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Guidelines for sustainable soil management
Digest: Forest management

Caring for Soils
- Where Our Roots Grow

April 2020

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Summary for decision-makers

These guidelines bring together the current state of knowledge regarding good practices for sustainable soil management that could be applied in forest management.
Their aim is to provide a synthetic, useful tool for practitioners that can help them mitigate potential threats affecting mountain soils, and to promote sustainable soil management. This booklet describes the main threats to Alpine soils resulting from forest practices and suggests selected mitigation measures.

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1.Introduction: What is the biggest challenge this sector faces?

Soil is an essential part of forest ecosystems. It provides several soil ecosystem services: e.g. it is a habitat for living organisms that supports biodiversity, enables water filtration and purification, regulates nutrient cycling, captures and stores water, as well as reduces surface runoff. Soil proprieties are crucial for forest biomass production of wood, timber and non-wood forest products. Forest productivity considerably influences tree height, total wood production, growth development and consequently forest management.

However, t it is also the other way around: i.e. forest practices affect soils. Forest ecosystem, and consequently forest soils, are under pressure due to human use. Adaptation and careful management will allow us to accomplish both goals: preserve soil ecosystem services and manage forests at the same time.

It should be acknowledged that while forests are renewable natural resources, forests soils cannot be considered as such from the humankind perspective. Hence, prevention of main soil threats – degradation, erosion, loss, compaction, and contamination – is even more crucial.

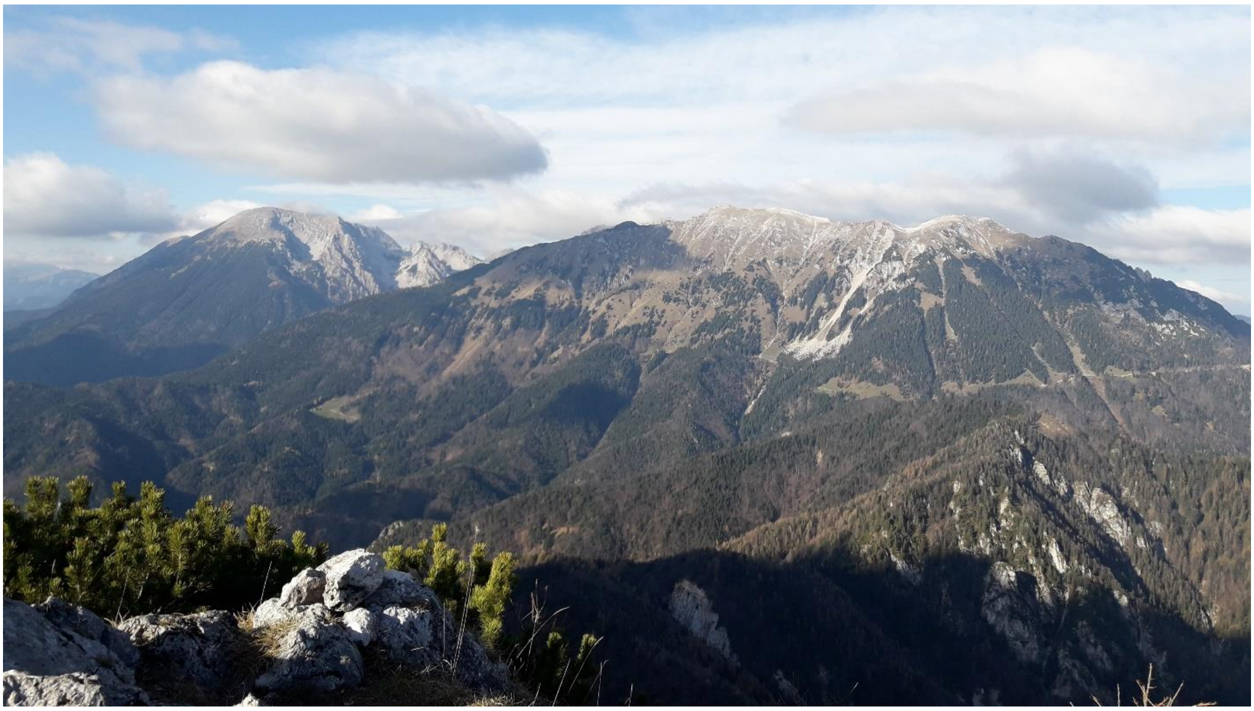

Figure 1: Alpine forests in the Karavanke mountains, Slovenia (Ph. Ž. Bončina)

2. Guidelines for sustainable soil management in forest soils

2.1 Biomass use

Harvesting methods for different forest conditions

Harvesting methods strongly affect the quantity of extracted biomass, while uncontrolled removal of stems and branches by harvesting machinery has a damaging impact on the forest productivity. The best approach for tree harvesting regulation is to divide the forest area into categories with different harvesting measures (see Figure 3) that are based on the site productivity. Following the whole-tree method, trees are felled and removed completely including crown, branches and logs. More biomass, like needles, stems, branches, is left in the forest following a modified method at less productive sites. Finally, log harvesting is only recommended for very poor sites. When maximising the amount of extracted biomass, topping diameter plays an important role. E.g a study estimated the leftover biomass totalling 16% of the total amount of stands with topping diameter of spruce being 15 cm: this leftover biomass would be enough to guarantee productive soils (Göttlein, 2013). A holistic approach, considering all relevant aspects, is the best choice for improving the assignment of the biomass use categories.

Figure 2: Tree length system and short wood system: stems are extracted while other organic material is left in the forest. (Ph. Ž. Bončina)

Consider forest characteristics

Forest types, especially when natural, can tell us a lot about site conditions. SI and volume increment, together with other site characteristics, can help forest planners define areas as more or less productive.

We should consider all stand characteristics in combination with other factors, e.g. water regime, climate conditions, slope, and land forms. Following "the traffic-light approach", groups of soil types, depths, geology, coarse fragments, land forms are categorised into 3 classes (green – 1, orange – 2 and red – 3). For example, if we isolate only the geological aspect, siliceous-carbonate material with high rate of impurities produces high nutritious soils, while forest types with most soils developing from dolomitic, pure rocks would be categorised into the third category of the traffic light system (red). As some characteristics are more relevant than others when considering the site productivity, expert knowledge established the weight of each parameter for each individual case and defined a specific category of biomass use for each forest type unit.

Leave dead wood in the forests

Certain amount of biomass of different dimensions and shapes – standing and laying trees of different diameters should be left in the forests since they provide a habitat to many fungi, animal and bacteria species. Legislation about dead wood differs among Alpine countries, but some measures are already in use troughout Natura 2000.

Consider geological and pedological information

Since pedological and geological factors have strong impact on suitability of forests for biomass use, the enhancement of forest management databases with this information is a step further to provide site-based measures. Different information could be used: the existing categorisation of geological units with information on lithogenetic, chemical and physical substrate characteristics, ortho-images and laser scan data, a collection of chemical properties (e.g. water capacity, saturation, cation exchange capacity, pH, and C/N proportion) from soil profiles and results of more detailed analysis.

Create a useful and handy tool for practitioners

Information for forest planners and workers should be summarised on no more than a page or two. The report can include productivity of the potential natural vegetation and the dominant tree species, risks, limiting factors and site characteristic, such as exposition, slope, water balance, typical soil type, parent material and bioclimatic growth regions. A simplified "traffic-light approach" is a useful demonstration with 3 regimes of use. The red, orange and green colours show the consequences of our use (in this case harvesting system) and define the ideal behavior in certain conditions (Figure 3).

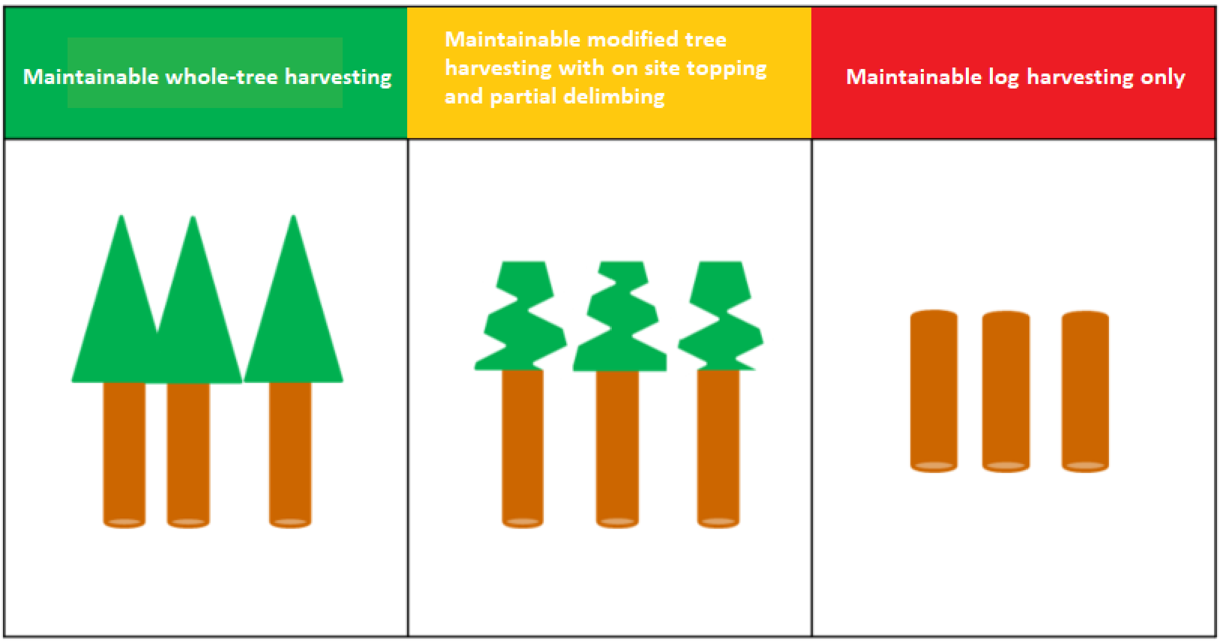

Figure 3: Suggested measures for tree felling for each biomass use category

2.2 Compaction risks

Carefully plan management measures to decrease the risk of natural hazards

Of all the forest operations, harvesting has the greatest impact on the forest environment. Timber extraction (and the increasing weight of forwarders and skidders) is the most critical regarding soil compaction. Harvest planning should consider all technical factors. Based on soil information (soil maps, map of functions, protective forest, and information on extremely rare and vulnerable soil types) and other factors, we should divide the area into zones with different harvesting system regimes in connection with weather conditions. Soil properties mostly affecting compaction are bulk density, soil depth, soil water content, soil structure and particle size distribution (Cambi et al., 2014). Topsoils are particularly important, especially the upper 30 cm.

It is important to locate the vulnerable sites and distinguish them from more resilient environments, e.g. harvesting operations should be completely banned in the vicinity of water bodies.

Figure 4: Machine harvesting is critical with regard to soil compaction. On the other hand, it is efficient and safer for workers. (Ph. J. Primožič)

Figure 5: While planning forest infrastructure, special care should be given to water bodies, not only because of high biodiversity and importance for game species but also in order to protect vulnerable soils. (Ph. Ž. Bončina)

Consider seasonal and weather impact

Soil properties should be considered in combination with weather conditions. It is advisable to implement time restrictions and schedule harvesting operations for different categories of soils based on weather conditions. Soil capacity increases (a) after the soil has been frozen for 10 days, provided the temperature is below minus 10 degrees Celsius, (b) after the soil has been covered by snow (more than 30 cm) and (c) after long-lasting droughts. Soil damage is greater in wet conditions. During and after periods of heavy rain mechanised harvesting should be suspended or postponed. A simple test performed with dropping a ball of soil onto the ground can be useful for the evaluation of current soil condition on the field.

Figure 6: Inappropriate use of forest infrastructure in wet conditions. In such cases, work should have been postponed. (Ph. J. Beguš)

: A simple test for the evaluation of working conditions. The ball of soil dropped onto the ground looks different in dry, moist, and extremely wet conditions. In the first case, driving causes elastic deformations on forest ground and risks for soil damage are low. In the second case, a plastic deformation occurs; in some areas, it is not recommended to perform work. In the third case, the soil structure is completely destroyed and horizons are remixed. Work should not be allowed under any condition. (Bodenschutz beim Forstmaschineneinsatz, 2012)

Possible transit	Occasionally critical	Locations at risk
Not in presence of wet soil/ limit at logging trails	Only in presence of dry/frozen soil or with technical adjustment (low pressure tires)	Transit should be avoided
		

Figure 7: Categories describing measures for heavy machinery transit on forest soils (Forest Type report of Tyrol)

Plan forest infrastructure efficiently

Minimising the transit of vehicles in forest is the best way to reduce soil compaction. Efficient planning could lower forest infrastructure density and avoid vulnerable parts with deeper soils and moist micro locations. Forest infrastructure density depends on the harvesting system and it is lower when timber extraction is performed with skidders (around 100–230 m/ha) than when machine harvesting with forwarders (around 330-550 m/ha) is used. Density of forest infrastructure for machine harvesting could be reduced by pre-use of chain saw.

Only use forest infrastructure

Forest machinery should use forest infrastructure only. Driving outside the infrastructure should only be allowed in exceptional cases. However, in this case, we should revise soil disturbances due to harvesting effects. Compaction declines productivity, decreases share of small root, resulting in ecologically non-active soils.

Figure 8: *Appropriate use of forest infrastructure for wood harvesting (Ph. J. Primožič)*

Use machinery cautiously during the harvesting

Good practices begin with trained and motivated workers and technically competent supervisors. Operational plans that provide an array of specific activities can help mitigate the damage on soils if they are carried out with great care.

Realisation of a mitigation measure: form a carpet of logging residues

Logging residues could improve storage capacity and mitigate soil compaction and rutting during timber extraction (skidding or forwarding). On critical sections, carpets from branches of the felled trees and tops of trees should be placed under the wheels to support the machines. Best effects are obtained when 2 m sections are placed crosswise on the skid road. Longer sections (4–5 m) are not recommended since they may result in »W effect« breaks and greater soil damage.

Figure 9: A carpet of logging residues mitigates damage on the soil (Ph J. Primožič)

Realisation of a mitigation measure: machinery adjustments

In order to minimise soil damage, adjustment measures should be used on vehicles: thus, contact with soil surface is enlarged and therefore the pressure on the surface is lowered. The most common mitigation measures are the following: lower tyre pressure, increased number of tyres, large soft tyres, boogie axes and use of appropriate caterpillars.

2.3 Erosion risks

Define erosion risk areas

With soil information and expert opinion in situ, define an erosion risk area with different regimes of use. For forest management, adequate maps need to be available with information about waterways, steep slopes, sensitive areas and drainages.

Legislate protection forests

Protection forests are a special category of forests under special legal protection and with specific regimes of use. Protection forests can be defined (a) *in situ* by experts, (b) based on available soil and terrain information, or (c) with remote sensing data. Current and potential effectiveness of protection forests should be evaluated. Protection forests should be maintained and carefully managed.

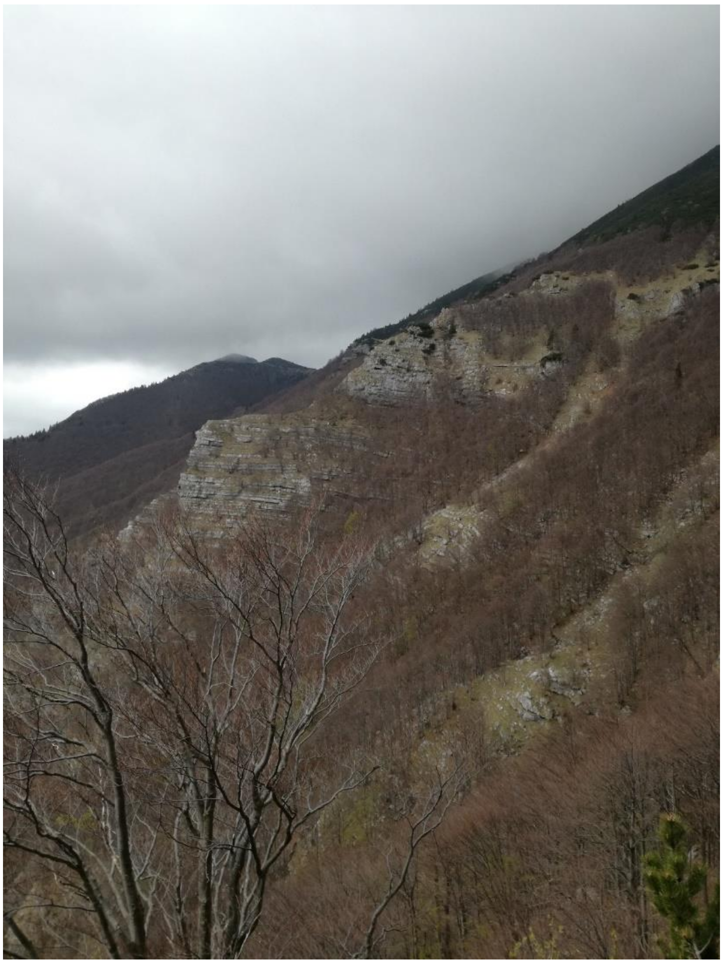

Figure 10: Protection forests above the Kolpa river canyon, Slovenia, on steep slopes provide protection for themselves and the soil they grow on. In Karst areas, protective function is even more crucial. (Ph. Ž. Bončina)

Plan wood harvesting carefully

Define areas where wood harvesting is forbidden or the ones where it is allowed under mitigation measures. Charts with clearly defined erosion risk areas can help us avoid critical sites.

Ensure continuous forest cover

Maintain continuous vegetation cover by avoiding clear-cutting, encourage gap regeneration techniques and promote natural regeneration with carefully selected tree species. Special care should be given to extreme areas, e.g. steep slopes and areas with high percentage of surface stoniness.

Figure 11: Continuous forest cover is crucial in karst areas with high percentage of stoniness. Mountain beech forests on moraine in the Ložnica Valley, Triglav national Park (Ph. Ž. Bončina)

Plan forest infrastructure carefully

Define areas where construction is forbidden or the ones where it is allowed under mitigation measures. Clearly defined erosion risk areas can help us avoid critical sites and design an efficient forest infrastructure network.

Figure 12: Bad practices in infrastructure use can be very damaging and costly in erosion risk areas. Ložnica Valley, Slovenia. (Ph. Ž. Bončina)

Use machinery prudently during the work in the forests

Ensure adequate soil protection measures to decrease erosion during forest infrastructure construction and wood harvesting operations. Choose machinery with regard to its weight to minimise soil degradation. Only well-trained and motivated workers and technically competent supervisors should be engaged in the process.

Adapt vegetation structure and species composition to natural hazard types

Forests can increase slope stability and reduce risk to an acceptable level by ensuring appropriate forest structure.

Figure 13: Forests with vital trees and high tree density ensure better protection against erosion (Ph. Ž. Bončina)

Restrict livestock grazing in the forest

In agroforestry systems, we should consider soil type in combination with relief on areas designated for grazing. Livestock can accelerate erosion processes and have other harmful effects, such as contamination and increased risks regarding the infection with honey fungus.

Figure 14: A mix of forest and high pastures is typical for Alpine region. Erosion caused by livestock may present a problem. Raduha mountain, Slovenia (Ph. Ž. Bončina)

2.4 Improving soil productivity

Promote natural tree species

Effects on soil are different in non-native and natural vegetation regarding the depth of roots, the quantity and chemical structure of litter. Sometimes, even allelopathy is present. Therefore, biodiversity in soil underground vegetation can be decreased, soil nutrient proportions can be destroyed, and pH of soil can change. For example, spruce litter can trigger eutrophication of forest floor and decelerate natural regeneration when planted outside its natural habitat.

Figure 15: Spruce litter can cause eutrophication, especially on acid bedrock. Spruce plantation in lowlands in the Kočevsko region, Slovenia (Ph. Ž. Bončina)

Figure 16: Spruce in its natural habitat. Upper tree line with larch, spruce, and dwarf mountain pine in the Karavanke mountains, Slovenia (Ph Ž. Bončina)

Increase tree species richness

Mixed tree species composition is beneficial for adaptation to variety of conditions, while each species has its own ecological niche. Some of the examples include the following: pioneer tree species are important for empty areas after big disturbances, some species develop root system quickly even in compact soils, ameliorative species have quick litter decomposition.

Figure 17: Natural regeneration on big open areas after natural disturbances is more efficient with mixed species in the neighborhood. Regeneration on the Jelovica plateau, Slovenia, with rowan, willows, spruce, and sycamore. (Ph. A. Nève Repe)

Use silvicultural systems adapted to site conditions

Through its effects on soil properties, the used silvicultural system affects not only the conditions for tree growth of the current generation but also of the next generation. Size of regeneration gaps defines the temperature, moisture, water balance and light conditions on forest floor. In temperate forests, continuous vegetation cover can be maintained with planter system or group selection cutting. In boreal forests, however, regimes with bigger gaps are desired to accelerate nutrient cycle.

Understand and mimic disturbance regimes

We should understand disturbance regimes and integrate them into silvicultural systems, e.g. by using bigger regeneration gaps in boreal forests and continuous cover on potential drought areas. Natural disturbances play an important role in forest dynamics and affect soil by opening a tree closure, changing forest climate, mixing soil horizons, triggering erosion processes, and creating a micro relief. Especially in rough conditions, effects of disturbances are high, e.g., fires accelerate mineralisation, the wind exposes the mineral part and enables mixing of soil horizons and creates a variety of micro conditions suitable for different tree species. In boreal forests, a century-long absence of disturbances can lead to paludification.

Figure 18: Wind exposes the mineral parts and enables mixing of soil horizons as well as creates a variety of micro conditions suitable for different tree species. (Ph. Ž. Bončina)

Leave organic matter in the forest

Regulation of the amount of extracted biomass can be obtained by planning the felling quota, prescribing wood harvesting systems, and restricting of non-wood products use. Biomass in the forest is not only wood; it also includes leaves, bark, fruits, branches and roots which proportionally store even more nutrients than wood. The amount of taken biomass differs between harvesting systems. In full tree systems, trees are extracted with full crown. More biomass is left in the forest where the tree length system or the short wood system is used. A system in which all litter is taken out of the forest may cause a decrease in growth for the next 20 years, especially in the case of conifers.

Figure 19: Signs of former inappropriate forest use: presence of the common bracken (Pteridium aquilinum) and low tree heights in the Kočevsko region, Slovenia. In the past, litter was taken out of the forest for livestock; today, soil is degraded and biomass production is low (Ph. Ž. Bončina)

Limit the intake of chemicals in forest areas

Avoid fertilisation and use of pesticides in the forests. Prevent contamination of soil during construction of forest infrastructure and forest harvesting operations. Absorption of chemicals affects forest soil on different levels; soil biodata is reduced, and proportion of nutrients can change dramatically and consequently affect other soil properties.

Did you know?

The protection of soil and water resources in eight percent of the world's forests counts as their primary objective. Around 330 million hectares of forests are designated for soil and water conservation, avalanche control, sand dune stabilisation, desertification control or coastal protection (Global Forest Resources Assessment 2010).

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Imprint

About this report

These guidelines bring together the current state of knowledge about good management practices for sustainable soil management.

About the Links4Soils project

The Links4Soils project focuses on awareness raising regarding 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

Agricultural Institute of Slovenia, SI (project leader) ● Office of the Tyrolean Provincial Government, AT ● Autonomous Region of Aosta Valley, IT ● Municipality of Kaufering, Department of Environment and Nature, DE ● National Research Institute of Science and Technology for the Environment and Agriculture, Grenoble Regional Centre, Mountain Ecosystem Research Unit, FR ● Slovenian Forest Service, SI ● Institute of Geography, University of Innsbruck, AT ● Climate Alliance Tirol, AT ● University of Torino, Department of Agricultural, Forest and Food Sciences, IT

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