pizza” and stored aside. In very dry conditions, there is a risk of losing a lot of fine soil from the root system during handling. In this case, an attempt early the morning can be made to extract these sods, when there may still be some dew in the topsoil.

Figure 17: Sods are carefully peeled off with an excavator shovel or grading bucket (Photo: T. Schmid).

The best results are achieved with turf sods if they can be installed directly at their destination without intermediate storage (direct relocation). If this is not possible, a suitable intermediate storage facility must be defined (Krautzer et al. 2007, Marti et al. 2016).

Soil and sod storage

Topsoil (including sod), or sod, and subsoil should, in principle, be stored separately. Sods are stacked differently, depending on the duration of storage. Ideally, the sods should be stored soil side on soil side and plant side on plant side. The sods must neither dry out nor decay (Krautzer et al. 2007), and for this purpose, the sod stockpiles are placed only at limited heights (max. 60 cm). At long-term construction sites, stacking runs the risk of smothering the lower layers, especially at moist, humus-rich sites. If space permits, these sods, as well as those with particularly sensitive vegetation, should be laid out over a large area. To save space, subsoil stockpiles can be covered with sod (Figure 18). This leaves the sods intact and the stockpiles vegetated.

Figure 18: Soil stockpile, covered with sods (photo: K. Edelkraut).

Vehicles are not permitted to drive on the stockpiles. The surface water should be able to drain off unhindered.
A separation layer serves to separate the stockpiling material from the ground. In the case of short-term stockpiling, the existing short-cut vegetation cover or straw can be used as a separation layer; in many cases, water-permeable nonwoven is also used (Figure 19). Equal layers are stored without a separation layer, e.g., subsoil on subsoil.

For long-term stockpiles, a decision based on the situation must be made whether or not to remove the topsoil from the stockpile site. In the case of vegetation of protection value at the site of the stockpile or in the case of clay-rich

Figure 19: Short-term storage of sod directly on existing vegetation. The soil stockpiles are poured onto a separation layer (Photo: K. Edelkraut).

soil, removal of the topsoil is recommended (oral communication, AGHB). Otherwise, soil removal is not mandatory if the height of the stockpile is limited (Bellini 2015).

A trapezoidal, loose fill and a height limit will avoid anaerobic conditions in the temporary stockpile (Bellini 2015). The following maximum fill heights should be considered for interim storage (Figure 20) (Krautzer et al. 2007, Bellini 2015):

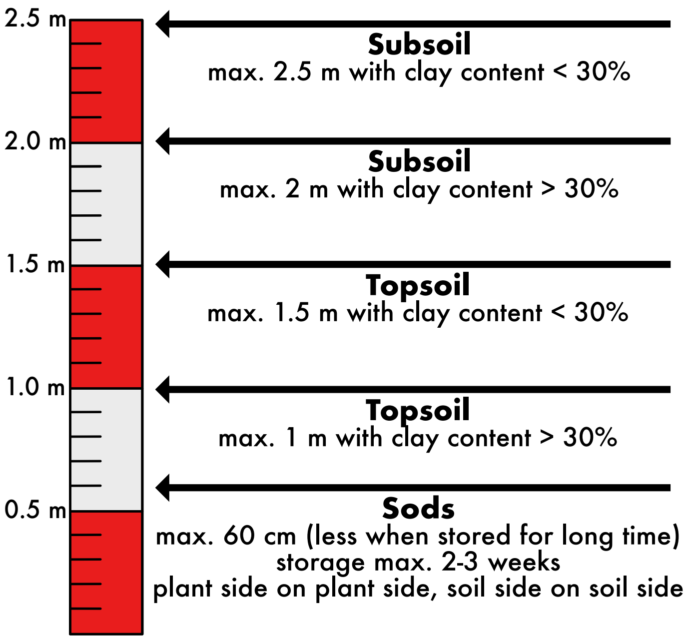

Figure 20: Maximum storage heights for stockpiling. The heights indicated refer to loose fill (Bellini 2015).

6 Execution

During the execution of the restoration work (Figure 21), the procedure generally follows the project planning. Unforeseen scheduling or other difficulties may require a deviation from the planned procedure. In this case, the procedure must be clarified among the parties involved (client, greening company, UBB).

Restoration methods, including plant material and additives, as well as the possibility of using machines, and the time of year in which the revegetation is to take place, all influence each other and must therefore be coordinated.

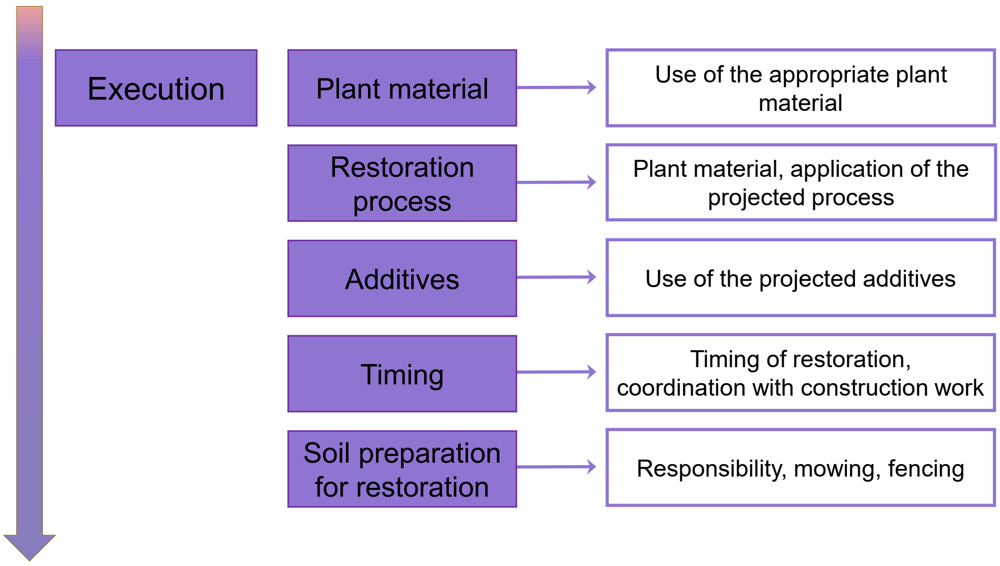

Figure 21: Overview of the sequence of activities

6.1 Soil preparation for greening

During soil replacement works, the natural stratification of the soil must be restored (Schmid and Frei 2005). Correct soil replacement is important in order to preserve soil fertility. To avoid compaction, work should only be carried out in dry conditions. The subsoil is poured as loosely as possible, without pressing it firmly or compacting with the grading bucket. Coarse stones serve as a possible drainage (if the aim of the planting is appropriate). The topsoil is then poured onto the loose subsoil. In this way, a connection (pores) of the two layers can be achieved. After that, the topsoil can be shaped. A roughened topsoil provides protective niches for seedlings, reduces erosion and slows down desiccation of the soil (Schmid and Frei 2005, Krüsi 2014). It gives the sods better support and contributes to a more natural appearance (Marti et al. 2016).

Requirements for the seedbed
The following requirements apply (Graf 1998):
- stability of soil matrix and pore structure (aggregate stability, microstructure)
- fine sediment content of at least 30%
- sufficient water and nutrients in plant-available form
- sufficient aeration
- intact conditions for re-establishment of soil organisms

If the seedbed does not meet the requirements, instructions and restrictions for soil improvement can be found in chapter 6.4.

6.2 Plant material

Sods from construction site
Securing the sods from the construction site is described in chapter 5.3

Propagation of seedlings from local ecotypes
Seeds are collected from the immediate vicinity of the construction site. From these, young plants are grown and propagated in nurseries. If the climate of the nursery and the substrate are similar to the restoration site, the young plants are optimally adapted. The use of self-propagated plants requires a lead time of at least one growing season.

Harvesting methods for direct revegetation
The following methods allow harvesting of local seed if the appropriate donor sites are available. Only the harvesting process is described. Further information on the seed, such as its origin, can be found in a separate chapter "Seed". The description of the use of the material obtained is given in detail in chapter 6.3.
The ratio of application to donor area is 1:1 to 1:2 (Krautzer et al. 2000, Bosshard et al. 2013). The transfer of cuttings from pastures is very laborious, because pastures are uneven due to trampling and are therefore difficult to mow.

Fresh mown material
A suitable donor area is harvested when most of the seeds of the target species have reached nearly maturity level. At this stage, the seeds have already reached their full size but are still soft and do not detach at the first touch (RegioFlora). The donor crop is mown early in the morning when still covered with dew. For a gentle cut, mowing is done carefully and at low speed (Agridea 2015). The seeds and some small organisms stick to the usually moist cuttings and fall off only when they are dry. At high elevation, the ideal season for harvesting does not coincide with that of sowing, which is why this method tends to be limited to lower elevation.

Brush harvesting / seed stripping
Alternatively to direct revegetation, not the entire cuttings are transferred, but only the seeds are harvested on the donor area. Even in steep terrain with more than 100% slope, seeds can be harvested with suitable machines (Bosshard 2016). In uneven terrain, however, the use of machinery is difficult. Brushing out by hand is recommended there.
Seed harvest is done when seeds are completely ripe and fall off easily. A meadow can be harvested several times a year using this method (Agridea 2015). Seeds can be dried and stored which allows for greater time flexibility in revegetation. This makes this method more suitable for high elevations than fresh mown seed. However, low-stature plants are collected to a lesser extent (Sengl et al. 2014).

Hay threshing
The donor area is mown, and the mown material is dried and threshed (Kirmer and Tischew 2006, Agridea 2015).
If threshing is done in the same operation, a small combine harvester is used for harvesting at high elevation.

Hay flowers
This method uses dry material that accumulates in the hayloft. Early arrangements or contracts with the farmer offer the possibility of separately storing the hay of a certain selected area. Testing for germination prior to seeding is recommended, especially for hay flowers of unknown age. Seeding rates vary greatly with the proportion in the mixture of hay, and the layer should be applied thinly to allow light to reach the soil and to avoid competitive pressure among seedlings (oral communication, AGHB).

Seed mixtures
Seed mixtures have the advantage that they can be applied at the ideal time and their composition can be precisely determined. Thus, the proportions of hard-to-establish species can be increased over those that germinate easily. Since the composition of the mixture is known, establishment success can be assessed and the mixture composition can be adjusted.

Local vegetation should be considered as much as possible when choosing a suitable seed. If donor meadows are available, revegetation with locally collected seed is the first choice. In high alpine areas, where mowing or mechanical collection is hardly possible, hand collection with subsequent propagation under conditions as similar as possible offers a good alternative. For this approach, seed producers ideally need a lead time of up to three growing seasons before revegetation.
Where these options are not available, commercial seeds are used. Seeds with non-native components, with species from other altitudes and cultivated forms should generally be avoided. Seed cannot be ordered until the areas to be revegetated are known. However, in the case of a seed/sod combination, this may not be able to be assessed until it is known how many sods will be retained. In that case, it is advisable to make a preorder with the supplier

Seeding rate
Quantities given by producers for dry, pure seed vary from 5 to 30 g/m². Mixtures with a high proportion of grasses usually require higher rates, as grass seeds are heavier than most herb seeds. Practice shows that 5 to max 10 g/m² are sufficient when working with mixtures of high-quality ecotype seed.
It is advisable to avoid excessive seed rates, as plants can interfere with each other in overly dense initial stands, and the desired spontaneous establishment of local species can be delayed (Schneider et al. 2017).

Locally sourced seeds, dried
Seeds are harvested and dried from suitable donor areas in different ways (see chapter Harvesting methods of direct revegetation).

Commercial seed
Seed producers use different brand names for their products. In the product descriptions, information should be available on the following three factors in order to be able to compare the products: the degree of breeding of the selection, the ecological requirements and the origin. With the mention of all three characteristics, a seed mixture can be described sufficiently well.

Table 4: Classification of seed according to the origin, breeding modification and ecological requirements.

Factor	**Designation**	**Description**
Change through breeding	Ecotype	Collected from wild plants and propagated without breeding selection. To avoid unintentional selection, new genetic material from wild sites should be introduced into the propagation after four generations at the latest (Kirmer et al. 2012, Krautzer et al. 2012a).
	Cultivated form	Modified by breeding with the aim of promoting certain traits. Often with variety name. Used in forage production.
Ecological requirements	Suitable for the site	The ecological requirements of the species correspond to the site conditions.
	Not suitable for the site	Ecological requirements and site conditions do not match (e.g. wrong elevation).
Origin	Local	From the immediate vicinity max. 30 km distance and the same valley and biogeographical region.
	Regional	From the same main biogeographical region or subregion (see Figure 22).
	CH	From Switzerland.
	Foreign	From abroad, not further defined.

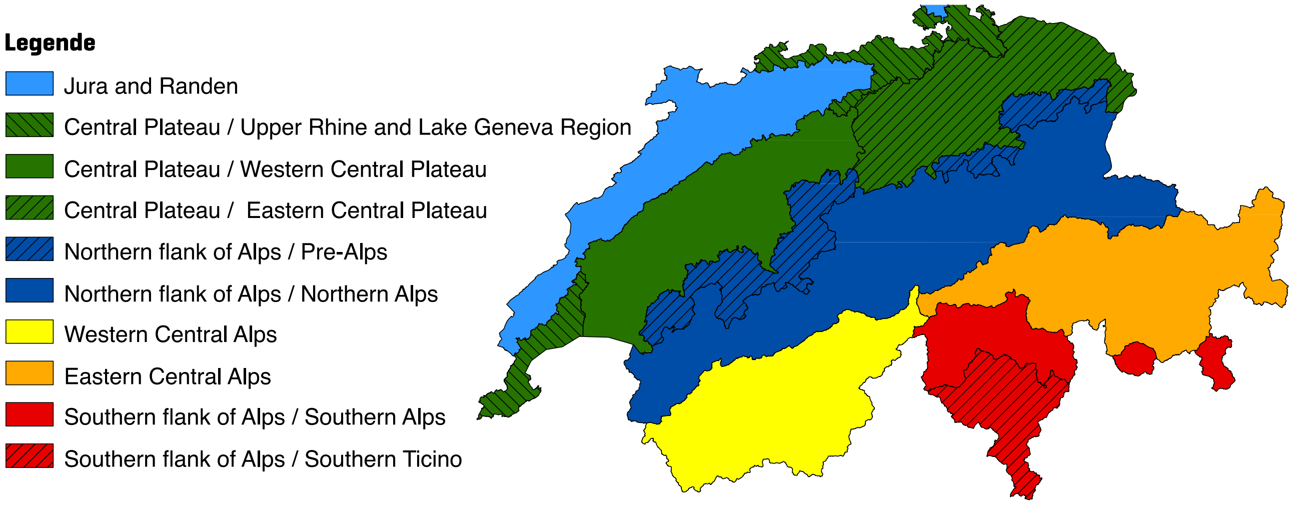

Figure 22: Biogeographic regions of Switzerland: main regions (color) / subregions (hatched) Data: InfoFlora

Today, commercial seeds with regional ecotypes for high elevation are generally available for the main regions, partly also for the sub-regions (Figure 22). CH ecotypes are offered by all major seed producers.

Note on origin

Studies show that genetic differences within a species vary with increasing distance between sites. This makes it difficult to make a generally valid statement about which geographical distance is still suitable (Durka et al. 2017). Biogeographic regions (Figure 22), as defined for Switzerland (Gonseth et al. 2001), can be seen as a compromise between the feasibility of revegetation and the conservation of biodiversity (Malaval et al. 2010). In order to do justice to regional genetic differences as far as possible, seed from the geographically closest possible suitable location should be selected.

Nurse species

Fast-germinating nurse species serve the purpose of providing shade and protection from wind and erosion for the later-germinating species of the actual target vegetation. In the literature, perennial nurse species and annual cover crops are distinguished; in practice, the term "nurse species" is often used for both. The use of nurse species can be problematic because there is no guarantee that they will not emerge in subsequent years according to their function. Perennial species sometimes persist for decades and can form nearly pure stands (Figure 23) (Isselin-Nondedeu and Bédécarrats 2009, Rydgren et al. 2016).

Nurse species may also compete with local vegetation instead of promoting it (Hagen et al. 2014). Excessive density of nurse species inhibits the germination of slower target species (Suter et al. 2013). Annual cover fruiting

Figure 23: Non-local species can still be dominant decades after revegetation and thus hinder the emergence of local vegetation (photo: M. Peters).

species such as Rye Brome (*Bromus secalinus*) should only be sown if they are mowed before flowering, or if it is clear that they will not reach seed maturity at the appropriate elevation level. Climate change should be taken into account, as warming temperatures increase the competitive pressure of heat-adapted species (Kulonen et al. 2018, Steinbauer et al. 2018).

Figure 24: When securing and setting the sods, excavator and manual labor are required (photo: B. Krüsi). Later, the intervention is often hardly visible or not visible at all (photo: K. Edelkraut).

In trials at altitudes of 2100 to 2400 m above sea level for better and faster erosion control, sowing of annual cover crops showed poorer results than mulch sowing. Cover crops provide good cover at the beginning, but after their disappearance the areas showed a lower cover than comparative areas with mulch and had larger gaps (Florineth 2000, Graiss and Krautzer 2011).
As an alternative, site-adapted pioneer plants that grow quickly in the first year can function as nurse species (Kardol et al. 2006). However, here too, there is a risk that slow-germinating target species will be suppressed.

6.3 Revegetation process

Direct transfer

In this method, the vegetation cover is stripped off in segments (sods) before working at the site and immediately laid out again in the prepared area at a nearby location (Figure 24). This method is applicable if there is a (closed) vegetation cover before the intervention, which can be removed intact and if the organization of the site allows the direct use of the sods. Sods are peeled off and re-installed using an excavator, if possible. In order to secure the valuable plant material as completely as possible, it is recommended to place the sods by hand if the terrain is unsuitable for the excavator (e.g. between large boulders).

The root zone including the local soil organisms and mycorrhizal fungi is largely preserved during direct relocation. It is the best way to preserve heterogeneous plant communities. Experience at the Julier Pass Road shows that even with mosaic-like installation of the sods, the initial large gaps were overgrown after 5 years with species that largely corresponded to the species composition of the sods (Marti et al. 2016).
Certain vegetation types, namely exposed alpine grasslands that are little or not affected by human activity (*Caricion firmae, Caricion curvulae* etc.) can only be recultivated with difficulty (Krautzer et al. 2006). These plant communities grow extremely slowly (Delarze und Gonseth 2008). Therefore, special care must be taken when working with these vegetation types. It may be necessary to excavate and replant entire boulders. Direct relocation is usually the only way to preserve the habitat at these sites.

Sod transplantation

This method corresponds to a large extent to direct relocation, but the sods must be stored temporarily. The success of the method depends strongly on the careful handling of the sods.
Temporary storage is carried out according to chapter 5.3. The best time to apply the sod is just after snowmelt or immediately before the first snowfall (Krautzer et al. 2006). The sods are laid out in groups at dry sites and in a grid pattern at wet sites on the area to be revegetated. Care

Figure 25: Planting pre-grown seedlings is worthwhile where exposed soil on steep slopes requires stabilisation (Photo: M. Schutz). This approach can result in successful restoration (photo: K. Edelkraut).

must be taken to ensure that the roots have good contact with the soil. If dry weather is expected after the sods have been laid, watering the area is recommended (Sengl et al. 2014).

Implantation / planting of grown seedlings

Revegetation is carried out with pre-grown individual plants (Figure 25). The seed for growing the plants is obtained from local stands in comparable exposure. This method is mainly used at extreme locations, such as high elevation, steep or dry slopes, or areas affected by topsoil loss (Urbanska 1997, Rixen and Schmid 2016). Because the roots quickly penetrate deeper layers, deep erosion can be inhibited at an early stage. Planting density is up to 10 pieces/m^2 depending on the species (Heuerding 2005). Implantation requires a long lead time and a great deal of work, but can yield good results (Nüesch 2012, Bosshard et al. 2013).

Seed-sod combination

This method combines the installation of existing sod (see above) with wet or dry seeding. This method is used when there are not enough sods available for a closed plant cover or the target cover, and additional erosion protection through root penetration is necessary (Figure 26).
On flat surfaces, it is not necessary to sow seeds in open areas (Krautzer et al. 2000), as there is only a low erosion risk. In erosion-prone terrain and in areas with a slope of more than 30% or with large gaps, geotextiles, wooden nails or similar materials should be used to secure the sods and prevent topsoil erosion (Krautzer et al. 2006).

Mown grass transfer (grass/hay mulch seeding)

The clippings from a suitable donor site with the desired site-adapted vegetation are transferred directly to the recipient site. The biomass is deposited so that the soil is still clearly visible (oral comm. AGHB). Too thick layers can cause anaerobic decomposition processes or mutual obstruction of germinating plants. Erosion control measures must be provided for slopes of 30% or more. If direct planting is carried out gently, a part of the insect fauna is also transferred together with the cuttings. Basically, the transfer of cuttings requires seeding in summer when the donor meadow is “ripe”. At high elevation above about 2300 m, this method is unsuitable due to the short vegetation period.

Figure 26: If insufficient sods are available for complete revegetation, they are arranged in a mosaic pattern and the gaps are seeded (photo: K. Edelkraut).

Dry seed

The application of seed (and additives) in dry form is relatively simple. The prerequisite for pure dry seeding without mulch is a topsoil that is suitable for cultivation (Graiss and Krautzer 2006). At high elevation or in erosion-prone areas, dry seeding is only recommended in combination with a protective cover of the topsoil (mulch materials, net, mat) (Lichtenegger 1994, Krautzer et al. 2011).
In dry seeding, a moist soil ensures the immediate effect of additives (glue) and an optimal starting position for growth (Andrey and Streit 2005). However, the soil contact with the seeds is poorer than in wet seeding (Lichtenegger 1994). In stony terrain, dry seeding offers the advantage over wet seeding that the seed falls to the ground between the stones before the adhesive takes effect (AGHB). In general, dry seeding is the first choice wherever there is no water supply to produce wet seeding.
On large, easily accessible areas that can be driven on with a tractor and seed drill, this is a very efficient method. Machine operation is possible up to a maximum slope of 45% (Schmid and Frei 2005). The seed drill can be adjusted exactly to the desired amount (g/m^2) and sows very evenly. A roller is used to gently press the seeds into the upper soil layers.
Even with hand seeding, the seed must be pressed down after sowing to reconsolidate the soil and reduce drying. For larger, poorly accessible areas, dry seeding by helicopter may also be considered. For dry seeding, the seed mixture must be designed in such a way that it can be sown in one pass, so the dust is kept to a minimum, and that the components do not segregate during application (Figure 28). It is not possible to fly in windy conditions and insufficient visibility. The seeder must be suitable for operation from the helicopter (Andrey and Streit 2005).

Wet seeding / hydroseeding / spray seeding

In this method, seeds, fertilizer, soil additives and adhesives are mixed with water in a spray barrel and sprayed onto the areas to be revegetated using the wet seeding machine called a “hydroseeder” (Figure 27). This allows areas that are difficult to access to be efficiently seeded from the vehicle. However, due to the limited the operating radius, the construction site must be accessible by vehicle.

Figure 27: Wet seeding method (Image: T. Schmid).

The application radius from the vehicle is about 30 m, and with a small height difference, a range of 300 m is possible using a hose (Andrey and Streit 2005). On steep slopes, the seed-fertilizer mixture can be sprayed onto a previously fixed, biodegradable erosion control net (Krautzer et al. 2007), if the mesh size of the net allows adequate penetration. Slurry application achieves a tight bond between seed, soil, and fertilizer (Lichtenegger 1994). Wet seeding is a simple, efficient method. It is frequently used, especially when the terrain is too steep for dry seeding or there is too little moisture due to unfavorable soil conditions (e.g. raw soil).
Very steep, poorly accessible areas can be revegetated by helicopter. The method requires numerous flights, since the payload is limited (Florineth 1995). For the flight conditions, the requirements are the same as for dry seeding.

Cover seeding

In cover seeding, organic material (hay or straw) is applied over the previously sown seed for cover and protection. In climatically extreme locations or seasons, the mulch layer provides protection from cold, heat and drought (Florineth 2004). Mechanical protection of the soil surface promotes rapid and safe germination (Krautzer et al. 2007). Mulches should always be attached with adhesives to protect against erosion. Hay becomes more compacted when treated with the adhesive and is therefore not as suitable as straw (Krautzer et al. 2007). Further information on mulches and adhesives can be found in chapter 6.4.

Seed mats
Seed mats are made of natural fibers, which are held together by a fine natural fiber mesh. The seed is incorporated into the mats. Seed mats require perfect soil contact and are therefore limited to use on flat and regular soil surfaces. Therefore, seed mats are only partially suitable for use at high elevation (Krautzer et al. 2007). Because decomposition is very slow at high elevation, mats must only be composed of materials that will be weathered within the necessary time frame for achieving the revegetation objectives regarding erosion.

6.4 Additives
Depending on the situation, various additives are used. Since sufficient erosion protection is achieved by the plant cover at the earliest in the second vegetation period after successful revegetation, erosion must be prevented until then through appropriate revegetation techniques (Krautzer et al. 2007). If there is a risk of erosion from surface or slope water, it can be drained by cross channels with a low gradient (Lichtenegger 1994). Cross drains also reduce the erosion-effective slope length (LfL 2017).
Organic soil conditioners usually have multiple benefits, both improving soil structure and providing nutrients. The same is true for mulches, which both serve as erosion control and add nutrients. Soil conditioners are mainly used in the absence of topsoil and for recultivation purposes (Stalljann 2006). The list of inputs of the Research Institute of Organic Agriculture ("Forschungsinstitut für biologischen Landbau" FiBL) lists the suitable fertilizers, soil conditioners, and adhesives that are approved for organic farming (FiBL). This also provides guidance for high elevation as to which products can be used.

Mycorrhizal fungi
The use of arbuscular mycorrhizal fungi aims at improving the growing conditions for plants. For this purpose, soil fungi involved in natural processes are added to the seedbed. At high elevation, they are usually used in combination with an organic germination aid and starter fertilizer. When grown on carrier material, the fungi can be applied by both dry and wet methods (Streit 2006). Mycorrhizal plants exhibit enhanced stress tolerance and are more resilient to drought, nutrient shortages, disease, and extreme pH (Schmid et al. 2005).
The finely branched fungal tissue improves soil stability and erosion control, and the absorption area of the plant root is increased considerably (Figure 29). Not all fungal species are equally suitable for revegetation (Graf et al. 2017). When acquiring mycorrhizal fungi, it should be ensured that the strains are adapted for high elevation sites.

Fertilization
Goals
Fertilization serves to improve growing conditions on nutrient-poor soils and can promote the establishment of young plants. It should serve as a start-up aid, but not change the general nutrient availability and the competitive situation between plants at a site.

Figure 28: Seed mixture for dry seeding with additives (image: T. Schmid).

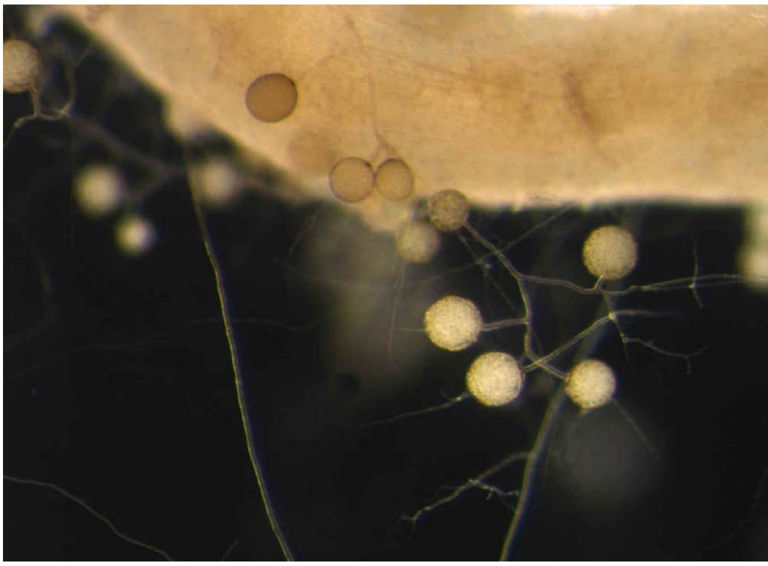

Figure 29: Root (above) and hyphae (fine fungal filaments of the mycelium) with spores (round) of the mycorrhizal fungus (photo: K. Ineichen, Botanical Institute of the University of Basel).

Limitations
Fertilizer alters competitive dynamics, so that fast- and tall-growing species are favored, outcompeting slow-growing, small-stature species.
With high nutrient supply, plants produce more aboveground biomass and invest less in a root system. Less rooting reduces erosion control. At high alpine locations, nutrient-poor conditions are common. Fertilization should therefore only be carried out in a targeted and restricted manner to avoid permanently altering the naturally nutrient-poor site conditions.
For the fertilization of alpine pastures, special regulations apply according to Art. 30 DZV. Fertilizers that are foreign to the alpine farm as well as the use of mineral fertilizers, liquid fertilizers and pure nitrogen fertilizers require a cantonal permit (Schneider et al. 2017).

Necessity
The need to apply fertilizer depends largely on the plant-available nutrient content of the existing topsoil, the revegetation method, and the target vegetation. Turf sod does not require fertilization. When revegetating with hay flowers, mown grass, seeds from meadows, or site-adapted mixtures, fertilization can promote turf establishment (Krautzer et al. 2013, Schneider et al. 2017), and should therefore only be used moderately, in accordance with the target habitat.

Timing
Fertilization typically is carried out while sowing. Commercial seed mixtures contain a proportion of organic starter fertilizer, which sufficiently supports germination and initial establishment of the young plants, but does not change the site conditions in the medium to long term.

After sward closure, fertilization is only considered for agricultural purposes (Krautzer et al. 2013). Nutrient-poor pastures (pastures with *Nardus or Sesleria*) are not fertilized after seeding (Schneider et al. 2017).

Products
Organic products are preferable to mineral fertilizers. Since raw soils have a low nutrient storage capacity, mineral fertilizers are quickly washed out. In lightly decomposed organic products, the nutrients are bound and are only released by the decomposition activity of microorganisms. Since these, like plants, depend on temperature and humidity, nutrient availability is better synchronized with plant demand. In addition to purely supplying nutrients to the plant, organic products also improve soil structure and water storage capacity and promote humus formation (Stalljann 2006). The aggregate stability is thus improved which additionally reduces the risk of erosion (Kretzschmar 2017). Where possible, fertilizers such as well-stored farm-yard manure, composted manure, or compost (only harmless material) of regional origin should be used (Krautzer et al. 2007).
Organic fertilizers based on fungal and bacterial biomass and various algal products have also proven effective (Stalljann 2006). The use of liquid manure is not recommended (Krautzer et al. 2007).

Quantities
The amount of fertilizer is to be determined on the basis of a site assessment. On land regularly used for alpine farming with reduced resupply, fertilization in organic form (e.g., 15 t/ha of stored farm-yard manure) is recommended for seeding, which corresponds to a nutrient quantity of 25 kg N, 60 kg P_2O_5, and 90 kg K_2O per ha. Intensively grazed or mowed sites can be re-fertilized with the same amount approximately 2 to 3 years after sowing (Schneider et al. 2017).

Mulch materials
Covering the exposed topsoil with mulch materials reduces surface runoff, soil loss, and erosion. Materials used include straw, hay, wood and cellulose fibers, or grass. The application of mulch cover reduces surface water runoff by about 20 times. Soil rates may be reduced by a factor of 40 to more than 100 (Graiss and Krautzer 2006). Mulches also improve the microclimate. Moisture is retained longer, and temperatures due to solar radiation are reduced. On south-facing slopes, a mulch cover can reduce surface temperatures from 65°C to below 40°C (Stalljann 2006). The mulch layer should be translucent and still provide protection. Thick mulch layers can lead to suffocation of seedlings. In contrast, layers that are too thin are less effective (Krautzer et al. 2007, Krautzer and Graiss 2008). Material requirements vary depending on the type of mulch, combination with other additives (geotextiles), and soil conditions. Steep slopes, strong sunlight, wind or precipitation require more material.
Empirical values are 150 to 300 g/m^2 for hay, 40 to 200 g/m^2 for short straw, 250 to 400 g/m^2 for long straw, and up to 300 g/m^2 for wood fiber (AGHB).

Geotextiles
In addition to a mulch layer to cover the open topsoil, nets made of natural fibers provide further protection for sites at risk of erosion or areas with slopes greater than 30% (Krautzer et al. 2007).
Geotextiles (Heuerding 2005, Stalljann 2006):
- absorb tensile forces;
- decrease the impact energy of water;

- reduce the run-off speed of precipitation water;
- roughen the soil surface artificially;
- prevent soil erosion;
- provide filtration functions;
- regulate the thermal balance and promote the effect of shade.

Figure 30: Fastening the geotextiles with wooden nails. Care must be taken to ensure continuous contact with the soil, especially in the case of fine-meshed fabrics and mats (photo: M. Schwager).

Basically, when using geotextiles, it must be considered that they are weathered only very slowly at high elevation. Products made of natural fibers (wood wool, straw, jute, coconut, sisal, hemp, cotton, etc.) should be used, preferably without a synthetic carrier net so that they are completely biodegradable. Their service life is at least four years, depending on the climate (Krautzer et al. 2007). Synthetic nets and foils are not degradable and must therefore not be used at high elevation. During installation, it needs to be ensured that the mesh is continuous in contact with the ground and that sufficient anchors are installed (min. 4/m^2) (Figure 30). To prevent the nets from being torn, it must be possible for loose material to escape at the base of the embankment, and the anchoring at the face of the embankment should be reinforced (Krautzer et al. 2007). In combination with wet seeding, care must be taken to ensure sufficient permeable fabric so that the mixture, including seed, reaches the soil surface (Stalljann 2006). If the risk of erosion is high, mats and tightly woven meshes are preferred. However, too dense a mesh can hinder seed emergence and smother vegetation.

Adhesives

Adhesive soils improve erosion control in the short term (Stalljann 2006). They are used whenever there is a risk that the fresh seed or mulch layer will be blown out by wind or washed away by rain. At high elevation, they are recommended for all seeding operations. Products with organic adhesives (e.g. alginates, psyllium, guar gum, starch, pectin, waxes) are used. They are inexpensive and ecologically unproblematic, but the adhesive effect is lower than with synthetic products. They can be used for dry and wet sowing. Synthetic products adhere better, but germination may be impaired. Bitumen emulsions are problematic for animals on contact because the adhesive sticks to the fur (Polizzi 2017). There are few studies on the toxicity of bitumen, but because the constituents are similar to other crude oil derivatives, some risk to the environment can be expected (National Academies of Sciences and Medicine 2016). Bitumen emulsions and other synthetic plastic-based adhesives should therefore not be used in revegetation applications.

6.5 Timing of the revegetation work

Different regulations apply regarding timing depending on the chosen revegetation method, elevation, and erosion risk. The risk of introduction of undesirable plant species must also be considered during planning. Several key considerations must be balanced: Soil should not erode, should not dry out, and should not provide conditions for undesirable plant species. On the other hand, weather conditions at high elevation make reliable seeding difficult to plan (risk of frost and freezing of seedlings). For dormant seeds it must not be too warm, so that germination occurs only in the spring. Often, the optimal times are rather late in the year. At high elevation, an early onset of winter must generally always be expected in late summer and fall. If the ground is frozen, sod must not be relocated (AGHB). Often scheduling must also take into account periods when machinery, equipment and workers are still on site. To reduce the loss of fine soil, revegetation must be carried out as quickly as possible, especially on steep slopes. However, the seasonal constraints must be considered (Tables 5 and 6). If it is not possible to plant immediately, a temporary covering of the unvegetated soil with a layer of mulch is recommended. Revegetation should be carried out as early or as late as possible in the growing season. In mid summer, heat, prolonged dry periods, or heavy rains can endanger the development of the seeding or the growth of the sods. In the montane zone, seeding can be done until July. At high alpine elevation, seeding should be done in June at the latest. Early seeding takes advantage of winter moisture and gives seedlings time to develop (Krautzer et al. 2012b). If revegetation must be done during drought periods, it is advisable to use the ski slopes snowmaking conduits or other nearby water sources, where available, for irrigation (AGHB). However, irrigation also involves risks: Once started, it should be consistently applied throughout the dry season. In addition, irrigation requires careful

Table 5: Optimal (dark green) and possible (light green) time period for direct transfer, sod transplantation and implantation.

	April		May		June		July		Aug.		Sept.		Oct.		Nov.	
subalpine							1)	1)	1)	1)				2)		
alpine							1)	1)	1)	1)				2)		
subnival													2)			

1) Danger of desiccation: Watering is required in dry weather conditions

2) Impending cold snap, it is necessary to act quickly. When the ground is frozen, sod must no longer be moved

Table 6: Optimal (dark green) and possible (light green) period for all seeding methods.

	April	May	June	July	Aug.	Sept.	Oct.	Nov.
subalpine								
alpine								
subnival								

management and control to prevent surface erosion. In general, “sleep seeding” is preferred at high elevation, which is carried out at the end of the growing season as late as possible, preferably shortly before snowfall (Krautzer et al. 2012b). Except for the transfer of fresh mown material, all methods can be carried out as dormant seeding. In areas prone to erosion or to improve the germination bed, the same additives are used as for conventional seeding (Krautzer et al. 2007). Germination occurs the following spring after snowmelt. The emerging seeds thus profit optimally from the winter moisture (snowmelt) and can take advantage of the entire growing season. Sleep seeding is particularly recommended at higher elevation when the remaining weeks of the growing season no longer allow safe seed establishment or when there is a risk of drying out in summer. Snow cover in winter increases revegetation success (Krautzer et al. 2012b). This method provides good results, but high losses can occur if seeds are sown too early or if there is bird predation due to a lack of snow cover, if premature or germination is triggered by warm autumn or winter days (Krautzer and Graiss 2008, Bosshard et al. 2013). In spring, there is a certain risk that seeds are being washed away by meltwater (Tamegger 2017).

6.6 Completion maintenance

Completion maintenance includes all maintenance measures that are carried out until formal acceptance of the work (Bosshard et al. 2013). This is followed by development maintenance which extends from the acceptance of the work until the restoration target is reached (see chapter 8.1). If the areas are not used for agricultural purposes after completion of the performance review, long-term maintenance measures may be agreed upon (see chapter 9).

Responsibility
The company commissioned with the restoration is usually responsible for the completion maintenance (Bosshard et al. 2013). This obligation should be specified in the tender for the restoration.

Cleaning cut
A cleaning cut - also called a clean-up or maintenance cut - is recommended when the ground cover of alien vegetation exceeds 50% or when vegetation height reaches 30 cm (Krautzer et al. 2000).

Fencing
Fencing delimits the re-vegetated area and protects it from grazing and trampling damage (Figure 31). It is recommended to maintain fencing for at least two years (see chapter 9.3).

Figure 31: Fenced area (photo: M. Schneider).

7 Acceptance and success checks

When a project is completed, both acceptance tests and performance reviews are carried out (Figure 32). These are interdependent in terms of time. The completion of the restoration is checked with the acceptance of the project and, if necessary, with the acceptance of the construction. The environmental acceptance takes place when the effect can be assessed conclusively. It can take place at the same time as the acceptance of the work or after completion of the performance review (Brunner and Schmidweber 2007).

7.1 Acceptance

Acceptance of the project

The acceptance of the project according to SIA 118 represents the handover of the completed construction to the client. Acceptance takes place between the client and the construction company. It releases the contractor from his responsibilities to the owner. The results are recorded in the acceptance protocol. With the acceptance, the complaint period begins (see chapter 4.2) (Brunner and Schmidweber 2007).

Acceptance of construction

According to VSS standard SN 640 610b, acceptance of construction takes place between the authority and the client at the end of the implementation phase and releases the client from its obligations to the authority (Brunner and Schmidweber 2007). Construction acceptance does not take place for all construction projects, but it is necessary, for example, for cable car construction in order to obtain the operating permit (Brunner and Schmidweber 2007).

Environmental acceptance

Once all requirements have been met and all measures have been implemented, the environmental acceptance is carried out by the licensing authorities (BAFU and BAV 2013). This inspection is conducted by the licensing authority 1–3 years after completion. During the inspection, the environmental construction supervisor is usually

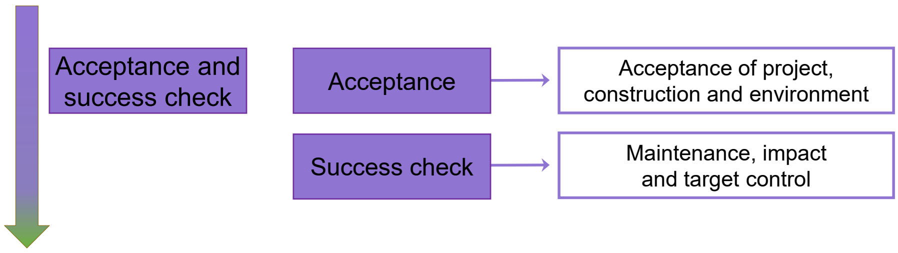

Figure 32: Overview of contents procedure for acceptance and performance review.

responsible for explaining the restoration work and determining the current degree of success. At the acceptance stage, the developer is issued an official assessment of the revegetation success and, if applicable, a release from duty to the authority (Brunner and Schmidweber 2007). However, depending on the development of the revegetation, or in case of partial success or failure of the revegetation, subsequent improvements and a new acceptance date can be set. At high elevation, the success after 1–3 years is too early to assess due to the slow development time of the vegetation. So at this time only success in terms of erosion control can be evaluated, as well as a tendency of the development of the revegetation. The achievement of the revegetation goals can often only be conclusively assessed after 5–10 years (see chapter 4.4). Acceptance confirms that the environmentally relevant requirements for the construction have been satisfactorily met. At this point, the vegetation is developing int the desired direction and is at a stage that indicates that no undesirable species are present - if necessary, with the implementation of targeted maintenance measures - and that the restorations objectives are being achieved (Krautzer et al. 2000).

7.2 Success check

The success check is a generic term for the implementation, impact and target control. It checks whether the previously formulated objective of a measure has been achieved and, if necessary, proposes corrections. The implementation control checks whether the planned measures have been implemented correctly.
During the actual impact control, it is determined whether the implemented measures lead to the planned effect or whether any undesirable developments can be identified. Individual measures and effects (e.g. cross gutters as erosion protection) can be considered separately, but in the end, they must contribute to the overall goal of a successful restoration.
A possible target control serves to check whether the originally defined targets were also appropriate under the current conditions. It does not take place within the framework of the UBB (Maurer and Marti 1999, Brunner and Schmidweber 2007) but is the subject of a strategy review by the authorities and allows for an optimization of the situation for subsequent approval procedures. The prerequisite for the success check is the prior definition of quantified and controllable targets. This is achieved by considering site conditions and defining restoration goals.

Responsibility
Implementation and impact control are to be carried out by the UBB or the restoration management. The target control, i.e. the appropriateness of the goals, is – if at all – carried out separately by an expert from the authorities (Brunner and Schmidweber 2007).

Timing of success check
With the implementation and impact control and the formal environmental acceptance by the authorities, the project-related success check reaches its provisional conclusion. The time at which this occurs must therefore already be predictable for the developer when the project is approved (Brunner and Schmidweber 2007). The implementation control takes place successively during the execution and/or as part of the acceptance process. The impact control runs in parallel with the implementation control and/or after completion of the construction work (Brunner and Schmidweber 2007).
The success of the project can only be definitively assessed once the vegetation has reached a stage of development that ensures all restoration objectives have been achieved. The timeframe is determined by the restoration objective and is usually between two years for first interim targets and 10 years for a final assessment of restoration success.

Failure to achieve the goals
The success check also determines if the formulated goals have not been achieved. At the same time, it offers the opportunity to formulate measures to improve the situation and achieve the restoration objectives (Brunner and Schmidweber 2007). The SIA standards 118 and 318 contain further details (SIA 2009, 2013). If necessary, the authority prescribes appropriate substitute measures if the objectives are not reached.

8 Maintenance / final work

After acceptance of the work, the restored areas must be monitored until the restoration target is reached (Figure 33). If gaps are identified during the performance monitoring, reseeding is required in addition to maintenance. Land use must be appropriate to the site conditions and revegetation objective. In order to ensure the financing of this work and to establish transparent conditions, maintenance, success checks and subsequent use must be planned and the responsibilities defined during project planning.

8.1 Development maintenance

Concept

The responsibility, type of maintenance and maintenance period, etc. for the development and, if necessary, the subsequent maintenance must be defined during the planning phase, for example in a maintenance concept.

Scope

Revegetation that is appropriate for the site conditions usually requires little maintenance (Krautzer et al. 2012b). The extent depends on the state of development, emerging alien vegetation, and site conditions. Initially, areas should be checked annually in spring for erosion damage and the emergence of undesirable species until vegetation provides sufficient erosion control (AGHB). Mowing may be useful to control tall grasses in areas of too vigorous growth. This is done early in the growing season when the grasses have reached a certain height (max. 15–20 cm).

Duration

The development process is usually divided into different work steps and lasts until the restoration goal is reached (Bosshard et al. 2013).

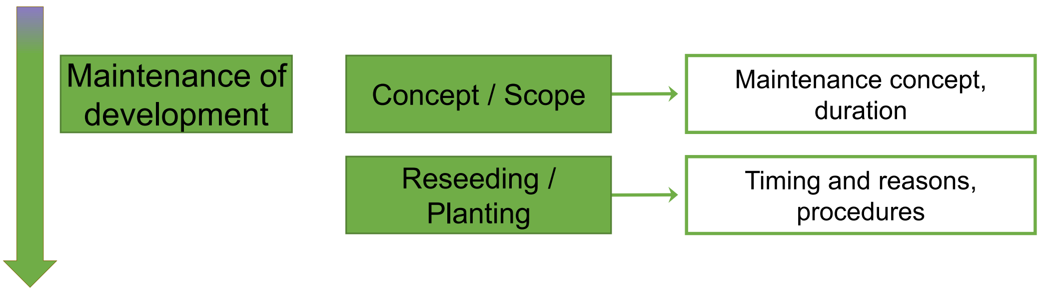

Figure 33: Overview of maintenance of development.

8.2 Reseeding and replanting

Timing

Reseeding takes place at the earliest after one vegetation period. Due to dormancy, seed emergence may require a frost period, a certain day length or warm temperatures (Schwienbacher et al. 2011). This should be considered when making decisions. For reseeding, the same seasonal indications apply as for normal seeding (Tables 5 and 6).

Reasons for reseeding

- Coverage 50% below revegetation target (Krautzer and Klug 2009);
- Insufficient root penetration of the soil;
- Achievement of revegetation goal unlikely (Krautzer et al. 2000);
- Erosion phenomena, trampling damage, landslides, and drought damage.

Procedure

For small-scale reseeding, the soil is roughened and then sown by hand (Krautzer et al. 2007). Alternatively, re-planting is carried out (Krautzer et al. 2000). In the case of large-scale surface deficiencies, a second, complete revegetation may need to be carried out.

Responsibility

Responsibility is to be determined during planning.

Further measures

Depending on the cause, the following measures can promote the success of reseeding:

- select better adapted seeds (Bosshard et al. 2013);
- local soil improvement and loosening;
- repairing damage with structural measures.

9 Subsequent use, maintenance

The completion of the success check marks the end of development maintenance. This is followed by subsequent land use or maintenance (Figure 34).

9.1 Criteria for approval

If the soil stability and the degree of vegetation cover meet the requirements of the planned land use, the area is released for long-term subsequent utilization (Krautzer et al. 2000). If the area is not used for agriculture, maintenance care may be appropriate for areas of ecological value.

9.2 Mowing

Reasons for mowing

Mowing of meadows serves for agricultural purposes. Apart from this, mowing may be desirable for various reasons:

- to prevent abandonment, scrub encroachment and reforestation (Bosshard et al. 2013);
- when too dense plant growth leads to lack of air and light (Lichtenegger 1994);
- when low-growing species should be encouraged (Lichtenegger 1994);
- in the case of later land use as pasture, to stimulate root growth (AGHB).

Timing of mowing

Frequency and timing must be adapted to the present species and local conditions (Lichtenegger 1994). In this context, care must be taken to ensure that the mowing time is appropriate for the elevation in accordance with the requirements of the DZV. If mowing only serves to prevent shrub encroachment, cutting every 1 to 3 years is sufficient (Dux et al. 2009).

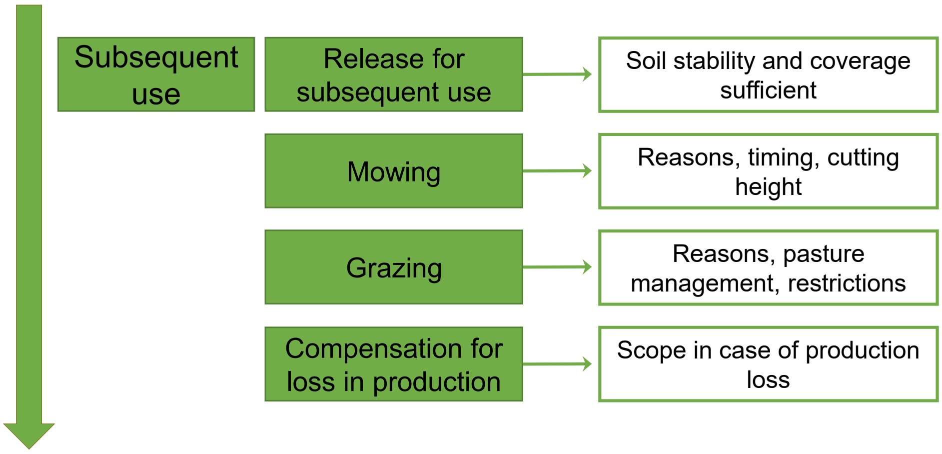

Figure 34: Contents overview after use.

Cutting height
The cutting height varies from 6 to 10 (12) cm (Bosshard et al. 2013). Mowing close to the ground favors only a few species (mostly grasses); meadow herbs in particular are more sensitive to cutting very close to the ground. When cutting higher above the ground, the remaining biomass has a positive effect on the microclimate.

Removal of the mown material
In the case of young vegetation with relatively little cut material, this is usually left on the ground to enrich the organic matter in the soil. This also applies in principle to soils where the organic content has been greatly reduced due to construction activity. If nutrient enrichment is not desirable (e.g. on semi-dry meadows, dry meadows or wet sites), the cut material should be removed (Bosshard et al. 2013). This also applies if mowing is carried out because of the risk of a lack of air and light (Lichtenegger 1994).

9.3 Grazing

Reasons for grazing
On structurally rich areas at high elevation, grazing is often the only possible form of land use. This creates additional small structures such as bare patches, cow trails and grass tufts due to cattle trampling (Dux et al. 2009).

Timing and type of grazing
Grazing is recommended after two years at the earliest and after complete scar closure (Lichtenegger 1994).

As newly planted areas and young seedlings do not yet have a firm sward, the first grazing should be carried out gently, for a limited period of one to two weeks and only when the ground is dry (Krautzer et al. 2000, Schneider et al. 2017). Grazing strengthens the sward and topsoil over time (AGHB).

To avoid major damage from trampling, animal breeds that are as light as possible should be selected, and the livestock density should be adapted to the conditions (Pauler et al. 2019).

To prevent overgrazing at individual locations, for example areas close to stables or wetlands (Figure 35), management planning is recommended (Bollmann et al. 2014). At steep, clay-rich sites, only light livestock, preferable in dry conditions, should be used for grazing (Lichtenegger 1994). Young cattle or sheep/goats are more suitable on such sites (Krautzer et al. 2000). For agricultural land, the directives of the DZV apply.

Figure 35: Grazing in wet areas leads to trampling damage (photo: M. Peters).

9.4 Compensation for loss of earnings

The compensation rates for areas in forage production depend on the elevation (below/above 1400 m a.s.l.) and the intensity of use (non-intensive, low-intensity, intensive). The calculation of compensation for short-term yield loss is carried out with the help of experts according to the “Guidelines for the estimation of crop damage” of the Swiss Farmers’ Union. In the case of yield loss over several years, the “Guidelines for the assessment of income loss for cultivated land used over several years” of the Swiss Farmers’ Union (Schweizerischer Bauernverband, SBV) is authoritative. These guidelines are published annually.

10 Outlook

Twelve years after the publication of the first edition of the guidelines for high altitude revegetation, the latest results from research, but also the experiences of the members of the AGHB, have been incorporated in the second edition. Much has been achieved since then, but there are still opportunities to further improve the quality of revegetation. In the case of seeds, efforts by seed producers have resulted in CH ecotype seed and in many cases also regional ecotype seed being available for the large regions. It is important for planners or restoration workers to obtain high-quality seed in the desired quantities in reasonable time. Further efforts may help to ensure that seed can also be ordered on short notice for the sub-regions in the future. With regard to species composition in the mixtures, additional species were included in propagation based on vegetation surveys in order to use species as similar as possible to existing vegetation types. However, not all species can be propagated equally well, so further research is necessary here.
Even when seeding with local ecotypes or planting directly, differences between a seeded area and the surrounding vegetation remain visible for a very long time due to the slow growth of alpine plants, especially above the treeline, and the disturbed soil structure. Using pre-grown plants and rooted topsoil for restoration partially eliminates this disadvantage. Soil transplantation or direct relocation is therefore the most promising measure in high-altitude revegetation. However, it is not always possible to secure sod in sufficient quantities at the site. Efforts are currently underway to produce sod with the desired target vegetation (site-appropriate grasses and herbs in the desired composition).

In addition to current efforts by researchers, seed companies, and practitioners, there are also ideas that are currently in the early stages of development. For example, using powerful drones instead of helicopters could save costs and energy.

New challenges arise due to climate warming, which affects the site factors at high elevation and thus the vegetation. In addition to the increase in temperature, less snow in winters and drier summers in Central Europe pose new challenges for vegetation (Bloemer 2008). Adaptation to new situations will be necessary and will be included in future versions of the guidelines.

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