Guidelines for sustainable soil management in ski areas

Digest: Ski runs

Caring for Soils
- Where Our Roots Grow

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University of Torino, Department of Agricultural, Forest and Food Sciences

Editor

Dr Borut Vrščaj

Authors (alphabertical order)

Emanuele Pintaldi, Davide Viglietti, Claudio Francione, Silvia Stanchi, Csilla Hudek, Michele Freppaz

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Summary for decision-makers

These guidelines collect the current state of knowledge about the soil good management practices applied in ski areas. The aim is to provide a useful and practical tool that may allow the sustainable soil management, favouring the mitigation of impacts caused by the construction and management of ski runs and related facilities.

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1. Introduction

Tourism on ski resorts brings many benefits to a mountain region, including economic diversification and the improvement of services and infrastructure (Lasanta et al., 2007). However, as with many human activities, the development of winter sport resorts can impact the mountain landscape and environment (Freppaz et al., 2013; De Jong, 2017). The growing popularity of skiing has increased the demand for wide, smooth ski runs with snow grooming and the option of using artificial snow (Freppaz et al., 2013). Construction and operation of ski runs, snowmaking facilities and lifts can have a large impact on mountain soils and ecological sustainability of this new land use requires maintaining essential soil ecosystem services, including water storage, nutrient cycling, and surface runoff regulation (e.g. erosion control) (Sanchez-Maranon et al., 2002). To effectively reduce the environmental impact of ski run and related facilities construction and management, specific regulations need to be implemented along with effective, state-of-the-art best practices in order to ensure a successful soil restoration and plant/grass establishment. Good soil management techniques applied in ski areas construction and management could successfully mitigate site hazards such as erosion, the contamination of the on- and off-site environment and the aesthetic impact on landscape. In addition, although the effects depend also on the ski resort's dimension and organization, ski management practices affect strongly mountain grassland vegetation (Bacchiocchi *et al.,* 2019). Furthermore, as reported by IPCC (2019) the soil summertime slope preparation, represents one of the practices to reduce climate change impacts and risk to economic losses within the ski areas management.

2. Sustainable soil management on ski runs and related infrastructures: GOOD practices

Restoration techniques play a crucial role in the success of damage mitigation and the rehabilitation of damaged ecosystems (Freppaz et al., 2013). In several studies Hudek *et al*., submitted (Krautzer *et al*., 2013) the use of appropriate agronomic/pedologic techniques, conservation and reuse of the topsoil, selection of suitable plant material, and manuring after sowing led to the establishment of a sufficiently dense plant cover in a ski run, although it did not reach the percentage cover values of the adjacent undisturbed sites (e.g. natural alpine pasture). Machine-graded ski runs lose their seed bank, therefore the replenishment of seeds is a vital factor in the restoration process. There are various techniques used depending on site specifications, availability and cost-effectiveness; natural colonization or succession, use of commercial seed mixtures, site-specific seed mixtures and their combinations (Krautzer et al., 2013).

In the following section, we propose a good practice approach focused on soil management in 3 steps: 1) before the construction work (ante-operam): preliminary investigation; 2) during construction work (work in progress): management of the construction site and storage of the topsoil; (3) after the construction work (post-operam): management and reuse of the topsoil, application of seed mixtures adapted to site conditions.

The proposed approach can be applied to both construction and management of ski runs and their facilities (e.g. ski-lifts, cableways, snowmaking plants, etc..), even if some operational activities, such as levelling and boulder removal, are specific of the ski run construction, whereas others (e.g. re-turfing) are more suitable and easily applicable in ski run related infrastructures.

2.1 Ante-operam: preliminary investigation

In the preliminary phase, all the environmental information about the construction site should be collected, focusing particularly on:

- geology and geomorphology;
- climate;
- native soil type and properties;
- native vegetation characteristics.

Before the starting of the operational activities the geology and geomorphology of the area should be assessed, through the available thematic maps and/or through a specific field mapping. In flat terrains with a very gentle slope it is possible to plan the storage of the topsoil while specific geology (e.g. serpentinite, limestone) could influence the soil development and plant establishment. Also the climatic conditions should be carefully described, considering, if possible, data from neighbouring meteorological stations covering the whole elevation gradient. The characteristics of the native soils should be checked on available sol maps. If a map is not available, a specific soil survey should be organized in order to represent the distribution of the different soils in the construction site, with a special focus on the potential presence of rare or ecologically relevant soils, such as in peat bogs. Moreover, the determination of the depth of the whole soil and of the topsoil would help the subsequent operational activities (e.g. excavation operations).

Figure 1:Soil profile opened under alpine meadow in an Alpine ski area (2300 m asl).

In addition, a detailed vegetation survey should be carried out, in order to assess the plants distribution and the presence of endangered species and plant communities.

2.2 Work in progress: management of the construction site and store of native topsoil

The construction activities can put the soil ecosystem back to the beginning of primary succession (parent material outcrop), in case the existing soil horizons are not handled in an appropriate way (Pintaldi et al., 2017). In order to prevent excessive depletion of the ecosystem and warrant successful restoration, one of the priorities is the speed of the operational activities coupled with proper soil management. In general, the topsoil should be carefully removed and stocked on a gentle slope or a flat area (where possible), whose surface was previously covered with a geotextile. The height of the stockpiles should not exceed 2.5 m. These indications can be specifically applied for ski run infrastructures, whereas for ski run, they have to be adapted, depending on the sky run and site characteristics (e.g. size, steepness, elevation, etc.).
In specific sites, for example compromised by the construction of cable car pylons, it is recommended, if necessary, to apply the transplantation of grass turfs (especially when rare species are

present), transferring both topsoil and plants in a suitable site, close to the construction area. Since the transfer should be done manually, the maximum distance depends on the surface roughness and steepness.

The re-use of topsoil is crucial for several reasons. Firstly, following the execution of the construction work it is possible to achieve soil conditions similar to the original ones (Krautzer et al., 2006). This represents a prerequisite for native plant species to be able to recolonise the areas to be restored relatively quickly. In addition, most of the organic matter is found in the topsoil, where most of the available nutrients are located (Krautzer et al., 2006). Moreover, the topsoil contains microorganism such as nitrogen-fixing bacteria (Rhizobium) and mycorrhizal fungi (Graf et al., 1996) which are able, through root symbiosis, to improve the plants' supply of nutrients, thus reducing the need of fertilization (Krautzer et al., 2006). The microorganisms also help the quick restoration of the soil biological functions (Graf, 1997a) for better soil aggregation, thus increasing protection against erosion (Graf et al., 1997b; Frei et al., 2003). Topsoil contains above all generative and vegetative propagules and the still living parts of plants of existing vegetation, which make resettlement possible with vegetation from the original site (Krautzer et al., 2006). This ensures the restoration is enriched with indigenous plants, because their seed litter cannot be obtained on the market or is very expensive (Krautzer et al., 2013).

The lack of expert reuse of available topsoil is a waste of valuable autochthons plant materials (Krautzer et al., 2006; Krautzer et al., 2013) which could be available for a site-specific, low impact restoration (Peratoner, 2003).

2.2.1 Operational activities

Based on previous indications, it is of paramount importance that the available topsoil should be carefully removed and properly stored for the shortest time possible, and then reapplied before restoration (Krautzer et al., 2013). The operational activities should be done only when the soil moisture conditions are suitable to avoid excessive soil degradation (e.g. aggregate disruption, compaction etc..), considering also the machinery employed (size, weight, etc.). In addition, they can be adapted according to the different type of constructions (e.g. ski run, skilift, cableway, etc.), evaluating also the cost/benefits in relation to the size of the works and site characteristics. In detail:

i) remove carefully grass clump, grass swards or larger pieces of vegetation by hands (when possible) or using lightweight machinery. Such plant material, which is very suitable for quickly restoring graded areas (Krautzer et al., 2013), should be stored in stockpiles separately (from topsoil and mineral subsoil) for the shortest time possible. Stockpiles must be no larger than 1 meter and taller than 0.60 m (Krautzer et al., 2007). On steeper banks, the grass turfs must be fixed with wooden nails (Gottschlich, 2008). Best results for restoration will be obtained through the direct reuse of such plant material, i.e. without temporary storage (Krautzer et al., 2007).

ii) Remove carefully the topsoil, usually corresponding to A horizon (20-30 cm depth) and mineral subsoil (B and/or C horizons, > 30 cm depth) which should be stored separately in stockpiles as briefly as possible under suitable conditions. Choose carefully the surface for the storage, eventually covering it with protective materials and building a suitable drainage system in order to minimize soil erosion.

Figure 2: Topsoil storage area.

iii) Stockpiles realization (trapezoidal shape): it depends on the type of the materials and the length of storage, which in general should not exceed 4 weeks (Locher Oberholzer et al., 2008):

- with topsoil and storage duration < 1 year: max height 2.5 m;
- with topsoil and storage duration > 1 year: max height 1.5 m;
- with mineral subsoil: height from 1.5 to max 2.5 m.

For longer storage periods, in order to preserve the soil fertility, avoid erosion and prevent unwanted species, the stockpiles, should be covered by geotextile material or seed mixture rich in N-fix species (e.g. legumes). In general, it was observed that after 6 months of storage, a strong decrease of microorganism occurs (AASHTO, 2011). When the storage exceeds 6 months, it is also recommended to spread compost on the stockpiles in order to restore soil structure and soil biota.

Other management practices during the work in progress should avoid the potential release of toxic substances from the construction machineries, through periodic monitoring activities. Rare soils, cryo-geomorphic features (e.g. patterned ground) and plant communities should be protected, by fencing and placing a geotextile.

Figure 3: Protection of a snowbed area through a geotextile and a layer of mineral soil rich in stones

Moreover, during ski runs construction, after the removal of the topsoil, rocks should be removed and the surface levelled in order to obtain a smooth surface requiring a lower amount of snow for the skiing activities. An accurate drainage system has to be applied in order to limit soil erosion.

2.3 After the construction work: management and reuse of native soil

At the end of construction activities, all the soil material should be spread on the construction sites, following the layering of the previous natural soil profile, starting from subsoil until, if present, the surface plant materials (e.g. grass turfs). The main objective is to recreate conditions as similar as possible to the initial ones, thus setting the best condition for recolonization by natural species. The procedures for correct soil management after the end of the construction work are reported below. They are the basis for a successful application of restoration techniques and the colonization by local plant species.

i) Elimination of earthworks residues (e.g. protective materials, etc.).
ii) Spreading of the soil accurately stored, following the natural soil profile development. In particular, if the site conditions are suitable (e.g. not excessive slope), it is recommended to follow the operations reported below:

- spreading of subsoil fine mineral fraction and levelling it (i.e. no coarse stones have to be present on the surface). If the spreading of fine mineral subsoil occurs on very coarse substrata (with higher macro porosity), consider the possibility to cover the latter with geotextile material before the spread of subsoil, in order to avoid the loss of the finer mineral fraction;
- original topsoil spreading: the quantity of topsoil to be used represents a crucial factor in the restoration process (Rivera et al., 2014). As reported by Rivera et al. (2014) the depth of the spread topsoil (30 or 10 cm) does not seem to affect the restoration process

significantly with respect to plant cover, species diversity (richness and equitability) or floristic composition. In contrast, other studies reported an increase in plant cover (Holmes et al., 2001) and lower species richness with increased topsoil depth (Bowen et al., 2005), due to the increased availability of organic matter, nitrogen, phosphorus and water. It seems that woody and perennial herbaceous communities can take advantage of deeper fertile layers due to their deeper root systems (Rivera et al., 2014) However, regardless of the quantity, the correct storage and re-use of native topsoil represent a key factor for sustainable soil management and the success of restoration process.

- Manuring: if topsoil is naturally poor, or depleted of nutrients, provide fertilisation in order to ensure suitable conditions for a quick development of dense vegetation cover. Generally, a single fertilisation treatment is sufficient, however if in the second year of the restoration project the vegetation cover is still insufficient, further fertilisation measures may be required (Krautzer et al., 2006). The use of liquid manure, sewage sludge or unhygienic fertiliser should be avoided, whereas the use of organic-mineral and mineral fertiliser should be restricted to the necessary degree (Krautzer et al., Krautzer et al., 2006, Krautzer et al., 2013). It is recommended the use of organic fertilizer, such as well-rotted farmyard manure, composted fertiliser or officially certified organic compost (Krautzer et al., 2013).

iii) Prevention of soil erosion: after topsoil spreading, mostly on steep slopes, it is recommended the application of a mulch layer or geo-textiles in order to minimize surface drainage and soil erosion (Krautzer et al., 2013). This includes seeding processes combined with covering the topsoil with a layer of mulch, netting or matting, as well as hay-mulch seeding or the combined use of vegetation from the restoration site (Krautzer et al., 2007). Erosion protections are a prerequisite for successful restoration, because for instance if the soil is not covered with mulch material, seed mixtures have less ability to establish and prevent erosion (Krautzer et al., 2013). During at least the first two vegetation periods following restoration, erosion can only be prevented through the use of a high-quality application technique (surface cover with a layer of mulch) (Krautzer et al., 2010).

3. Application of site-specific seed mixtures

The aim of all restoration projects on ski slopes should be the achieving of a vegetation cover of at least 75% within the first two vegetation periods (Krautzer et al., 2011). Various revegetation techniques exist and are used depending on site specifications, availability and cost-effectiveness: a) natural colonization (succession), b) use of commercial seed mixtures containing mainly seeds from forage species, and c) site-specific seed mixtures or seed material collected (e.g. by harvesting) or directly transferred from local plant communities, and combinations of all the above (Krautzer et al., 2013).

Succession based on natural transportation of propagules of nearby species is the slowest process of all mentioned above and required other erosion control measures (e.g. fixing jute nets, etc..). However, in most restoration projects, commercial seed mixtures containing mainly tall, fast-growing grass are still used, due to their low costs. In addition, the environmental conditions at high elevations, such as temperature, precipitation and exposure, act as ecological filters, which constrain plant life. Several species of conventional seed mixtures do not tolerate such conditions and either do not germinate, suffer during the seedling stage or survive only during the first growing seasons. Consequently, in most cases the use of such non-adapted seed mixtures does not, achieve a sufficient vegetation cover to stop or significantly reduce erosion, even with fertilizer application. Moreover, commercial seed mixtures currently used, usually contain fewer (Freppaz et al., 2013; Abegg et al., 2007) species, mainly grasses (up to 99% of seeds) and legumes (Barni et al., 2007; Argenti et al., 2009) which are hardly adapted to ski slopes and can have competitive advantages over native species during the first years. Also Barrel et al. (2015) confirmed that the commercial mixtures grow faster, allowing to cover earlier the soil, at the expense of spontaneous species. Soil quality can subsequently be altered as the decomposition of litter dominated by grasses can take twice as long compared to forb-dominated plant communities which influences the nutrient discharge of the soil (Zu Schlochtern et al., 2014).

A long-lasting vegetation cover and a reduction of surface erosion seem much more achievable with local seeds (Krautzer et al., 2011). Local seeds can be obtained through different methods (e.g. Barrel et al., 2015; Török et al., 2011): a) collected from local plant communities and then propagated in breeding field or used directly; b) obtained from autochthonous seed material collected in situ (e.g. fresh plant material, raked litter, or hay) and directly transferred on the field.

The use of site-specific seed mixtures can provide a great number of advantages. Site-specific seed mixtures require fewer nutrients and a lower amount of seeds compared to commercial seed mixtures. They provide lower amounts of biomass but produce a higher quality of biomass and become self-sufficient, natural grassland in a shorter period of time (Krautzer et al., 2011). Higher species diversity compared to commercial seed mixtures also increases slope and soil stability (Körner, 2003; Reubens et al., 2007) and provide a more diverse plant composition that can successfully survive and function under the effects of climate change.

In general, as suggested by Krautzer (2013), restoration activities in the alpine zone should require 100% site-specific seed mixtures, whereas for restoration in the montane and sub-alpine zone, the additional use of site-adapted subsidiary components is possible. In particular, seed mixtures for the ecological restoration of ski-runs in montane and sub-alpine zones should contain at least 60% weight of site-specific main components and 40% of subsidiary components (Krautzer et al., 2013). Mixtures must include at least five species, considering that the weight of the seeds of an individual species should not exceed 40% of the total weight. Moreover, high elevation mixtures should contain at least 10% legumes on the total weight (Krautzer et al., 2013). Usually the amount of seed necessary for restoration at high elevations is approximately 300 kg ha^{-1}, however using site-specific seed, the amount decreases, ranging from rom 80 to 150 kg ha^{-1} (max 180 kg ha^{-1} under extreme conditions) (Krautzer et al., 2013).

For about 20 years the use of local seeds has been tested on ski slopes in the eastern Alps, with clear results indicating a competitive advantage of local seeds over seed mixtures containing mainly lowland seeds (Klug, 2006). Studied conducted by Barrel et al. (2015) in the western Alps, reported also several benefits (environmental and economics) provided by the use of local seed coupled with a proper soil management.

4. Results and long-term monitoring

The success of the soil restoration, particularly at high elevation, requires constant and accurate maintenance, as well as several years of monitoring (Felber et al., 2000). The time factor, which implies constant and prolonged monitoring and maintenance, is crucial for the success of restoration process. Barni et al. (2007) in ski runs at elevations ranging between 2000 and 2700 m asl (N-W Italy) showed the establishment of a sufficiently dense plant cover in 10–12 years, though it did not reach the cover values of the adjacent natural alpine pasture. It is therefore unlikely that the ecosystem can recover enough in the immediate future to provide functions and services comparable to natural ones. However, with an appropriate restoration strategy, these ecosystems, although artificial, may represent new habitats, able to sustaining biodiversity, providing also increase in other ecosystem services, such as recreational activities and biomass production (e.g. for pasture).

Did you know?

- Over 2000 ski resorts worldwide, 400 million visitors in 100 different countries.
- The Alps host 36% of the ski resorts and 84% of the major ski areas, attracting 80% of total skiers.
- Around 37,590 km of slopes and 15,808 ski lifts available in Europe, which reach a maximum elevation of 3899 m a.s.l. and make up to 64.6% of the total length of ski runs in the world.

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Imprint

About this report

These guidelines collect the current state of knowledge about good practices for sustainable soil management in ski areas.

About the Links4Soils project

The Links4Soils project focuses on awareness raising on soils in Alpine region, review of the existing regional and national soil data, transfer of knowledge and best management practices to policymakers and other stakeholders, and the promotion of efficient soil protection strategies. Links4Soils aims to overcome soil awareness, information, knowledge and networking gaps and to contribute to better implementation of the Alpine Convention Soil Protection Protocol.

Links4Soils project partners

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Alpine Soils: alpinesoils.eu/

Additional information and contacts

info@alpinesoils.eu