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The protective functions of forests in a changing climate

European experience

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Cover photograph: Photo taken in Rudolfsturm of Lake Hallstatt in Upper Austria, specifically taken from a viewpoint on the Salzberg at the slope of Mt. Plassen ©Kopfsache

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Preface

by Yuka Makino[1]

[1]Food and Agriculture Organization of the United Nations

Building resilient communities and landscapes is an urgent global imperative, never more so than now as the impacts of climate change increase. Communities worldwide, especially those living in watersheds and whose livelihoods depend on these ecosystems, can be particularly vulnerable to hazards of increasing magnitude and frequency. Protective forests provide a barrier to safeguard these communities, while combatting climate change.

The European Forestry Commission Working Party on the Management of Mountain Watersheds (WPMMW), formerly called the Working Party on Torrent Control, Protection from Avalanches and Watershed Management, was created by the European Forestry Commission (EFC) of the Food and Agriculture Organization of the United Nations (FAO) in its Third Session in 1950. The technical body was established in order to study the technical aspects of torrent control and soil restoration in mountainous regions, given that these were considered as challenges in the European region.

In June 1952, the first meeting of the Working Party was held in Nancy, France, focusing on the issues related to torrent control and protection from avalanches. In 1970, during its 9th Session, it was concluded that the Working Party mandate should be enlarged, comprising torrent control, protection from avalanches, soil and water conservation in mountain regions, mountain land use with a special focus on forest land, and the evaluation of benefits of mountain watershed management. In order to encompass the new topics, the group adopted its current name – the "EFC Working Party on the Management of Mountain Watersheds."

The core vision of the Working Party is to promote sustainable development in mountain watersheds with a view to enhancing resilience to climate change and natural hazards, and to ensure the long-term provision of environmental services by watersheds for both upstream and downstream areas. Its goals include supporting EFC member countries to increase knowledge, enhance capacities and exchange experiences for the sustainable management and conservation of mountain ecosystems, exchanging policy advice on integrated approaches to sustainable mountain development and conservation, building bridges between science and practice, providing on-site training and international exchange for practitioners, and improving mountain livelihood systems and security of mountain ecosystems.

The Working Party has successfully established a dialogue among European mountain stakeholders and allowed a common vision on best practices to promote sustainable development and enhance resilience in mountain watersheds. It has played an important role in international processes, including Chapter 13 of Agenda 21 (mountain ecosystems), the implementation of the International Year of Mountains (2002) and the International Year of Freshwater (2003), as well as commitments from Warsaw Resolution 2 Forests and Water (2007) of the Ministerial Conference on the Protection of Forests in Europe (Forest Europe).

The Working Party meets every two years in a host country. Each member country is represented by a focal point who is directly nominated by the relevant ministry. The dialogue among scientists and policymakers is one of the unique and particular features of the group. Through the reports and presentations submitted for each session of the Working Party, the member countries and the external observers from different regions contribute to a flow of information on watershed-related issues. A number of inter-sessional activities, including workshops, conferences and publications ensure that the exchange of information between countries continues on a regular basis, especially within the three Working Groups that the Working Party has (Forest & Water, Hazard and Disaster Risk Management in Mountains, and the recently created Protective Forests).

In September 2019, focal points from 11 countries met in Innsbruck, Austria, for the 32nd Session of the Working Party. The session included presentations from each country with an overview of protective forests and mountain watershed management in their contexts. All participants emphasized the important role that protective forests play in mitigating the impacts of natural hazards, such as avalanches, debris flow events and mudslides, especially in mountainous regions. Each country also provided a national report on its protective forests, which were compiled and are presented in this publication.

WPMMW explores the potential of managing mountain forests and watersheds to reduce risk. Resilient watershed management is essential in achieving the 2030 Sustainable Development Goals (SDGs) 11 (Sustainable Cities and Communities), 13 (Climate Action) and 15 (Life on Land). In particular, SDG target 15.4 aims to ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

As the Secretariat, we are pleased to publish this collection of experiences regarding protective forests. Given that climate change is affecting mountain forests and their protective functions, influencing the occurrence of forest fires, precipitation patterns, invasive species and changes in the tree line, it is paramount that the management of mountain forests evolves in response to the changing conditions. In this sense, this publication is an opportunity to share and learn from experiences across European countries.

Acknowledgements

The editorial team would like to express gratitude to the authors who supported the creation of this publication with their contributions (country reports). Most of the authors also presented their results and approaches at the WPMMW Protective Forest Conference 2019 in Innsbruck. This publication would not have been possible without the support of Yuka Makino, Azul Popper, Vitor Brito and Enrico Aloi from FAO in Rome. We also appreciate the technical editing undertaken by Alex Chepstow-Lusty, the proofreading by James Varah and the layout by Roberto Cenciarelli.

Several experts from academia as well as practitioners have contributed valuable comments and feedback to the country reports, which constitute the main part of this publication. The project coordinators at FAO and the Austrian Federal Ministry for Agriculture, Regions and Tourism cordially thank the reviewers for their expressed support and time. Without the external expertise, the high quality of contributions would not be possible. The following are gratefully recognized:

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Executive summary

The European Forestry Commission (EFC) Working Party on the Management of Mountain Watersheds (WPMMW) recognizes the importance of improving collaboration for the sustainable management of mountain watersheds and the urgency of addressing climate and natural hazard risks. The present document combines contributions from twelve member countries — Austria, Bulgaria, Czech Republic, France, Germany (Bavaria), Greece, Italy, Norway, Poland, Slovenia, Switzerland, Turkey – and their respective practices, legislation, history and experiences in relation to protective forests, and how this varies both geographically and culturally across Europe.

The objective of this publication is to present the policy and management approach of each member country on its protective forests. The goal of the member countries is to increase the resilience of mountain forests and ensure the sustainability of their protective functions for society. Each country report covers the following topics: 1) definition of protective forests; 2) characteristics of the national protective forest system; 3) challenges encountered in the management and strengthening of protective forests, including climate change impacts; 4) governance of the protective forest system; and 5) monitoring and planning systems for protective forests.

The definition of protective forests (also referred to as "protection forests") varies among the countries. Nonetheless, most consider them as forested areas that provide ecosystem services such as control of soil erosion and water retention, as well as the mitigation of natural hazards, including floods, landslides and avalanches. Definitions are mostly based on whether the forest fulfils a protective function for inhabited areas, infrastructure, biodiversity or the soil. As such, countries identified the role of forests in mitigating soil erosion in mountain watersheds as the key policy objective. The location, altitude and/or social significance of the forest may further define its protective function.

The characteristics of the protective forest system are described for each country. Indeed, the percentage of protective forests within the total forested area in each country varies significantly, ranging from 1 to 87 percent. There is no uniform dataset or monitoring for protective forest cover in the EFC region. The level of public attention and official strategies differs between the countries and according to national circumstances. Largely mountainous countries generally have a more pronounced protective forest policy. The main species found in protective forests consist of fir, beech, spruce and pine species, i.e. largely comprising coniferous forests, the exception being beech, a very important native component of Alpine forests and in south-eastern Europe.

The main challenges for the management of protective forests are that they are often even-aged and have limited diversity of tree species. These forests tend to have a higher susceptibility to large-scale impacts from forest fires, windstorms and bark beetle infestation. Diverse land use is also a critical challenge. Agricultural use of the land in some countries does not conflict with protective forest use as most protective forests are in lands unsuited for agriculture, while in others, cattle grazing endangers the integrity of the ecosystem services provided by these forests. Furthermore, some protective forest areas suffer from browsing damage by game, while tourism and recreational uses require special management measures. The level of conservation and/or extraction of forest products from the protective forests also differs by country.

Climate change is considered a fundamental challenge by all countries. Protective forests are largely in mountainous regions that are particularly affected by climate change. Temperature rise, variations in precipitation, stronger storms and increased drought events are the main hazards identified as having negative impacts on the protective functions of forests. Moreover, increases in pest and pathogen outbreaks are expected, the main concern being the impact they will have on the already vulnerable matrix of even-aged forests with little species diversity. Changes in mountain zonation are expected, with consequent variations in the biodiversity of forested areas.

Each country analysed its protective forest governance system and the existing laws and institutions that manage protective forests. National forest strategies, framed by international and European environmental conventions, are present in every country. The country reports describe the legislations and policies regarding the use and management of protective forests. The legislation is translated into regulations and management actions carried out by regional or local authorities, or specific forestry national institutions. Differences are observed between countries that have national or regional policies, which give rise to inconsistencies in the management of forests between regions.

The analysis of ownership of protective forest land reveals large contrasts among countries, ranging from a high percentage of forested areas being privately owned to entirely publicly owned forests. Difficulties in the implementation of integrated strategies exist where the majority of the forests are privately owned. Another identified challenge is the fragmentation of ecosystems.

The financing for the management of protective forests in most countries comes from European Union funds and national governments. Most reports mention that financing for protective forests is generally available after disasters, because the funding obtained is related to relief funds, and not specifically to the sustainable management of forests.

Monitoring and planning measures are implemented in order to manage protective forests. Forest inventories are carried out via physical and geospatial methods, and are used alongside maps of protective forest functions, hazard zones and watershed classifications in order to prepare zoning maps. Regulations on the types of tree felling, cutting and grazing are prepared according to the zoning maps.

Planning is implemented through both preventive and reactive measures. Preventive measures are taken in order to enhance the protective effect of forests via sustainable management. Afforestation, payment for ecosystem services and awareness raising with the public are mentioned throughout the reports. Reactive measures involve different types of monitoring and afforestation. The impact of game browsing on forest regeneration is studied in order to determine administrative hunting plans for controlling the populations of hoofed game. Meanwhile, the impacts of pests and fires are monitored in order to adapt management accordingly.

Research and communication are deemed key components of protective forest planning by all countries. Efforts in communicating the importance of the protective function of forests are being carried out by forest institutions, for example, producing content for schools and creating outreach activities. Participatory approaches involving stakeholders are also very important to minimize conflicts of interest.

Actions to address threats associated with climate change are being planned and carried out using modelling of future scenarios for protective forests. New management criteria point towards a change in the composition of forests, such as encouraging the use of drought-resistant species. As such, finance and projects are envisioned to support climate-adapted forest conversion.

In conclusion, the reporting countries confirm the importance of protective forests for their territories and citizens. The forests provide protection to people, infrastructure and nature, but require protection from land use and increasing climate fluctuations with the associated risks, such as droughts, pests, storms and fires. Countries have defined, characterized, and identified challenges inherent to their protective forests, and it is through their appropriate governance, management and planning that the forests are able to provide ecosystem services in a sustainable way. In the context of a changing climate, the approach has to be revisited and adapted to novel and increasingly more uncertain conditions. This review of reports from 12 countries shows that especially mountain regions in Europe are facing common challenges and that different approaches can be learnt from each another. We hope that this report may provide a basis for further actions in transboundary and international cooperation for maintaining and enhancing protective forests.

1. Editorial

FOREST PROTECTION AND PROTECTIVE FOREST: DIAMETRICALLY OPPOSED OR MUTUALLY BENEFICIAL?

Florian Rudolf-Miklau[1] and Ansgar Fellendorf[1]

[1]Austrian Federal Ministry for Agriculture, Regions and Tourism

Forests help stabilize the climate, sustain biodiversity and provide economic opportunities. Hence, the strategic importance of sustainable forest management appears undeniable and should be a top priority on the political agenda. However, reality reveals another picture. The FAO Global Resource Assessment (FRA) 2020 Key Findings show that from a global perspective, the loss of forested areas has increased, but the rate of loss has slowed down (FAO, 2020). According to the International Union for Conservation of Nature (IUCN) livestock, insects, diseases, forest fires and other human-linked activities have damaged millions of hectares of Europe´s forests over the last years (IUCN, 2021). The main causes of forest destruction are agriculture, the timber industry, mining, large infrastructure projects such as hydropower plants and forest fires. Notwithstanding the major political efforts to foster the concept of sustainable forestry, the social recognition of the benefits and functions of forests remains limited in many countries, while conflict-related uses are omnipresent. Indeed, in the light of global climate change, deforestation counts among the emerging global threats for humanity's life support system.

Not surprisingly, the protection of forests counts among the most important political goals in nature conservation policy. Forest protection is concerned with the conservation or improvement of forests and prevention and control of damage by natural or man-made causes, such as fire, animals, insects, fungi, invasive plants and adverse climatic conditions. Globally, human impact is, by far, the dominant reason for deforestation. Forest protection seeks to prevent *inter alia* unsustainable farming and logging, forest soil pollution and expanding city development caused by population increase and the resulting urban sprawl. The benefits of forest conservation include biodiversity protection, non-timber products, erosion control, water conservation, pollination, ecotourism, and other ecosystem services.

Hence, in many countries, policymakers put forest protection on a level with forest conservation. The protective functions of forests for air, soil, water, biodiversity or human living space are understood as a part of conservation. This integrated ecological perspective often leads to a segregation policy, separating woodland under strict nature conservation from managed forest stands.

In contrast, countries with a longstanding tradition in forestry have developed a divergent concept of sustainable forestry. According to this concept, forests perform a great number of functions, both as an ecosystem and as a product of skilful human activity, where nature is partly harnessed to fulfil people's needs. The value of particular functions of the forest is limited – an increase of one may occur at the expense of others. At the same time, many functions are either co-dependent or linked together and may change in time and space. Forests provide three major functions: (1) the protective function, i.e. a stabilizing effect on the natural environment and resources, as well as a protection of human living space from the impact of natural hazards; (2) the productive function, i.e. mainly the provision of the raw material timber and non-wood forest products; and (3) the social function, i.e. creating a favourable environment for health, jobs, livelihoods and recreation for society.

Forest policy in Central Europe is oriented towards a multifunctional approach, based on the idea of the compatibility of the different forest functions. The basic idea of multi-functionality is that the socio-economic effects of forests and the satisfaction of anthropogenic needs require a different kind of forest treatment, rather than a purely ecologically-oriented conservation of natural forests. Both approaches are sustainable in their own way and aim to avoid forest over-exploitation. However, the motives of forest conservation are divergent, whereby the belief in the compatibility of humans and nature contrasts with the requirements for a strict separation of natural space (wilderness) and human habitat. This tension applies in particular to the terms forest protection and protective forest.

Protective forest: a conceptual approximation

A "protected forest" is not the same as a "protective forest." These terms frequently lead to some confusion in European forest policy. This is reason enough to take a closer look at and clarify the nature of the protective functions of forests.

The term "natural protective forest" is commonly associated with the capacity of ecosystems to balance or buffer the action of natural hazard processes, such as floods, droughts, snow avalanches, mass-movements or soil erosion. One of the most important protective functions of forests relates to soil and water resources. Forests conserve water by increasing infiltration, reducing runoff velocity and surface erosion, and decreasing sedimentation, which is particularly relevant behind dams and in irrigation systems. Forests play a role in filtering water pollutants, regulating water yield and flow, moderating floods, enhancing precipitation (for example, "cloud forests" capture moisture) and mitigating salinity. Multifunctional forest area with protection of soil and water as the primary designated function refers specifically to the area of forests set aside for the purpose of soil and water conservation, either by legal prescription or decided by the landowner or manager. More specifically, multifuntional refers to soil and water conservation, avalanche control, sand dune stabilization, desertification control and coastal protection. It does not include forests that have a protective function in terms of biodiversity conservation or those in protected areas, unless the main purpose is soil and water conservation.

All forests and woodlands, including productive forests, play a protective role to varying degrees and the protective functions can often be enhanced by an alteration of the management regime. In view of the many protective functions of forests and their increasing importance, there is a growing imperative for countries to gather, analyse and present information on the extent and condition of forests with a protective function. Especially in Central Europe, forestry spatial planning comprehensively deals with the importance of forest functions in wooded areas and their priorities.

Forests where the protective function dominates are generally referred to as protective forests. In the Alpine countries particularly, protective forest stands are mostly the mountain forests above villages, roads and railways. These stands offer protection from falling rocks, landslides and avalanches to the people in the valley. Protective forest is not only important for the immediate area, as the forests in the mountain areas prevent, for instance, flash floods and flooding in the lowlands. In forest law, protective forests also include forests on steep slopes outside of mountain areas (i.e. road protective forests forests, erosion protective forests), on unstable locations (i.e. flying sand) or next to water (bank protection). In addition to the direct protection of the soil on which they stand, protective forests also have protective functions against surrounding infrastructure (i.e. noise protective forests), water bodies (groundwater protection and water retention, i.e. for avoiding flood peaks) or crops (i.e. forests above vineyards prevent cold air flowing out).

Regardless of the conflicts of goals described ahead, forest conservation and the protective function of forests can be compatible goals and part of sustainable forest management. The central question is how far humans can or even have to intervene in these forests so that they can adequately fulfil their protective functions and safety requirements. In addition, the protective effect represents a social function of the forest and thus a social value and an ecosystem service. A relationship arises between the forest owner and the beneficiaries that can be represented in legal, economic or social terms. Forest policy has to deal with this relation, in terms of evaluating the protective effects for society, in balancing benefits and costs and in solving related conflicts.

Protective forests and a changing climate

Undoubtedly, forests are major carbon sinks with paramount importance for climate change mitigation. Trees and forest soils fixate and store carbon from the atmosphere. Conversely, the destruction of forest area leads to climate-harming greenhouse gas emissions. According to the IPCC Report on land use, carbon emissions from deforestation and associated land use change are estimated at 10 to 20 percent of the world's total human-induced emissions.

On the other hand, the impacts and effects of global climate change can be widely observed in European forests: in Central Europe, for instance, infestation by the bark beetle (mostly *Ips typographus*) has resulted in the loss of forest cover in entire regions, with the tree line moving upwards or with the species composition changing due to different climatic conditions. Moreover, altered weather and precipitation patterns have led to more frequent extreme weather events such as flash floods and storms. The changing climate affects the protective functions of forests, increases the forest fire risk in many areas, and in some mountain areas means that people need to adapt to a loss of the protective effects of forests because of natural hazard-induced deforestation. In addition, climate change affects the ecosystem services that forests provide for the inhabitants of mountain and downstream areas. Thus, it becomes clear that new policy and management measures have to be discussed, developed and adopted, in order to secure sustainable protective forests in mountain areas and watersheds.

Protective functions of forests: an ecosystem service in the public interest

In general, ecosystems contribute in multiple ways to the sustainable mitigation of risks for human life and the basic functions of existence. In this regard, natural protective services (functions) of forests can be characterized as typical ecosystem services.

Ecosystem services are the services supplied by nature that humans use to secure their livelihoods and nutrition. These services include, for example, fertile soils for the production of food and raw materials, clean drinking water, protection against natural hazards and providing recreational resources and spaces. As such, these services become scarce with increasing pressure on the forests. The concept of ecosystem services pursues an anthropocentric approach and focuses on people as the beneficiaries of ecosystem services. From a legal perspective, protective effects provided by forest ecosystems, which emerge from their natural conditions or processes, constitute positive economic effects that spread from the source area, either directly to adjacent properties (parcels) or even to remote spaces farther downstream. While the source area of these effects, i.e. the protective forest, as a rule, is clearly assignable to a defined property (forest ownership), the area where the benefits take effect is usually spacious and difficult to demarcate. According to the prevailing opinion in European forest policy, protective services related to natural hazards are considered as *public goods* or even a *common pool resource*. Hence, it seems conclusive to treat them as *public protective services*, which include the opportunity for everybody to consume the effects of forests "free of charge."

According to the origin of protective services in forest ecosystems, private rights of use and gains pertain to a specific treatment or maintenance in order to preserve the protective effects that restrict the free use of forests and induce substantial costs. Hence, theoretically the consumer of protection (beneficiary) owes the provider (forest owner) a monetary compensation. An established system of remuneration of protective services of forests presupposes cultural norms, such as a public consensus about the value of the service and the rules of consumption enforced by law. Concerning ecosystem services "*in the public interest*,", the state has set up a *rule- and compensation-based system* in most European countries that regulates the transaction (supply and demand) of forest protective services and enables both providers and consumers to enforce their interests and rights through injunction or compensation remedies.

One means of resolving the matter is to devise a rule that allows one property owner to force the other to change behaviour in land use. An alternative means of resolving the competing interests is to establish liability principles that define a compensation, if the owner of the protective forest uses the land incompatibly with the protective function or if the consumer of protection alters the safety claims by increasing the risk. The establishment of such a rule- and compensation-based regulatory system also comprises limitations on the open consumption of protective effects of forests that particularly prevent "free-rider" use without any compensation. This requires – according to the definition of "common pool resources" – that the state sets up rules which regulate the public access to natural protective services and takes into account the owners' agreement regarding the use of the service. Furthermore, the system should also provide incentives to the owners of the protective forests in order to invest in, use and maintain their property (the protective forest) in favour of the provision of protective functions.

The obstacles stated above to a fair compensation-based transaction system are mainly caused by market failure. Thus, it should be a prerogative of the state to regulate and manage the provision and transfer of protective services. For this purpose, it is necessary to assess the appreciation of the public concerning the protective effects provided by forests.

Purpose of this publication

In theory, the protective functions of forests and their characteristics as ecosystem services are adequately defined and clearly distinguishable from the forest protection concept. However, there is little knowledge about the wide range of protective effects and social appreciation in different European countries. The natural and social frameworks and the specific protection interests of respective countries primarily shape political concepts. In particular, the protective forest concepts of the Alpine countries differ fundamentally from the protective forest services in the lowlands, in coastal areas or in developing countries. Indeed, all that there is in common is the basic principle that forests offer security of supply and protection. An international protective forest policy has not yet been established at either the global or the European level. In the context of the many challenges to protective forests, from anthropogenic pressures to accelerating climate change, transboundary cooperation and exchanges, how best to preserve and sustainably strengthen the importance of protective functions remains crucial.

In the framework of the EFC Working Party for the Management of Mountain Watersheds (WPMMW), this publication compiles, for the first time, comparative country reports about the different concepts of protective forest policy in Europe. It includes socio-political requirements for the protective effects of forests, as well as for policy and governance, and the current challenges. The compilation of protective forest policy from 12 member states of the European Forest Commission (EFC) shows the wide range of policy concepts and allows for comparison of common principles. The abstraction of the heterogeneity of the protective services provided by European forests to the concept of ecosystem services, and the core issue of the relationship between forest owners and the beneficiaries of protection, combined with the comparability of the policy concepts, may create an important first basis for a European protective forest policy. The role of the state as a regulator of this relationship in the public interest features as a central factor. In this context, national legal norms regulating protective forests are presented in a comparative manner. The work should help to clarify the differences between protective forest and forest protection, both semantically and with regard to socio-political implications.

2. Country reports

AUSTRIA

Karl Kleemayr[1], Gernot Hoch[1], Manfred Kreiner[2], Christian Lackner[1], Frank Perzl[1], Florian Riccabona[2], Klemens Schadauer[1], Silvio Schüler[1], Heimo Schodterer[1] and Michaela Teich[1]

[1] Austrian Research Centre for Forests

[2] Regional Forest Service of the Tyrol

Preliminary remark by the Editor

In this country report, the term "protective forest" is used (as in the other country reports in this publication), as this term is prevailingly used in the international forestry nomenclature, especially in EFC/FAO-publications. Alternatively, especially in the German-speaking Alpine countries, the term "protection forest" is used, hence also in the current ETC-project GreenRisk4ALPs. When this alternative term is used in this country report, the text passage directly refers to an original quotation from this project.

General information

In Austria, a protective forest is a forest whose task is:

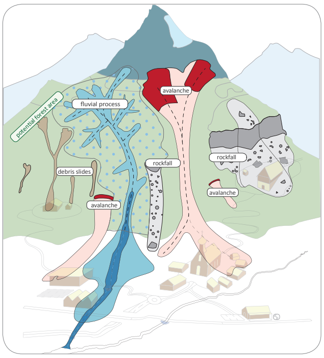
i) to protect the soil and maintain growth capacity on sites prone to soil erosion, soil degradation, climatic and/or edaphic inhibition of forest regeneration; and/or
ii) to protect human property, infrastructure and cropland from the impact of natural hazards and other damaging environmental influences.

In the case of the first task, this forest is a so-called "site-protective forest," and a forest with the second function is defined as an "object-protective forest." The "protection forest definition matrix" (Kleemayr *et al.*, 2019; Figure 1) gives an overview. The Austrian forest development plan distinguishes between four main functions of forests: protective function (PF), welfare function (WF), recreational function (RF) and economic function (EF). The importance of the functions varies strongly. In the Tyrol and other more mountainous regions, the average distribution is: 70 percent PF, 25 percent EF and 5 percent for RF and WF combined. In comparison, for the whole of Austria, the average distribution is around 30 percent PF, 65 percent EF, 4 percent RF and 1 percent WF.

With expanding settlement area, infrastructure and industrial activities in mountainous areas, the value of at-risk objects has significantly risen in the last few decades. As such, both site-protective and object-protective forests are of the highest importance for Austria.

Protection forest definition matrix

Interreg Alpine Space
GREEN RISK 4 ALPS
European Regional Development Fund



The figures illustrate important terms that are used to define protection forest:

Figure above:
1. potential forest area (green)
2. gravitational (snow avalanches, rockfall, debris slides) and fluvial (torrents, flooding) natural hazard processes
3. developed areas (settlements and infrastructure)

Figure below (see text for details):
Column 1 (yellow): soil protection forest (function-F1, effect-E1)
Column 2 (orange): protection forest that grows on formation and process areas (F2, E2)
Column 3 (red): forest that directly protects developed areas (F3, E3)
Column 4 (blue): forest with indirect protection benefits for developed areas (F4, E4)

Why a definition for protection forest?

The term protection forest is used inconsistently and sometimes misleadingly both nationally and throughout the Alps. In order to achieve the objectives of GreenRisk4ALPs, a consistent definition matrix is necessary to facilitate scientific progress and to communicate clearly among partners and to the public.

Terminology – protective function and protective effect

The term **protective function** is used in planning bases such as the forest development plan. To control land use development, desired forest functions such as protection, recreation, timber production or regulation of water quantity and quality are defined. The concept of function therefore represents the description of socio-economic interests. A forest with a protective function designation is a potential forest area intended to protect against soil degradation and/or natural hazards. In this context, it is of secondary importance in what condition the forest actually is or whether a forest currently exists on a potential forest area. The term protective function only describes an area's assignment to protect against soil degradation and/or natural hazards.

The term **protective effect** is used in the context of protection measures, forest or risk management. The protective effect describes the actual protective capacity of a forest against natural hazards or soil degradation. The concept of effect implies a description of the forest structure, which allows one to assess the actual protection against soil degradation and/or natural hazards. For example, a high protective effect against rockfall is only possible, if a stand has the necessary number of stems, basal area, DBH-distribution or tree species composition in the transit and/or deposit zones. If forest cover is absent from a potential forest area, this area will not have a protective effect.

Figures E1-E4 therefore show symbolically forest areas with stands that have a protective effect (tree elements) and forest gaps without protective effect (full color).

Terminology – site protection and object protection forest

The term **site protection forest** is used for forest areas in which the preservation of the forest itself is the main objective. Two types have to be distinguished:

1. Soil protection forest protects against soil degradation (e.g. loss of humus and/or other soil horizons, erosion) and supports the sustainability of the forest location (F1, E1).

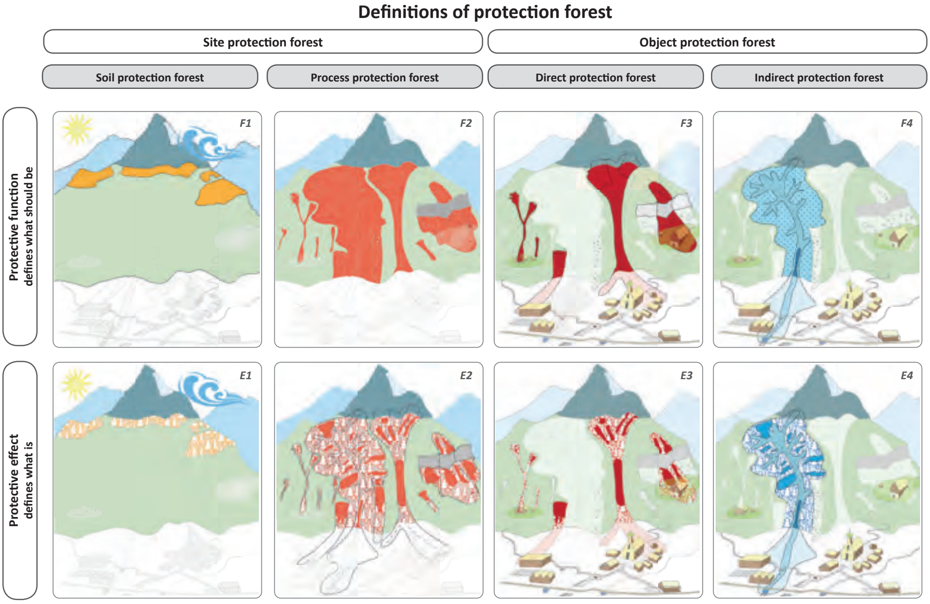
2. Process protection forest reduces the formation and development of hazard processes in the forest area (F2, E2). Depending on site conditions and process intensity, continuous forest cover loss can be caused by regular natural hazard processes (avalanches, rockfall) and erosion.

The term **object protection forest** is used for forest areas that protect objects in developed areas against natural hazards. An object protection forest can only be assigned, if an object is endangered; otherwise it falls into one of the categories described above (1, 2). Two additional types have to be distinguished:

3. Direct object protection forest (F3, E3) protects objects from gravitational natural hazards such as rockfall and snow avalanches. A direct link between the precise locations of the gravitational hazard process and an endangered object can be established.

4. Indirect object protection forest (F4, E4) protects objects from fluvial processes such as torrents. Typically, it is not possible to establish a direct connection between a precisely located protection forest area and a flooding scenario since the entire catchment area contributes to flood protection. The relationship is therefore indirect.

Definitions of protection forest



Published 2019 | Authors: Karl Kleemayr, Michaela Teich, Frank Perzl, Anne Hormes, Gerhard Markart, Matthias Plörer | Graphics: Karl Kleemayr
Austrian Research Centre for Forests (BFW), Department of Natural Hazards, Rennweg 1, A-6020 Innsbruck
This work has been carried out on behalf of the Interreg Alpine Space project GreenRisk4ALPs – www.alpine-space.eu/projects/greenrisk4alps/en/home

Figure 1 Definition matrix of site-protection and object-protection forests
Source: Kleemayr *et al.* (2019), as developed by the GreenRisk4Alps project, BFW.

Protective functions of forests in mountain watersheds

There are several protective functions of forests against natural hazards; for example, well-structured mountain forests reduce the release potential of snow avalanches below the timberline. As such, in response to climate change, forests are expanding into potential avalanche release areas. Indeed, the degree of forest cover in potential avalanche release zones is increasing. This forest development also reduces the potential for avalanches in forest-covered areas. Therefore, targeted forest management can enhance these protective effects. In addition, mountain forests provide an essential element in protecting human lives and infrastructure from rockfalls, by fixing loose rock masses with roots or reducing the speed by buffering the kinetic energy of falling rocks along the fall line. the fall line (Figure 2). Conversely, windthrows, i.e. trees uprooted by the wind, may significantly increase the local rock fall potential.

Furthermore, Alpine protective forests can reduce surface runoff potential, especially in the case of short-term heavy rainfall (torrential rain). In well-structured stands, the canopy breaks the kinetic energy of the precipitation and the intercepted raindrops discharge into the mineral soil via the ground vegetation and humus layer. Soils covered by forests or Alpine dwarf shrubs show a higher retention capacity in relation to other land cover units such as grassland, due to much higher interception and transpiration (Markart, Kohl and Perzl, 2007). Thus, they offer integral protection against surface erosion and runoff in mountainous regions. In addition, forest soils favour deep seepage. For example, decaying tree roots may act as channels for decades by favouring quick near-surface water discharge along root pipes. In contrast, subsurface flow is at least twenty times slower than surface runoff. Consequently, peak discharges in catchment areas with a high forest percentage are generally lower and occur with a time lag. These processes play a major role in flood prevention and in the reduction of damage potential for downstream areas (Markart *et al*., 2017).

For landslide prevention, the protective effects of forests depend on the type of the precipitation event. As such, the intensity and extent of shallow landslides (<2 m depth) can be strongly influenced by forest vegetation. For example, tree roots reinforce the soil and hold the substratum in place. The degree of interception and active evaporation by trees increase the free water storage capacity of the soil, while root channels increase the permeability of the soil. Hence, the forest has a significant influence on runoff and reduces disaster risk by flooding. For instance, during precipitation events in the province of Vorarlberg (1999, 2005), a lower landslide density was observed under forest cover compared to the surrounding open land (Rössel, 2015). Indeed, shelterwood regeneration[1] and small area regeneration are the appropriate rejuvenation methods with regard to mitigating the risk of landslides.

In Alpine torrent catchment areas, driftwood from lateral erosion, avalanches, landslides, wind or snow pressure can increase the risk of debris flows by forming log jams, hence potentially augmenting the magnitude of damage events downstream. Driftwood, deadwood and transported stems during flood events have increased the

[1] Progression of forest cuttings leading to the establishment of a new generation of seedlings of a particular species or group of species without planting.

Figure 2 Alpine forests protect, for example, against avalanches, rockfalls and erosion, and reduce water discharge

damage in several recent flood and torrent events in Austria since 2000. Thus, steep forested slopes along torrents require management at a small-scale level, in a targeted and site-specific manner, in order to maintain the cover of permanent forest ecosystems, with healthy rejuvenated trees, and short turnaround times. That is, an uneven-aged forest structure and a mix of tree species ensure that protective forests are resilient against biotic and abiotic disturbances.

Facts and figures

According to the Austrian National Forest Inventory (ÖWI[2]), there are 864 000 hectares of protective forests in Austria. ÖWI data are based on the inventory raster (4 *x* 4 km) and the assessed protection is primarily site-protective forest. According to the forest development plan (WEP[3]), which accounts for the primary forest functions, there exist 1.2 million hectares of object- and site-protective forest, i.e. comprising more than 30 percent of all the Austrian forest area.

In addition, the Austrian Research Centre for Forests (BFW) simulated in the last few years the extent of forests with an object-protective function for the whole of Austria. Simulations were carried out on a continuous 10 *x* 10 m raster for rockfalls, avalanches and shallow-seated landslides, independently of the assessment of the Austrian National Forest Inventory (ÖWI) (Figure 3).

The results of this numerical simulation are as follows (Figure 4): With a share of 61.2 percent, Norway spruce (*Picea abies*) is the most common tree species in Austrian forests, followed by European beech (*Fagus sylvatica*) with 9.6 percent. Mostly subalpine

[2] German: Österreichische Waldinventur.
[3] German: Waldentwicklungsplan.

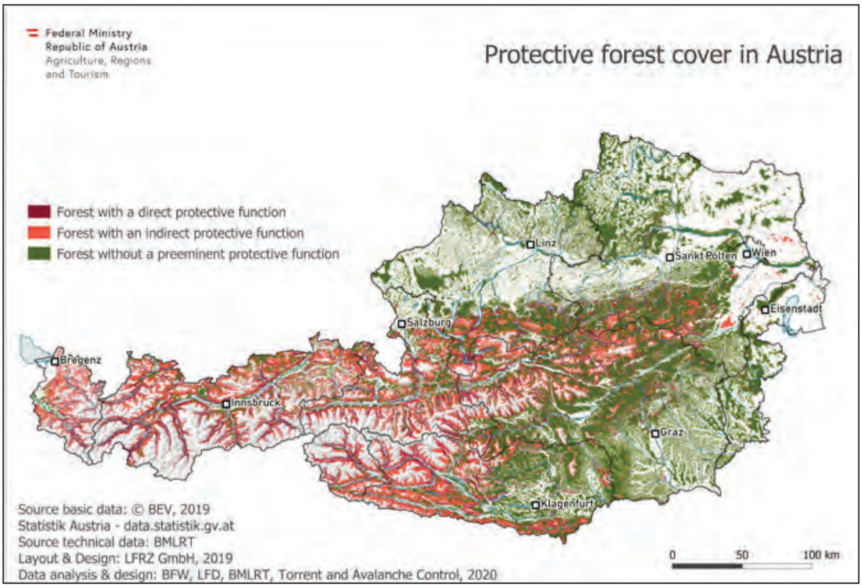


Figure 3 Forest use without (green) and with protective functions (purple and pink) in Austria

Source: BFW and BMLRT, 2019.

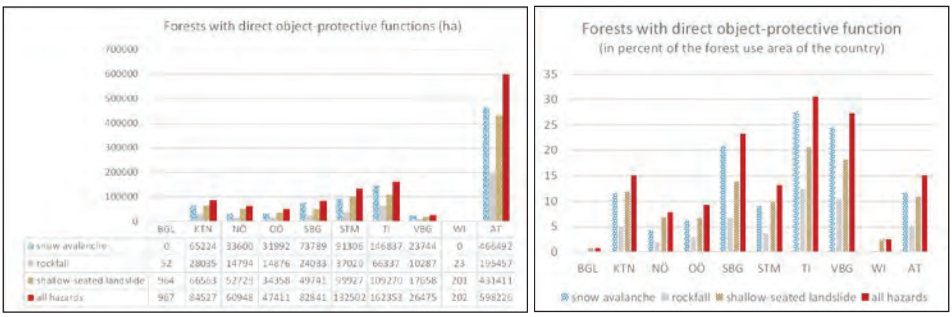


Figure 4 Results of simulations for assessing the extent of object-protective forests in Austria

Source: BFW, 2019 (based on data from Perzl, Rössel and Kleemayr, 2019). Index of abbreviation referring to Austrian provinces: BGL: Burgenland; KTN: Carinthia; NÖ: Lower Austria; OÖ: Upper Austria; SBG: Salzburg; STM: Styria; TI: Tyrol; VBG: Vorarlberg; WI: Vienna).

and montane spruce and montane mixed beech-silver fir (*Abies alba*)-spruce forests protect against gravitational natural hazards, such as snow avalanches and rockfalls, and indirectly against fluvial natural hazards, such as torrents and floods (Kleemayr *et al.*, 2019). Pure spruce stands tend to form relatively dense homogeneous stands of similar tree age and height with short crowns and only intraspecific competition. However, the ideal forest structure of a protective forest depends on the specific natural hazards occurring. For example, the primary purpose of avalanche protective forest is to reduce the probability of avalanche release by hindering the formation of continuous weak snow layers (Bebi, Kulakowski and Rixen, 2009). As such, this is achieved by evergreen coniferous tree crowns intercepting and releasing snow, modifying the energy balance at the snow surface and reducing near-surface wind speeds. Similarly, rockfall protective forest can halt falling stones in the transit and deposition zones (Dorren, Berger and Putters, 2006). From a static view, protective forests should have the highest possible stand density of the minimum effective tree size for the hazard in question and no large forest gaps (Brang *et al*., 2006). However, tree species, effective tree height and gaps vary depending on the hazard in question (Bebi, Kulakowski and Rixen, 2009; Dupire *et al*., 2016).

Protective forests are subject to specific legislation of federal and state laws. The Austrian Forest Act (Forstgesetz, 1975) and the ordinance for the management and use of protective forests (Schutzwaldverordnung, 1977) contain specific regulations at the federal level. The Forest Act limits the size of clearcutting (Forstgesetz, 1975, sec. 82) and requires official authorization for the reduction of crown coverage to less than fifty percent in an area of 0.5 hectares or more (Forstgesetz, 1975, sec. 85). In cases concerning protective forest, the thresholds are eighty percent and 0.2 hectares (Schutzwaldverordnung, 1977, sec. 1). Nevertheless, clearcutting is prohibited if it endangers the protective effect (Forstgesetz, 1975, sec. 82 para 1 lit a).

The Forest Act requires the timely regeneration of clearings by forest owners (Forstgesetz, 1975, sec. 13). In cases concerning protective forests, forest authorities are allowed and obligated to enforce this deadline, as well as to define methods of afforestation, cuttings for forest regeneration or slope stabilization and/or to limit forest usage for pasture (Forstgesetz, 1975, secs. 24, 100, 101; Schutzwaldverordnung, 1997, secs. 2, 3).

Major risks and challenges

In Austria, many stands do not show ideal and stable conditions with sufficient regeneration due to previous large-scale clearcutting, afforestation with spruce forests, and increasing deer populations. These practices often led to single-layer even-aged spruce forests that are susceptible to large-scale disturbances, for example, by insect infestations and storms.

According to the Austrian National Forest Inventory (ÖWI, 2018):

- 56 percent of protective forest stands are stable, but locally strongly overaged, which leads to critically unstable forest stands;
- 34 percent of the protective forest area is in the climax and decay phases; and
- 76 percent of potential regeneration areas in protective forest show browsing damage.

Major challenges leading to unstable protective forests include societal change, climate change, damage by game (for example deer), calamities and the economic situation. In some regions, certain tree species such as fir cannot develop, because bark and terminal shoots are being damaged by deer. With regards to societal change, protective forests are increasingly owned by "non-experts in forestry," i.e. people who have inherited forest. Often, these landowners take poor management decisions, or do not manage forests at all. Recently, the collapse of the timber market (caused by bark beetle and storm induced devastation of huge forest stands in Central Europe) forest management in protective forests appears to be unremunerative. Moreover, increasing settlement areas and commercial and touristic development raise the number of objects to be protected. For example, since areal development is mostly locally planned, the broader protective role of forests might not be adequately considered.

Climate change and its effects have led to increased dry conditions and water supply deficits, while warming has amplified the water demand. On the other hand, high precipitation over short periods of time and storms of greater intensity have increased. Higher temperatures have also led to more pest outbreaks and calamities, such as bark beetles on spruce (*Ips typographus*) and pine (*Ips acuminatus*) (Figure 5). Meanwhile, invasive pests or pathogens, such as Chalara ash dieback and brown spot disease on pine, are impacting important tree species in protective forests. In 2018, 5.2 million cubic metres (31 580 hectares) were damaged by bark beetles, 4.2 million cubic metres by storms (12 250 hectares) and 0.14 million cubic metres (1 000 hectares) by snow, ice or avalanches.

Continued high browsing intensity by game endangers the natural regeneration of protective forests. As a result, important tree species for climate-adapted future stands such as fir and oak have largely disappeared in mountain forest areas with high game populations. Bark stripping and browsing directly cause a loss of tree vitality. Selective browsing, e.g. by red deer, roe deer and chamois, also causes a significant shift in tree populations, such as segregating fir and oak. Therefore, a mixed forest adapted to climate change is currently failing due to overbrowsing by game.

In Austria, there are two nationwide monitoring procedures for surveying the impact of game in forests, namely: the i) Austrian Forest Inventory (ÖWI); and ii) wildlife-impact monitoring methods (WEM[4]).

Figure 5 Climate change-induced impacts such as windthrows and warmer temperatures damage Alpine forests and their protective functions: Damage by storm Vaia in Kals (Tyrol), October 2018

[4] German: Wild-Einfluss-Monitoring.

Governance and management of protective forests

There are no clear and uniform regulations for the management of protective forests. Management has been mainly reactive after problems occur. The costs in protective forests are relatively high, which reduces the willingness to carry out small-scale tree harvests, as well as the required thinning measures. In particular, high costs hinder the small-scale sanitary cutting necessary after natural disturbances, such as windthrows, snow breakages and bark beetle outbreaks.

In Austria, three main funding regulations exist for protective forest management and maintenance measures.

- First, funds according to the European Agricultural Fund for Rural Development (EAFRD), co-financed by national and provincial funding (BMLRT, 2021a). The federal government defines funding recommendations and more precise criteria are formulated on a provincial level.
- Second, investments through the disaster relief fund act (KatFonds) provide financial resources to projects for forests with object-protective functions (BMF, 2021). The Austrian Service for Torrent and Avalanche Control (WLV[5]) manages, in cooperation with the provincial forests service, projects in protective forest and watershed management (FWP), with co-financing by the province and local stakeholders (BMLRT, 2021b). Typically, both funding sources are used in cases of severe forest damage or predicted loss of protective effects (Figure 6).
- Third, funds through the forest fund act (Waldfondsgesetz), issued in 2020, also apply to protective forests, especially referring to climate adaptation and the recovery of forests after devastation and calamities (BMLRT, 2021c).

The national forest policy has been defined in the Austrian forest strategy[6]. This strategy defines major trends for Alpine forests. The following components are defined as a necessary basis for ensuring the sustainability of the forest:

- a broad-based commitment to comprehensive sustainability of the forest;
- the consideration of socio-political interests, including through systematic citizen participation in policy development and implementation;
- a sound legal framework;
- an efficient institutional structure;
- a well-balanced financing system;
- a smart monitoring and information system;
- a comprehensive knowledge of the ecological, economic and social interrelationships; and
- sufficient equipment with suitably qualified personnel.

[5] German: Forsttechnischer Dienst für Wildbach- und Lawinenverbauung.
[6] German: Österreichische Waldstrategie 2020+.

Figure 6 The system of torrent and avalanche control in Austria protects settlements and infrastructure with both afforestation and technical measures

The management issues necessary for the sustainable safeguarding of the “Alpine habitat” are further reflected in the protocols laid down by the Alpine Convention.

In 2019, the Austrian Federal Ministry for Sustainability and Tourism developed the Protective Forest Action Plan ("Forest protects us") (BMLRT, 2021d):

Protective forests account for 30 percent of the total forest area in Austria. Their special function often requires specific management and maintenance. However, the protective forest also faces major challenges. Climate change and the associated droughts, storms and heavy rains endanger the stability of the areas. For many forest owners, protective forest management does not pay off economically and the changed leisure behaviour in protective forests endangers renewable trees. This has led to outdated stands in many places in Austria – on almost half of the protective forest areas there is a need for rapid action. That is why we need strong answers now!

Our vision for a strong protective forest in the middle of the century is to have climate-friendly and stable forests that provide sustainable protection against natural hazards, are economically attractive to maintain and are recognized by society.

The main actors are the federal ministry, relevant provincial departments, forest owners and local forest managers, mayors, infrastructure owners, hunters, and tourism, nature conservation, research and civil society organizations. Due to the broad range of responsibilities and control functions of municipalities in Austria, their role is crucial.

The local level is most important in land use management, managing risk areas, and dealing with conflicts of interest.

The most relevant governance processes take place at a provincial level. As an example, 30 years ago the protective forest platforms[7] were started in Tyrol. Currently, there are two approaches and two focal points of action. The project "Bergwelt Tirol – Miteinander erleben" (Tyrolean mountains – experiencing each other) aims to find ways for outdoor sports to use nature in a natural and conflict-free way. For instance, new sports activities such as mountain and trail biking can cause conflicts, mainly with hunters and logging enterprises. Moreover, off-piste skiing can have negative impacts on wildlife management and regeneration areas.

The project "Klimafitter Bergwald Tirol" (climate-adapted mountain forest Tyrol) started in July 2019 (Amt der Tiroler Landesregierung, 2021). The Tyrolean parliament passed a resolution calling on the Tyrolean government to *launch an effective initiative for the bundling and targeted implementation of climate change adaptation measures in the mountain forests.*

Monitoring and planning

Austria conducts a plot-based national forest inventory, which includes many parameters for the protective forest. Additionally, remote sensing techniques are increasingly included within monitoring activities. The nationwide digital terrain model (DTM) is created by airborne laser scanning (ALS) data, with the spatial resolution being one metre, and therefore sufficient for many protective forest applications. Every three years, aerial images are provided for the whole of Austria. These are the basis for products such as orthorectified images with a spatial resolution of 20 centimetres and three-dimensional point clouds that are used in order to create digital surface models (DSM).

Both DTM and DSM are used for creating vegetation layers and thus forest layers. The creation of a highly accurate forest layer for the whole of Austria has been an ongoing process. Within the European Union's Copernicus Programme, Sentinel-2 images are available for free and used to determine forest types and detect forest cover changes, which is highly relevant for the protective forests.

Mapping of "forests with protective functions," as well as strategic planning of measures in order to improve the protective effects of forests, is the task of the forest development planning (WEP). Cartographic representation of "forests with protective functions" is part of the forest function map. The mapping scale of the forest function map is 1:50 000, with the minimum unit of polygon mapping being 10 hectares. The terms "protective function" and "protective effect" are used synonymously, although they may describe different aspects (Perzl, 2014). However, the map presentation of protective functions of forests does not differentiate between site- and object-protective functions.

Another instrument of forest land use planning related to protective functions and effects of forests is hazard zone mapping. In order to reduce the risk of natural hazard impacts by controlling the development of settlements and infrastructure, hazard zone mapping includes two maps. The hazard index map (1:20 000–1:50 000) shows torrent and avalanche catchment areas, while the hazard zone map shows the areas potentially impacted by torrents, avalanches, rockfalls and landslides (Perzl and Huber, 2015).

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[7] German: Schutzwaldplattform.

The Austrian forest authorities have had to set up special forest development plans in order to maintain the protective effects of forests, if improvement measures become necessary (Forstgesetz, 1975, sec. 24) and these are called "protective forest concepts." These special instruments include operational planning of measures without limitations by scale. However, the protective forest concepts are not up to date. Short-term changes and uncertainties concerning European and national funding policy and evaluation criteria, as well as challenging data management, complicate the planning.

Recently, the Federal Ministry for Agriculture, Regions and Tourism (BMLRT) has published a detailed map indicating the object-protective and site-protective functions of Austrian forests on a scale of 1:50.000 (BMLRT, 2021e), which is based on a nation-wide, high-resolution modelling of protective functions, realized by the Austrian Research Centre for Forests (BFW) within the project PROFUNmap (Perzl, Rössel and Kleemayr, 2019). In the medium term, this map will be – after the ongoing process of validation and quality control – the primary information source for the state of forests with protective functions in Austria on the local scale.

Climate change

Over the last decades, the IPCC Special Report on Oceans and the Cryosphere has shown that climate change has become particularly pronounced in mountain regions, reaching two to three times the temperature increase of the global average. Further warming is anticipated for the coming decades, and this will strongly affect mountain regions. Tree growth will increase as long as water and nutrient supply are not limiting factors (Elkin *et al.*, 2013); meanwhile the competitive relationships between tree species will change and disturbance regimes very likely will intensify (Seidl *et al.*, 2017). The direct influence of climate change on individual trees or natural forests has been shown in several studies (Alpine Space Programme, 2007). Indeed, the general shift from coniferous stands to more broadleaf and mixed stands is widely accepted in the scientific community.

Proposals for adaptive management have been derived. Elkin *et al.* (2013) project that, with a temperature increase of 2 °C, large negative impacts will occur at low and intermediate elevations in initially warm-dry regions with significant changes to the ecosystem services. Moreover, they state that considerable variation in the vulnerability of forests to climate change will lead to a significant decrease of protection against rockfalls and avalanches.

Spruce forests especially are highly vulnerable to changing climate conditions, and in particular to the resulting damage caused by natural disturbances such as storms and bark beetle outbreaks (Bebi *et al.*, 2017). Climate-mediated increases in disturbances are currently leading to changes in the forest structure of mountain forests and, therefore, have the potential to hamper a sustainable provision of protective functions (Seidl *et al.*, 2009, 2014). However, estimating the damage in terms of the protective effect loss for Austrian protective forests is challenging since disturbance-induced changes to the protective effect are not clearly understood (e.g. Teich *et al.*, 2019; Wohlgemuth *et al.*, 2017).

Nevertheless, the potential economic value of Austria's protective forests is enormous. According to a study to evaluate forests with a protective function in Austrian state forests (ÖBf), the value estimated with the replacement cost method was annually about EUR 14.7 million and EUR 268 per hectare (Getzner *et al*., 2017).

The Austrian Forest Strategy 2020+ takes into account the policy specifications of current national and international forest-related strategies, programmes and processes. These include the Austrian Biodiversity Strategy 2020+, the Austrian Forest Ecology Programme, the Austrian Strategy for Adaptation to Climate Change, the EU forest strategy, the EU Biodiversity Strategy, the Forest Europe process, the United Nations Forum on Forests (UNFF), the Sustainable Development Goals (SDGs), the UNFCCC and the Convention on Biological Diversity (CBD).

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Useful websites

https://www.schutzwald.at/
https://www.alpine-space.eu/projects/greenrisk4alps/en/home

BULGARIA

Albena Bobeva[1]

[1] Executive Forest Agency Bulgaria

General information

According to the Bulgarian Forest Act, forest territories carry out the following basic functions:

1. protection of soils, water resources and air quality;
2. maintaining the biological diversity of the forest ecosystems;
3. providing social, educational, scientific, landscape and recreation uses for society;
4. protection of the natural and cultural heritage;
5. production of timber and non-timber forest products; and
6. regulation of the climate and absorption of carbon.

The forest territories in Bulgaria (Figure 7) are divided into three categories according to their major functions: i) protective, ii) special and iii) economic, i.e. for common use. The law describes that forest territories are considered protective for the protection of soils, water, urban territories, buildings, sites of technical infrastructure and, lastly, biodiversity. Moreover, the upper forest limit, the protective belts, as well as forests created under technical projects to fight erosion, are defined as protective forests.

The forests designated for soil protection are those on slopes exceeding 30 degrees and those situated on shallow soils with slopes exceeding 20 degrees. Soil protective forest stands also play an important role between constructed dams for protection against the adverse impact of water, 200 m wide along the Danube River and 100 m wide around other large rivers. In torrential watersheds (Figure 8), soil protective forests are up to 15 m wide and in the lower plains, hills and hilly-mountainous terrain, about 50 m wide around the watercourses. Forests for water protection are located in the sanitary protection zones around the water sources and facilities for drinking water supply, and around the mineral water sources used for therapeutic, prophylactic, drinking and hygiene purposes. The green forest belts around the settlements are belts with a width of about 50 to 100 m from the village boundary. Forest territories for the protection of buildings and technical infrastructure include 25- to 200-m-wide strips along highways, roads and railway networks, and 25- to 50-m strips around the buildings and sites servicing technical infrastructure. In areas with active avalanches, the protective forest belt is 200 m wide.

Bulgaria is the third most biodiversity-rich country in Europe. Bulgarian forests protect more than 80 percent of protected plants and more than 60 percent of protected animal species. There are three national parks, 11 nature parks (Figure 9) and more than 700 protected areas, most of which cover forest territories. More than 55 percent of the

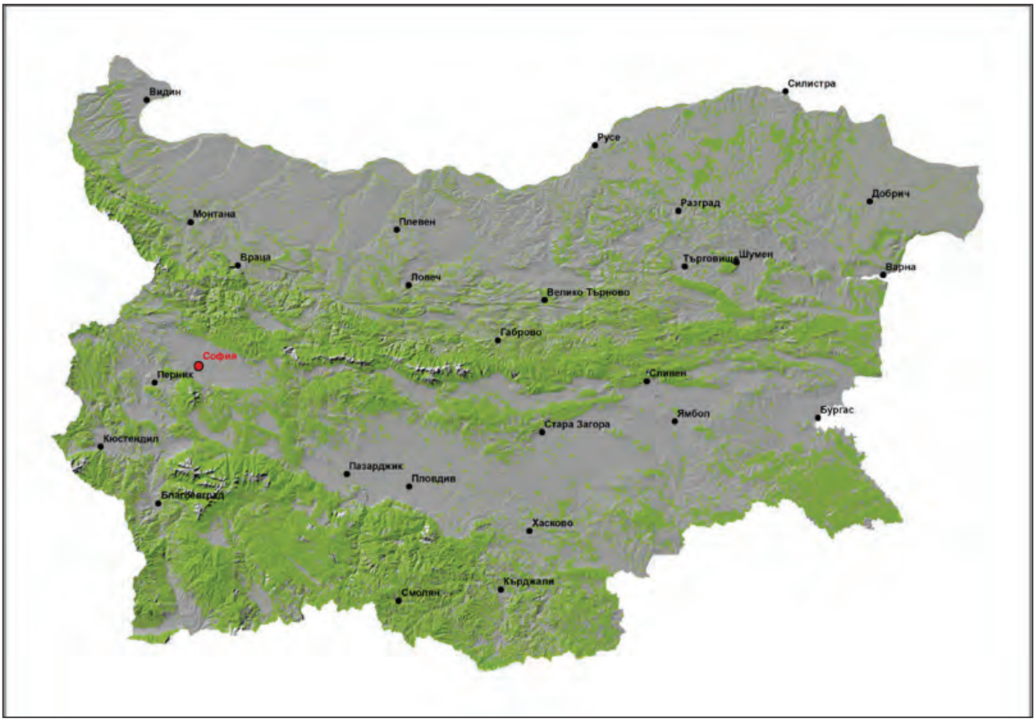

Figure 7 Map of the Bulgarian forests (in green) (EFA, 2013)
Source: EFA, 2013

Figure 8 Protective forests in the watershed "Ochindolska reka," Northwest Bulgaria

forest territories are in Natura 2000 areas (European Commission, 2021). Furthermore, Bulgarian forests provide and secure about 85 percent of the water flow and are of great importance for the drinking water supply in the country.

Figure 9 Protective forests in water protection zone in the "Vrachanski Balkan" Nature Park, Northwest Bulgaria

Successful erosion control management dates back more than 100 years. The main approach is a complex utilization of hydrotechnical and forest melioration activities. Forest watershed management has constructed over the last decades more than 617 000 cubic metres of barrages and thresholds, 395 000 cubic metres of small stone thresholds, 597 000 cubic metres of wattles and 428 000 cubic metres of low bank wattles. Moreover, 194 000 hectares of anti-erosion forest were afforested during the last century.

Protective forests (distribution and growing stock in Bulgaria is shown in Table 1) preserve and contain gullies, landslides, torrents, shorelines and other risk sources. In addition, protective forests form the upper tree line (upper forest limit) in high mountains, regulating surface water runoff and avalanches. The upper forest limit maintains the water flow of rivers, reduces spring floods, and preserves roads and settlements. Since this type of forest has a solely water-protective function, forestry practices are not recommended. If necessary, the activities should imitate the natural dynamics and restoration processes of ecosystems (see Assessment, Management and Monitoring

Table 1 Protective forest distribution and growing stock in Bulgaria

Reference year 2015	Area/hectares			Growing stock/cubic metres		
	Total	Coniferous	Broadleaf	Total	Coniferous	Broadleaf
Water-protective forests	177 033	63 398	113 635	39 706 852	18 314 906	21 391 946
Erosion control	154 412	62 911	91 501	24 742 518	15 877670	8 864 848
Meliorative forests	28 111	5 013	23 098	3 358 154	1 164 498	2 193 656
Total	359 556	131 322	228 234	67 807 524	35 357 074	32 450 450

of High Conservation Value Forests in Bulgaria, WWF, 2005. Practical Guidebook). These forests are marked as high conservation value forests (HCVFs), with most being coniferous forests, especially stands of the mountain pine (*Pinus mugo*), a small tree or shrub. In 2015, about 107 000 hectares of old-growth forest were declared, with the main function being the conservation of biodiversity in the country.

Pinus mugo forms the upper forest limit in the mountain areas in Bulgaria and covers 23 882 ha. However, the main tree species in the country are *Pinus sylvestris*, *Picea abies* and *Fagus sylvatica*. For Bulgaria, protected forest belts (PFBs) are very important, and comprise linear forest plantations designed to protect soils, civil engineering constructions and urbanized areas, and improve the microclimate. Indeed, the first forest belts were established in 1925, and in the early 1950s began their broader application as agroforestry practices. Furthermore, the protective belts were designed as shelterbelts in lines by planting appropriate tree species, including poplar (*Populus* spp.), false acacia (*Robinia pseudoacacia*), willow (*Salix* spp.), linden (*Tilia* spp.) and sycamore (*Acer pseudoplatanus*), among others, along ravines, canals, rivers, reservoirs, roads, fields and meadows for stabilization of river banks, flood abatement and achieving other environmental benefits.

Major risks and challenges

Recently, forest fires and bark beetle infestations have become major risks. However, there are no data available for the areas affected in the category of protective forests. Nevertheless, the authorities annually collect the data for forest fires and pests/diseases.

Due to climate change and global warming in the last decades, the risk of forest fires in Bulgaria has become as high as in the Mediterranean countries. During the last 15 years, around 500 forest fires have been recorded annually, which have damaged about 10 000 hectares of forest territories. Direct losses have been estimated on average at BGN 11 million (EUR 6.5 million) per year. Nowadays, forest fires are recognized in Bulgaria as one of the main threats for forests among other hazards such as erosion, floods and illegal activities (National Strategy for Development of the Forestry Sector in the Republic of Bulgaria for the period 2013–2020). One issue is the clearing of stubble in agricultural lands using fires, which is prohibited by law and often leads to forest fires. Fortunately, high-altitude protective forests are rarely affected.

The protective forests also do not have special plans concerning hunting activities, which in these territories are under the regular hunting management plan for the respective forest unit.

With the protective forests mainly situated in high mountainous areas, there are no major touristic interests in these zones, with ski areas covering only a small percentage of the forested mountain regions in the country. Similarly, although there are some touristic areas in or close to protective forests, they represent a very small percentage.

Sometimes there are issues with uncleaned river beds in mountain regions and in settlements, caused by a lack of sanitary felling or branches and rubbish not cleaned out. As a result, an uncleaned river bed increases the risk of flooding by creating obstacles for water passage. An example would be coniferous plantations, afforested 40–50 years ago outside of their natural areas, for the main aim of controlling erosion, and having reached their growth limit being consequently highly susceptible to bark beetles or other forest pests. Climate change and droughts in recent years have had a significant impact on the condition of artificially created forests. In particular, the drying out of coniferous stands with an average age of 40–50 years, created in areas with altitudes of up to 700–800 metres, has had a pronounced pathological impact due to the intensification of pest attacks. Indeed, recently, about 30 000 hectares of coniferous plantations have been impacted. Therefore, there is a need for urgent measures, such as cutting down the affected forests and removing the wood. Moreover, natural regeneration of broad-leaved species in their natural areas needs to be facilitated. In mountain watersheds, for instance, plantations of *Pinus nigra* (European black pine) and *P. sylvestris* (Scots pine) are being attacked by bark beetles, which leads to deforestation of certain areas and the risks of erosion and torrential flooding.

Protective forest policy and governance

The issue for protective forests is included as a special chapter in the National Strategy for Development of the Forestry Sector in the Republic of Bulgaria for the period 2013–2020, and in the Strategic Plan for the Development of the Forest Sector 2014–2023 (SPDFS).

Two of the four identified priorities are:

i) Sustaining vital, productive and multifunctional forest ecosystems, which contribute to the mitigation of the effects of climate change; and

ii) Protection, restoration and maintenance of biodiversity and landscape.

The strategic plan also identifies the concept for ecosystem services and their sustainable and socially acceptable management to be developed. The Forest Law and the ordinance on forest inventory have special chapters for protective forests, describing their functions and management.

The Forest Law states that:

Forest territories, depending on their major functions shall be divided into three categories:

1. protective

2. special

3. economic.

Protective forest territories shall be for: the protection of soils, water, urban areas, buildings and sites of technical infrastructure; the highest limit of the forest; the protective belts, as well as forests created as part of technical projects to combat erosion.

Art. 4. Forest territories shall fulfil the following basic functions:

- *protection of soils, water resources and clean air;*
- *maintaining the biological diversity of the forest ecosystems;*
- *providing social, educational, scientific, landscape and recreation uses for society;*
- *protection of the natural and cultural heritage;*
- *production of timber and non-timber forest products; and*
- *regulation of climate and absorption of carbon.*

Art. 90. (1) The protection provided by the forest territories against erosion and floods shall cover the activities related to preventing fine fractions being removed from threatened soils, in order to maintain the soil fertility, by limiting or decreasing the surface water flow, protecting the upper layer from wind erosion and providing opportunities for the development of vegetation, including by technical equipment.

(2) The protection of the forest territories against erosion and floods, as well as the structure of the supporting equipment shall be carried out under the terms and conditions of the ordinance under Art. 95, Para. 2, p. 4.

A chapter on forest ecosystem services is included in the Forest Law: Public ecosystem benefits from the forest territories.

Art. 248. (1) Public ecosystem benefits from the forest territories shall be the results from the specialized activities of its management.

(2) Public ecosystem benefits from the forest territories shall be:

1. *protection against erosion of soils by avalanches and floods;*
2. *guaranteeing the quantity and quality of water;*
3. *maintaining biological diversity;*
4. *maintaining microclimates;*
5. *providing conditions for recreation and tourism;*
6. *maintaining the traditional landscape;*
7. *protection of the natural and cultural heritage;*
8. *protection of infrastructure sites and equipment; and*
9. *slowing down and regulating impacts from climate change.*

Art. 249. (1) The public ecosystem benefits under Art. 248, Para. 2, where they are in favour of supporting economic activity shall be remunerated.

Any measures necessary in the forests are funded by the state budget, or by the budgets of every state or municipal forest enterprise respectively, or by European funds in cases where a thematic project is available. The activities are organized through the forest management plans.

The Executive Forest Agency (EFA) and its regional structures, the Regional Forest Directorates, are responsible for the regulation and control of forests. In addition, the Executive Forest Agency cooperates with the Ministry of Environment and Water, and with the Executive Environment Agency (ExEA) in order to protect and manage the protective forests in a sustainable way.

State Forest Enterprises are responsible for the management of the protective forests. There is cooperation on the regional level between regional and local forest services and River Basin Directorates related to water-protective forests. Meanwhile, the municipalities manage the municipal forests according to the forest management plans.

To increase public awareness, press releases on the EFA web page are an important communication instrument. In the framework of international projects, and EU-funded

Figure 10 Working with stakeholders on the local level in the Camaro-D project

projects in particular, stakeholder workshops (Figure 10) and field trips have been organized to raise awareness on the role of the protective functions of forests and related management activities.

Planning and monitoring of protective forests

There are no GIS data available for the forests in Bulgaria. Forest stand inventories are carried out approximately every 10 years for each local forest and hunting enterprise, which means that every year the forest inventory covers about 10 percent of the forest area. Forest data are not only received via the national forest inventory, but the forest area and the harvested timber are reported annually, and all other data are updated every fifth year.

Protective forests are included in the forest management plans, which cover the whole forest area in Bulgaria. Almost all protective forests are within the Natura 2000 network, and as such have a special management regime. Indeed, of the total forest areas in the country, 55 percent are located in Natura 2000 areas. In addition, there are several NGOs in the country dealing with the protection of biodiversity, protected areas and the protective functions of forests, and they are very active in decision-making processes.

The main area of protective forests is situated in mountainous regions where access is difficult. There are sometimes problems with bark beetle infestations on steep slopes and hardly accessible terrain. Furthermore, there exist issues with private forest stands not used by the owners, or in which the owners are not interested. As a result, for example, in the case of bark beetle infestations, it is hard to contact and communicate with the owners in order to implement sanitary fellings.

The Executive Forest Agency and its regional structures have undertaken projects, related to the protective functions of forests, funded through different EU projects. Hence, the approach of these initiatives is mostly transnational and within trans-border cooperation programmes such as Interreg. There are also research activities at the University of Forestry and the Forest Research Institute in Sofia.

Climate Change

As mentioned, in the last few decades the risk of forest fires in Bulgaria has become as high as in Mediterranean countries. For the last 15 years, around 500 forest fires have been recorded annually, which have damaged about 10 000 hectares of forest territories. In 2019, with the Council of Ministers decision, the National Climate Change Adaptation Strategy and Action Plan for the Republic of Bulgaria was approved (Ministry of Environment and Water of Republic of Bulgaria, 2021). By adopting the Strategy, Bulgaria will fulfil its international obligations on the United Nations Framework Convention on Climate Change (UNFCCC)/Kyoto Protocol and the Paris Agreement. The purpose of the Strategy is to serve as a reference document setting out a framework for actions and priority areas on climate change adaptation by 2030. The forest sector is one of the nine sectors covered by the Strategy and the Action Plan.

Moreover, there is a programme of measures for the adaptation of the forests in the Republic of Bulgaria and the mitigation of the adverse climate change impacts on them. The programme has been elaborated under a project called FUTUREforest and adopted by the Ministry of Agriculture. Other EU-funded projects related to climate change impacts on forests include CC-WaterS, CC-WARE, and Camaro-D.

Climate change scenarios based on meteorological data and modelling, and their effects on forests, are being developed for the next 50 years in the framework of a number of EU-funded projects. The predictions are that temperatures will increase by about 2 degrees Celsius and extreme disaster events will occur more frequently. Moreover, the scientific consensus predicts an increase in the number and scale of forest fires as a result of prolonged dry periods, a rise in forest damage due to storms, torrential rains and wet snow, as well as late spring frosts, which support secondary pathogens and insect pests.

Coniferous plantations afforested 40–50 years ago outside of their natural areas, with the main aim of erosion control, have reached their utmost growth limits. As a result, they are highly susceptible to bark beetles or other forest pests. Indeed, climate change and droughts in recent years have had significant impacts on the condition of artificially created forests.

In the framework of the EU-funded project CC-WARE, Bulgarian scientists from the University of Forestry in Sofia carried out a study on the effects of climate change on the protective functions of forests. The main outcomes showed that the overall changes in forests and forestry will be affected differently, but with a predominance of negative effects on ecosystem functions, mainly the supply of clean water from forests:

- The changes in species composition towards drought-resistant and pioneer species will increase transpiration (Raev, Knight and Staneva, 2003). On the other hand, forest areas will be retained to prevent soil and wind erosion, and will preserve the forest litter, which is important for the water quality in forest watersheds (Kitin, 1988).

- The predominance of young forest plantations is associated with increased evapotranspiration, which reduces runoff in the watersheds.
- The complex spatial structure and species composition of stands are predicted to improve their mechanical stability and the long-term preservation of ecosystem functions associated with watersheds.
- Windfalls, fires, calamities and other extreme phenomena lead to serious local adverse changes in the watersheds, including disruption to the infrastructure providing drinking water. Preliminary preventive measures for their limitation are essential for the forests, especially in the edge distribution areas for the different forest types. Additional investment funds in silvicultural activities will be needed to ensure suitable stand composition with better fire resistance and/or construction of fire prevention facilities.
- Impeded or delayed natural regeneration of forest stands in watersheds has a negative impact on both the quantity and seasonal distribution of the water runoff, as well as on water quality characteristics.
- A shortage of timber is a potential risk with the rise of illegal practices in forests and disturbance of their ecosystem functions, so that control over the markets for raw timber and forest guards should be increased, especially in the areas mostly affected by climate change.
- Changing the sustainability of forest ecosystems increases the risk of non-sustainable flow from forest watersheds. Therefore, it is necessary to introduce appropriate watershed classification in order to achieve the respective appropriate management.
- Increasing the cost-effectiveness of traditional forestry operations, and the need to increase the capacity for joint management of forest and water resources, create opportunities for EU funding of diversified activities through appropriate and attractive measures (Kostov, Tsvetkov and Slavov, 2014).

Good practice example

In Bulgaria, measures have been undertaken to maintain and improve the protective functions of forests, in order to enhance the protection of forests and conserve biodiversity in forest habitats. In 2010, the main measures to reduce erosion and other processes related to soil degradation were conducted in the following ways:

- carrying out anti-erosion afforestation in forests destroyed by fires and other natural disasters, and along the banks of watercourses – 7.02 square kilometres (Figure 11, 12);
- undertaking forestry activities to limit forest fires;
- regulating the grazing of domestic animals in reforested areas, and limiting forest crops and controlling erosion in forests;

- implementing terracing and other anti-erosion technologies for soil preparation in the afforestation of steep forest terrain; and
- supporting restoration by cutting down the undergrowth in thin plantations (EEA, 2010).

One good policy practice was declared in 2015 by the Ministry of Agriculture, Food and Forests, where 105 922 hectares of additional protective forests were recognized for the importance of their water-protective functions.

To summarize, protective forests in Bulgaria represent about 10 percent of the total forests in the country. They play an important protective role, for instance, in ecosystem conservation, in maintaining clean water, and in reducing the risks of impacts from floods, erosion and droughts. As such, water-protective forests in the country comprise about 5 percent of the total forests. Therefore, they are of major significance for the provision of clean water, as 85 percent of the drinking water in Bulgaria is provided from surface sources in forest areas.

Figure 11
Source: State Forest Enterprise Zenda, Regional Forest Directorate Kardzhali; Panov, 2000.

Figure 12
Source: State State Forest Enterprise Djebel Lebedski Dol site – Regional forest Directorate Kardzhali; Panov, 2000.

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CZECH REPUBLIC

Josef Křeček[1], Petr Navrátil[2] and Eva Pažourková[1]

[1] Czech Technical University in Prague

[2] Forest Management Institute, Czech Republic

Introduction

In the Czech Republic, forest stands extend over an area of 26 500 square kilometres, corresponding to a forest percentage of 34 percent of the state area. According to the mountain delineation criteria, at the local elevation range >300 m within a 7 km radius (Gløersen, Perlik and Price, 2004), mountain forests (18 600 square kilometres) represent 70 percent of the national woodland area (Figures 13a and b). The most important owner of mountain forests is the state, represented by the "Forests of Czech Republic, State Enterprise" (LCR). The state is responsible for forestry practices controlling almost 80 percent of national water resources, including 38 600 square kilometres of small headwater torrents and 887 small water reservoirs. These small water reservoirs are commonly referred to as artificial reservoirs with a lower depth and volume which serve diverse water management requirements, notably comprising multi-purpose hydraulic structures created for a variety of natural or artificial water accumulation and modification of the water environment (ČSN, 2011).

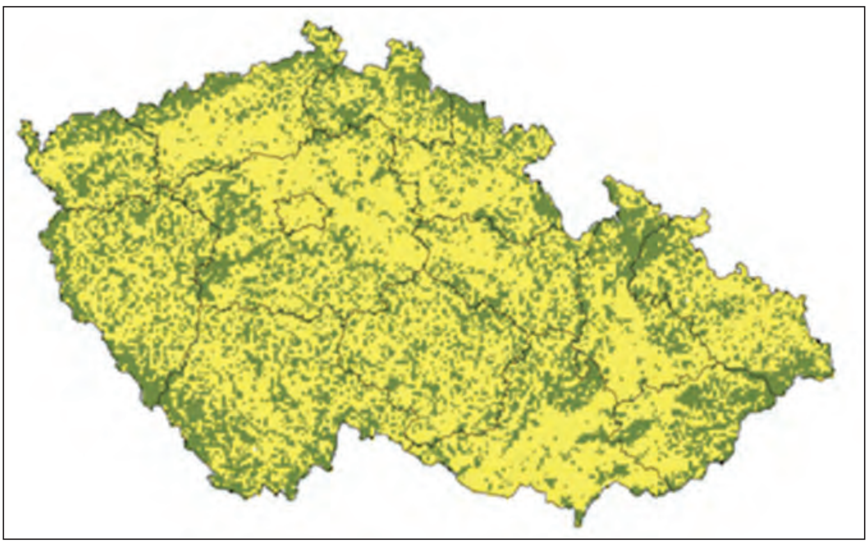

Figure 13a Forested area (green) in the Czech Republic
Source: Moucha and Pelc, 2008.

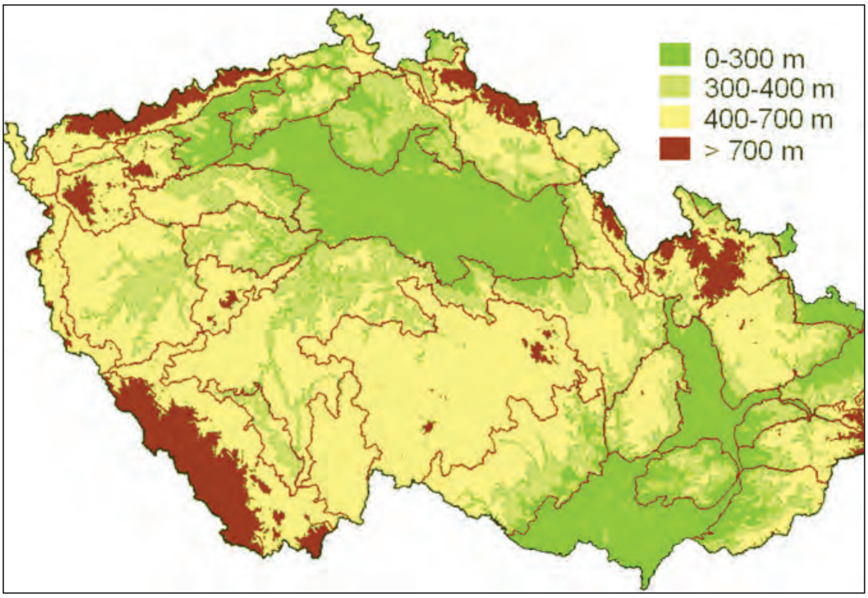

Figure 13b Elevation of the Czech Republic
Source: Information and data systems, 2021.

The management of protective forests in the Czech Republic has a long history. In particular, due to the poor state of mountain forests by the end of the nineteenth century, soil and water conservation measures were initiated by means of protective forests (Křeček, Palán and Stuchlík, 2019). Considering their environmental services (MEA, 2005), protective forests can maintain especially provisioning (drinking water supply), regulating (soil and water quality, flood mitigation) and supporting (biodiversity conservation) services. In the context of globalization, mountain forests face three, partly contradicting, challenges: to turn into "open museums" or areas for recreation and protected nature for industrialised societies; as regions to be economically exploited, or even over-exploited; and abandonment (Gløersen, Perlik and Price, 2004).

Protective forests: definition, functions and management

The management and policy of protective forests in Czech lands show a long history. In the Middle Ages, the forest protection strategy was along state borders and often concerned big game hunting. Later, environmentally sound choices played a role as well.

Protective forests on Czech territory are declared by the Forestry Act (289/1995, 90/2019 Coll.), differentiating the "protective forests" (sec. 7: forests on exceptional sites, like peatlands, extreme slopes, timberline areas), and the "special purpose forests" (sec. 8: forests with the priority of soil and water conservation, like hygienic zones for drinking water supply).

Areas of "protective forests" and "special purpose forests" comprise 533 square kilometres and 6 168 square kilometres, respectively. Thus, the total protective forests

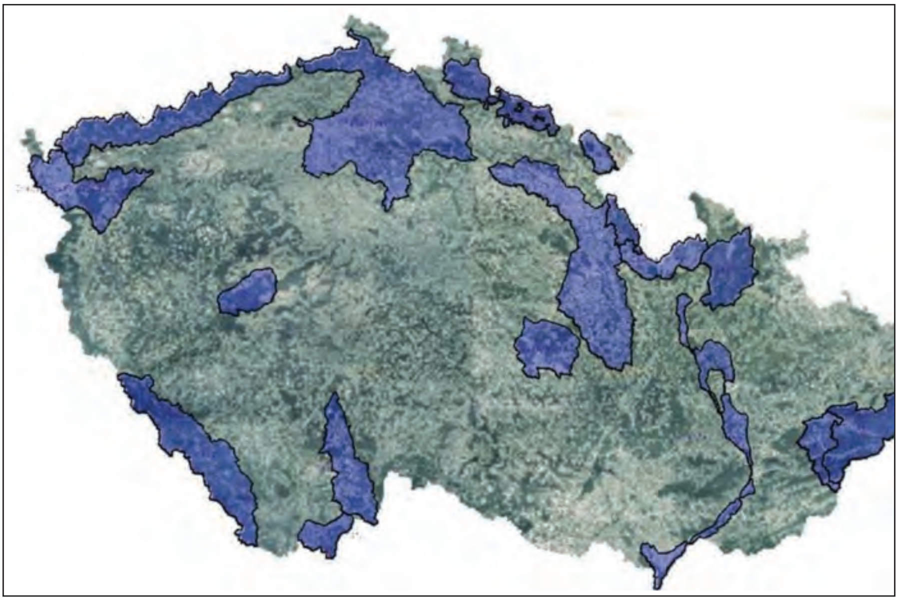

Figure 14 Protected headwater areas (blue) in the Czech Republic
Source: TGMWRI, 2021.

in the Czech Republic can be considered as 6 701 square kilometres, i.e. 25 percent of the national forests. This figure corresponds well with the statistics of FAO (2018) claiming that 25 percent of global forests should be managed with the priority of soil and water protection.

Similar requirements on the management of protective mountain forests have been formulated in the Water Act (138/1973, 40/1978, 254/2001 Coll.), that declares the important role of "Protected Headwater Areas" in water resource recharge and water quality protection. With a focus on mountain catchments, the total area of protected headwaters is 7 900 square kilometres (Figure 14).

In these areas, several limits for commercial forestry are prescribed, such as restrictions in forest area reduction, drainage of the soil, peat harvest and earthwork. Protective forests in the Czech Republic are located mainly in mountainous terrain, and their management is regulated by restrictions in clear-cut and drainage (sec. 36). Stands of Norway spruce (*Picea abies*) also dominate in protective forests, though the rotation period (130 against 110 years) and the timber reserve (416 against 227 cubic metres per hectare) are higher in protective forests.

Since the 1850s, ecosystems in Central Europe have deteriorated due to acid rain impacts, initiated namely by the airborne emissions of sulphur and nitrogen from several highly industrialized regions. After the Second World War, acid atmospheric deposition caused widespread damage to mountain catchments in the Czech Republic, particularly to spruce forests and surface waters (Křeček, Palán and Stuchlík, 2019). The situation culminated in the late 1980s and early 1990s. However, the first signs of recovery were observed in the 1990s, following the 1985 Helsinki Protocol on the Reduction of Sulphur Emissions or their Transboundary Fluxes. Sulphur loads decreased by approximately 60 percent. Nowadays, the stability of protective forests is threatened mainly by bark beetle calamities and adverse climate phenomena. In 2017–2018, with relatively extended dry periods and rapid insect development, salvage felling reached 4 cubic metres per hectare, while the impacts of abiotic factors such as wind, snow and frost were considerably lower. Current trends in sustainable forest management are based on the ecosystem approach and existing knowledge of forest typology and forest ecology (Vacek and Balcar, 2004).

Protective forest policy and governance

In early times, royal decrees had the aim of protecting the forested state border and big game hunting (Krečmer and Křeček, 1986). The first declarations by forestry in relation to soil and water protection (Acts 116/1884 and 117/1884 Coll.) were a response to the catastrophic floods witnessed in the former Austro-Hungarian Empire in the second half of the nineteenth century. More recently, protective forests in the Czech territory have been controlled by the Forestry Act (289/1995, 90/2019 Coll., sec. 7 - "protective forests" on extreme sites, and sec. 8 - "special purpose forests"), and the Water Act (138/1973, 40/1978, 254/2001 Coll. declaring "Protected Headwater Areas"). These protective forests are administrated by the Czech state, with the Ministry of the Environment and the Ministry of Agriculture responsible for the regulations; in particular, the planning procedure has to respect the important partial functions of protective forests. Protected headwater areas are administrated by five state watershed enterprises, which are managed by the Ministry of Agriculture. They are further controlled by the agencies on "Protected Landscape Areas" based on the Environment Protection Act (114/1992 Coll.) and directed by the Ministry of the Environment. As such, there is a high level of interaction and collaboration between these two administrative units (Křeček, Palán and Stuchlík, 2019).

The Forest Management Institute, operating as a service unit of the Ministry of Agriculture, launched an operating methodology on the protection of water resources by forestry in 2015. The state supports the stabilization of mountain watersheds with CZK 96 million per year, which corresponds to almost 25 percent of annual subsidies (CZK 390 million) in forestry. This support includes environment-friendly forestry technologies (CZK 36 million), torrent control (CZK 5 million), reforestation of forests damaged by air pollution (CZK 11 million), and aerial liming[8] (CZK 44 million). Some 20 percent (CZK 183 million) of the European Union Fund on Rural Development 2007–2013 (CZK 915 million per year) has been used in mountain catchments in the Czech Republic.

Climate change impacts

Mountainous regions in the Czech territory are defined by a temperate climate, and the categories Dfb (humid continental) and Dfc (sub-arctic) of the Köppen-Geiger climate

[8] The application of lime materials, such as calcium, to land and water areas to counter acidification.

classification (Peel, Finlayson and McMahon, 2007). Unfortunately, the climax mountain forest composition (Table 2) was transformed for commercial reasons to dominantly spruce plantations (78 percent) of a lower ecological stability, particularly during the nineteenth century. During the twentieth century, air temperatures increased on average by 1.2° C, and 0.45° C in the last 30 years (IPCC, 2015). The most intensive warming has been registered in the spring and summer due to the rising number of episodes with extremely high temperatures. The number of summer days has doubled, and tropical days have tripled. For the year 2030, the temperature rise forecasts range from 1.2 °C to 1.5 ° C. Estimations for precipitation changes are more complex, with a rising trend in winter and drier summers. The mean annual precipitation is expected to increase by about 4 percent, compared with the period 1961–1990 (CHMI, 2019). These changes are likely to affect the climate zonation of mountain forests. As a result, some 40 percent of the dominant spruce stands, including most of the protective forests, will be endangered.

Climate change, especially more frequent and longer droughts, can rapidly increase the intensity of insect calamities and the decline of forest health, including protective forests. Despite trends to increase the percentage of deciduous trees, spruce forests remain dominant with a relatively high risk of deterioration at protective sites. Risks associated with the loss of spruce forests include forest disruption, humus mineralization, soil erosion and storm runoff acceleration. Lastly, the long-term effects of acid atmospheric deposition represent an additional impairment factor.

Table 2 The climate zonation of mountain forests in the Czech Republic (Zlatník, 1976)

Dominant trees	Area (km2)	Elevation (m)	Ta (°C)	Pa (mm)	Growth period (days)
Fagus sylvatica and *Quercus* spp.	2 862	400–550	6.5–7.5	650–700	150–160
Fagus sylvatica	4 505	550–600	6.0–6.5	700–800	140–150
Fagus sylvatica and *Abies alba*	6 360	600–700	5.5–6.0	800–900	130–140
Fagus sylvatica and *Picea abies*	3 445	700–900	4.5–5.5	900–1 050	115–130
Picea abies and *Fagus sylvatica*	1 060	900–1 050	4.0–4.5	1 050–1 200	100–115
Picea abies	265	1 050–1 350	2.5–4.0	1 200–1 500	60–100
Pinus mugo	53	>1 350	<2.5	>1 500	<60

(Ta – mean annual temperature, Pa – mean annual precipitation)

Case study: Revitalization of protective forests in the Jizera Mountains

In the 1980s, the extreme acid atmospheric deposition led to the decline and clear-cut of spruce plantations in headwater catchments of the Jizera Mountains (Figure 15), and as a result *Junco effusi-Calamagrostietum villosae* became a new dominant community there (Křeček, Palán and Stuchlík, 2019).

In the 1990s, the open field load of sulphur already dropped to about 40 percent of

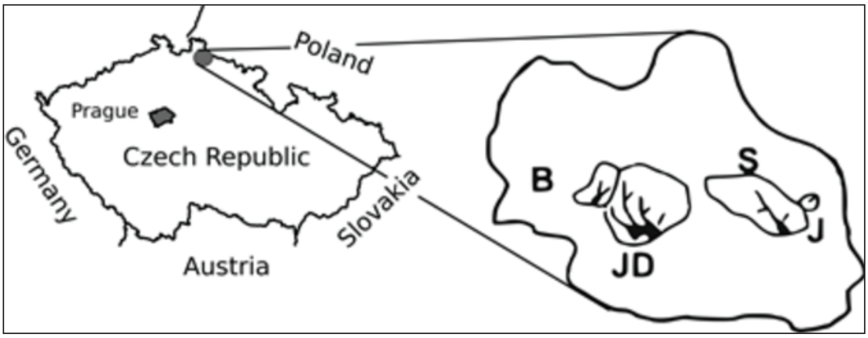

Figure 15 Investigated catchments in the Jizera Mountains
Source: Křeček, Palán and Stuchlík, 2019.

the mid-1980s level, thereby initiating the revitalization of mountain ecosystems. In the catchments studied, the ratio between the deposition of sulphur and nitrogen decreased from 2.7 to 0.35 (Figure 16).

However, the vegetative canopy furthermore controls the atmospheric deposition of sulphur and nitrogen. The harvest of spruce forests witnessed a drop in the acid load and a recovery of surface waters from acidification. The existing land use policy, protective forest management, particularly in zones of hygienic protection, and the protected headwater area were ineffective in this situation. On a catchment scale (Figure 17), the proposed scenario of structured forestry zones, respecting riparian buffers, stability of steep slopes, significant fog drip areas and peat spots, can decrease the annual load of sulphur and nitrogen by approximately 30 percent.

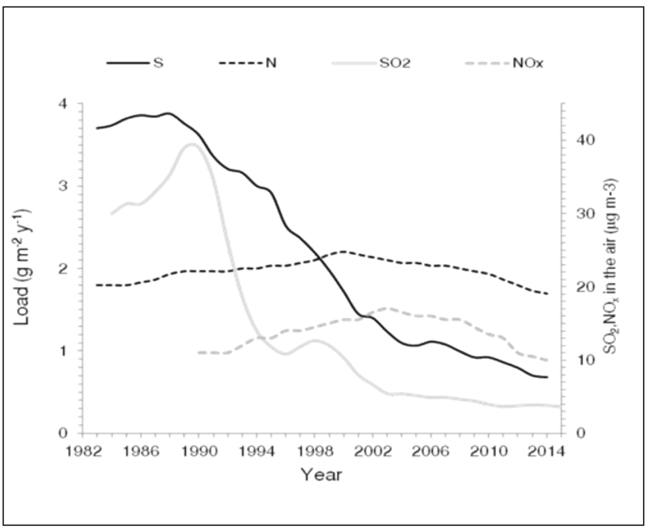

Figure 16 Open field loads of sulphur and inorganic nitrogen, and SO2 and NOX concentrations in the air (Jizerka, 1982–2015)
Source: Křeček, Palán and Stuchlík, 2019.

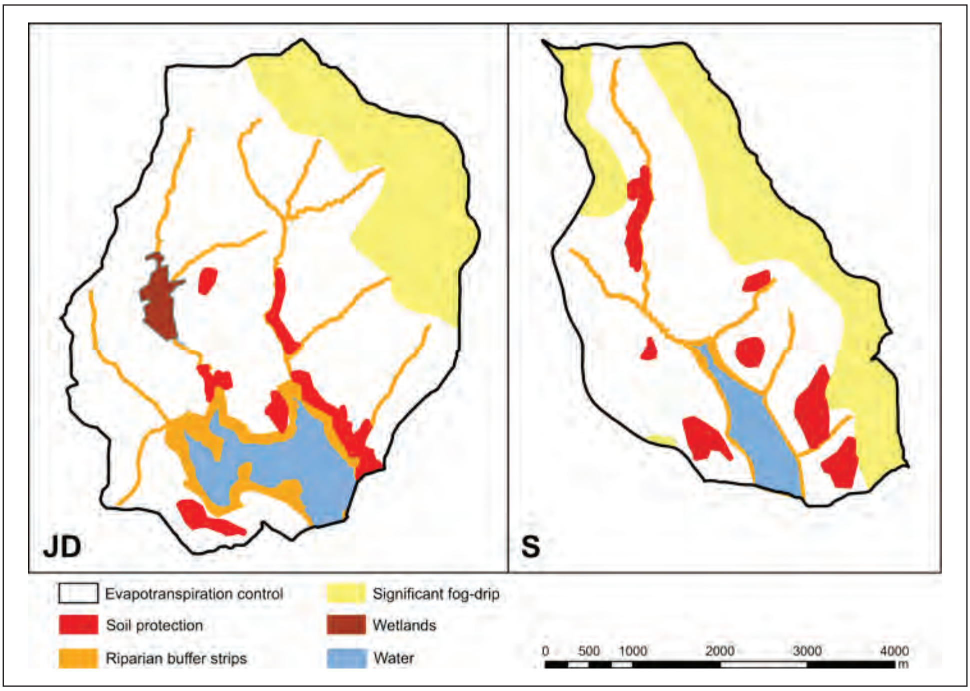

Figure 17 Structured protective forests in the Josefův Důl (JD) and Souš (S) watersheds
Source: Křeček, Palán and Stuchlík, 2019.

The positive changes in stream water chemistry of the investigated catchments and lakes were followed by a revival of fish. The acid-tolerant brook char (*Salvelinus fontinalis*) and the native brown trout (*Salmo trutta* m. *fario*) were reintroduced during the 1990s. In the 2000s, the population of brook char was surviving well with effective self-reproduction, while the brown trout starved. However, later, the population of native brown trout became dominant even at higher elevations, and the population of minnow (*Phoxinus phoxinus*), an endangered species in the Czech Republic, was successfully reintroduced.

Conclusions

The legal status of protective forests was established with a view to significantly reducing the hazard of water quality decline, drop in water resources recharge, acceleration of soil erosion and sedimentation, and decreasing stability of slopes within mountain catchments. Nevertheless, the legislative regulation in the management of protective forests remains rather conservative in terms of addressing solely the area of forest and drainage. The current governance does not sufficiently reflect new research outcomes on forest–water relations, forest resilience, ecological stability and sustainable development.

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FRANCE

Anaïs Denardou[1], Olivier Marco[2], Laurent Bélanger[2], Alison Evans[3], Anthony Dubois[1] and Simon Carladous[2]

[1] Office National des Forêts International (ONF International)

[2] Office National des Forêts – Département Risques Naturels (ONF-DRN)

[3] Office National des Forêts – Restauration des terrains en montagne (ONF–RTM)

General Information

In France, the protective forest can be understood in two different ways. On the one hand, the national directive on development and management of forests is a guideline that applies to all forests managed by the National Forests Office (ONF). It specifies that forests have several functions, including the protective function, which only applies to the management of natural hazards such as avalanches and erosion. On the other hand, some forests are officially regulated as "protective forests" by Article L141-1 of the French Forestry Code. This regulation is defined rather broadly because it includes forests that have a role in the control of natural hazards and/or an important ecological or social role, regardless of management. Forests that are classified under this regulation have strengthened rules of protection, but it concerns only a few forests and it is quite an exception to use this regulation for natural hazards management.

In the context of the European Forestry Commission's Working Party on the Management of Mountain Watersheds (WPMMW), we can consider that protective forests correspond to the first item, i.e. all forests with a protective function. Mountain forests, for instance, limit erosion, stabilize the snowpack and decrease the speed of rock falls. In France, practitioners and policymakers speak of protection only where forests mitigate and reduce a risk. Against this backdrop, a large part of mountain forests is included in the definition of protective forests.

French mountain forests are located at an elevation above 600 m and are either municipal or state forests or privately owned. The National Forest Inventory (NFI) further distinguishes two types of mountain forests, above and below an elevation of 1 200 m.

In France, the history of natural hazard prevention in mountains started in 1860. The major protective function of French mountain forests is to limit the soil erosion on slopes in order to protect infrastructure, such as roads and railways, that are vital to the development of mountain areas. The limitation of erosion has a second important benefit since it also limits the concentration of solid materials in torrents.

Mountain forests correspond to approximatively 27 percent of the total French forest area (i.e. 4.4 million hectares). Here, 11 percent are State forests (0.49 million hectares), 23 percent are public local municipality forests (1 million hectares) and 66 percent are private forests (2.9 million hectares). Among these forests, we can consider that 40 percent have a real protective function. Hence, it is possible to approximate that French protective forests have a total of 1.8 million hectares.

Protective functions

Protective forests have multiple protective functions (Sonnier, 1991). The three principal functions include:

- Limiting soil erosion and concentration of solid materials in torrents. Erosion is a natural phenomenon and it is important to limit its dangerous effects, i.e. loss of soil, transport of large solid materials in torrent floods, among others. Forests provide an optimal way to fix the soil and thereby reduce erosion. This was, at first, the reason for the creation of the policy of reforestation of mountain areas (RTM[9]) and still is a major function of protective forests.
- Prevention of avalanche detachment and reducing risk. Forests can prevent snow from moving by capturing the snow in their branches and stems. However, they are not able to stop an avalanche already in motion, only to potentially slow it by removing kinetic energy.
- Limiting or stopping rockfalls. Due to their stems and branches, trees can intercept rocks smaller than 1 cubic metre, decrease their speed or even stop them.

To prevent all these risks, different forest characteristics are necessary. A large stem density and basal area protect from rockfalls, evergreen species prevent avalanches and plant coverage reduces erosion.

Forest characteristics and risks

French mountain forests are mostly coniferous, covering 63 percent of the total wooded area. The most common coniferous species are fir (*Abies alba*), spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). Among hardwood species, beech (*Fagus sylvatica*) is the most common one.

Between 1860 and 1980, the policy of reforestation of mountain areas increased the forest area by around 200 000 hectares, mainly through a plantation policy, but also through measures banning grazing in critical places. This policy was developed to use forests in order to protect the population and critical infrastructure from natural hazards. The most planted species were Austrian pine (*Pinus nigra*) and larch (*Larix decidua*). Nowadays, because of climate change, French foresters prefer to replace Austrian pines with cedar (*Cedrus atlantica*), which is more tolerant to dry weather.

However, even though this plantation policy has been important, most of the mountain forests are naturally rejuvenated forests. In fact, in France, mountainous agricultural lands are largely abandoned, and spontaneous forests are steadily encroaching on the abandoned fields.

Moreover, as most of the previous plantations are even-aged forests, i.e. planted at a similar time, French protective forests are largely overaged and require rejuvenation.

[9] RTM = Restauration des Terrains de Montagne (Mountain Rehabilitation Programme).

At least 72 000 hectares of RTM stands are more than 100 years old, and they are either unmanaged or poorly managed. As such, they should be gradually replaced by uneven-aged forests that are more resilient and stable against natural hazards. The renewal of ageing stands figures in the objectives of the "Renewal of Protection Forest Stands Programme" (RPP) ordered by the Ministry of Agriculture and Forestry in 2007 (Vésino and Marco, 2014).

The average growing stand density in mountain forests is 20 percent higher than in the rest of French forests. The proportion of trees with a large diameter is more important for the protective function, especially in high elevation forests above 1 200 m, thus demonstrating the under-exploitation of forests in this area. Stands are not renewed, and the low stem density along with the age of the trees adversely affect the protective functions of these forests. If trees are too old, they display a limited resistance and resilience. In some cases of very old trees and forests planted in the past, the risk for downslope communities and infrastructure actually increases.

Natural hazards can influence forests. Two big storms devastated French forests in 1999 and 2009, but luckily, in each case, mountain forests were not highly impacted due to the geographic extent of the storms. However, another major and recurrent natural phenomenon that can impair these forests is fire. For the moment, forest fires mostly occur in the Mediterranean area and in the Atlantic western lowland regions. The Mediterranean part of the Southern Alps is therefore the first mountainous region already threatened. Nevertheless, forest fires have also been observed in the area of Grenoble in the Northern Alps. Due to climate change, this phenomenon is expected to become more frequent and to reach higher latitudes and elevations.

Lastly, wild game, mostly deer, has a negative impact on the regeneration of forest in the whole of France. This issue also affects protective forests and their species-rich regeneration and undermines renewing aging stands.

Management of protective forests

Private mountain forests are highly fragmented, and certainly more so than in the rest of the French territory. Indeed, most private forest areas are under 4 hectares, and in fact forests smaller than 25 hectares have no management obligations. Owners are responsible for the management of these forests, but frequently fragmentation makes it difficult. In addition, steep slopes and the lack of forest trails and roads increase the difficulty and contribute to the lack of management. Considering the management difficulties in private forests, we mostly focus on public forests in the report.

Management of public forests is based on a forest management plan in which the authority defines for one administrative unit the main function of the forests. The function can be, e.g. timber production, social reasons, biodiversity preservation or protection. As such, the management plan is the main guiding document for forest planning and strategy, with the methodological framework detailed in the forest management planning manual. The management rules applied to protective forests vary according to different parameters, from forest characteristics, location, level of protection and hazards resulting from non-intervention, to specific silvicultural operations.

A hazard control index (IMA in French for "Indice de Maîtrise d'Aléa"), created as a result of the RPP (renewal of protective stands) programme launched in 2005, is noted in the management plan. The index quantifies the protective role of forests on a scale from 0 (no efficiency of the vegetation in regard to the hazard) to 6 (maximal efficiency) and aims to determine the suitable silvicultural operations for maintaining the protective function of the forests (ONF, 2012). In fact, only 12 percent of RTM stands have been defined with a high protection potential (Vésino and Marco, 2014). Nevertheless, the determination of the hazard control index of these forests helps the manager to prioritize the logging and renewing operations.

The main challenges for the management of public protective forest are:

i. Financial. In public forests, financial support from the State for its forests or the municipalities for other public forests is key for enabling effective management. However, the state and the municipalities are often not willing to pay for those measures that may seem less urgent and visible than other priorities. Mountain forests are often difficult to manage, and wood production is limited by steep slopes. The management of these forests is expensive and less attractive, explaining that many stands remain unmanaged, with necessary operations postponed until they become unavoidable (Garet, 2015). The French National Forest Organization (ONF) receives around 600 000 euros per year for silvicultural measures on RTM-controlled forests to maintain their protective functions.
ii. To reconstruct an equilibrium of the life cycles in homogeneous forests.

Moreover, the damage caused by wild game remains a serious issue in French protective forests, as the impact of browsing is catastrophic for regeneration. Although damage caused by wild game is recorded in France, no specific monitoring has been set up specifically concerning protective forests.

Protective forest policy and governance

Since 1860, the prevention of natural hazards in mountains has been subject to territorial planning policies. "Mountain silviculture guides" (GSM), such as Gauquelin and Courbaud (2006) for the Northern Alps, and Ladier, Rey and Dreyfus (2012) for the Southern Alps, present the national strategy for mountain forests and good practices during timber marking, logging and other silvicultural operations. These guides have a specific part related to protective forests, classified according to natural hazard type and species. For each natural hazard and species or group of species, the technical guidelines describe the overall objectives, differentiate the situations – the location of the forest regarding the slope, its evolution, resistance to diseases and pests – and recommend adapted silvicultural interventions.

The State and municipalities are the most important actors in protective forest governance in France, and as such they decide whether to fund silvicultural works in protective forests. Subsequently, the ONF is in charge of implementation and management.

Even if forests overall protect human populations and infrastructure from natural hazards, in some cases negative aspects of forests in risk areas can be observed. These cases are scored with a negative hazard control index. For example, if the trees in an avalanche path do not resist the snow pressure, they can increase the risk by adding large solid elements to the snow flow. Moreover, trees or branches can create log jams in torrents and therefore create other hazards.

Communication about protective forests

ONF communicates a lot about forest biodiversity and the protection of forest species. However, little communication and effort have been put into raising public awareness about the role of protective forests. Therefore, the public is not truly aware of the protective functions of forests and their importance for the safety of human communities and infrastructure.

Protective forests and agriculture

For centuries, mountain agriculture has had a negative impact on forests. The population increase and the rise in demand for wood led to large-scale deforestation and overexploitation of forests at the end of the nineteenth century. Afterwards, with the rural exodus and the industrial revolution, agricultural lands gradually became abandoned during the twentieth century. At the same time, the protective function of forests was underlined, and reforestation policies were implemented. Nowadays, mountain areas have the lowest proportion of agricultural land in France, with only 26 percent in the Alps. In fact, agriculture has a low influence on mountain forests, especially on protective forests.

Recently, the role of pastoralism on biodiversity and tourism has been restated, with some efforts being made to foster silvo-pastoralism in mountain forests.

Protective forests, tourism and ecology

The Alps and Pyrenees host important touristic activity. Recreational activities and tourism do not directly affect protective forests significantly, even though they increase the spaces and objects that require protection. Some societal conflicts exist around protective forests. Most of them are linked to skiing in resorts and Nordic and backcountry skiing elsewhere. Ski resorts can also sometimes deforest areas to create new ski slopes. In these cases, compensatory measures have to be taken, though these situations are very limited.

Forest management also accounts for landscape issues. A varied topography gives multiple viewpoints and silvicultural operations are much more visible to the local public and tourists in mountain areas than in lowlands.

All forests provide ecosystem services. Mountain forests are particularly rich in terms of natural heritage and most protected forests are mountain forests (Dubois, Marco and Evans, 2017). Furthermore, most national parks, regional nature parks and reserves lie in mountainous areas. As such, protective forests have a large ecological importance because of their limited wood production and low accessibility.

Protective forests and research

In France, several institutions conduct specific research on the protective function of forests, mostly funded by the Ministry of Ecology, Sustainable Development and Energy. Some examples:

- The studies by INRAE[10] help to understand the impacts of rockfalls on trees and the protective functions of forests.
- The research department of ONF has conducted research projects about protective forests and their role in the reduction of risks regarding natural hazards.

Changing Climate

Climate change is having manifold major impacts on ecosystems and forests, notably temperatures increasing considerably, precipitation changes and decreases in summer rainfall, leading to more frequent and intense droughts. Moreover, the frequency of natural disasters such as storms and wildfires will rise.

First, for instance, climate change affects the vitality of certain mountain tree species that are not adapted to dry weather. Austrian pines (*Pinus nigra*), for example, are no longer in their maximal bioclimatic conditions, and require replacing by more drought-tolerant species such as cedar (*Cedrus atlantica*).

Second, forest fires are becoming more frequent with climate change and can occur at higher latitudes and elevations. Mountain areas have already faced wildfires in recent years, and their frequency is expected to increase with time. As such, forest fires will certainly be the most problematic cause of damage induced by climate change on protective forests.

Finally, storms with wind velocities higher than 100 kilometres per hour can also have catastrophic impacts on forests with windfall or broken branches, thus decreasing the density of the stands.

On the other hand, climate change increases the elevation of the tree line. Therefore, forests will be able to retain the soil and the snow of new areas and their protective effect will increase.

A national roadmap on forest adaptation to climate change is currently being developed and scenarios are being built by scientists to assist foresters in their decisions.

Regarding the range of all the different natural hazards, the silvicultural options are not identical. In the case of windfall, the recommendation is first to look at regeneration and see whether young trees regenerate naturally. For forest fires, measures are being taken to protect the forests, in order to decrease the speed of fire propagation and decrease the intervention time of fire brigades.

Good practice and additional information

During the Interreg project IV 2007–2011, systematic mapping of forests with a protective function was carried out in the urban area of Grenoble in the Northern Alps, using the hazard control index. The resulting map (Figure 18) shows the efficiency of the forest concerning rockfall and avalanche hazards. This case study is quite representative of the role of protective forests in the high elevation mountains of the Alps and Pyrenees.

[10] INRAE: The French National Research Institute for Agriculture, Food and Environment.

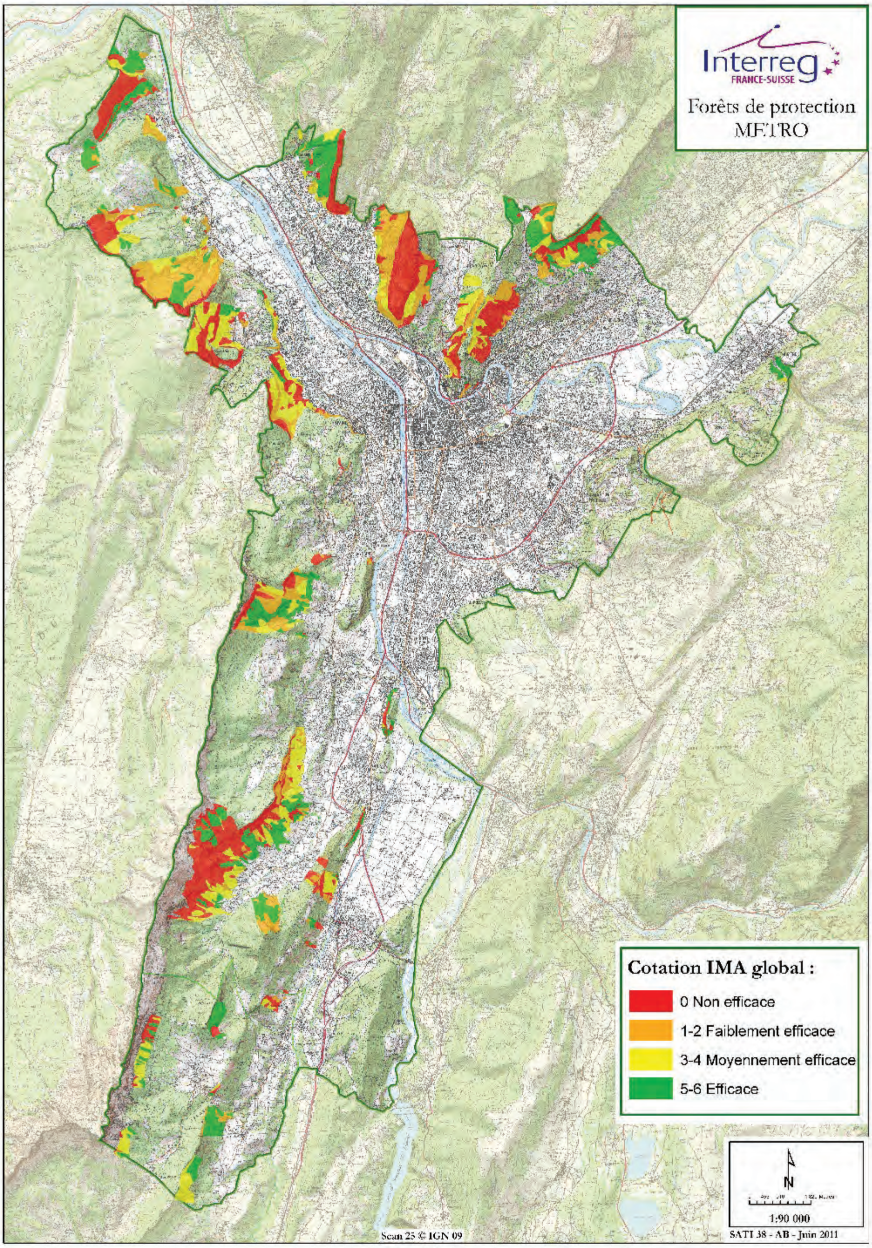

Figure 18 Map identifying and quantifying the protective functional effectiveness of the forests in the limits of the urban area of Grenoble

Red = 0: no effectiveness; Orange = 1–2: low functional effectiveness; Yellow = 3–4: moderate functional effectiveness; Green = 5–6: high functional effectiveness

Source: Interreg IV France-Suisse Forêts à fonction de protection, 2011.

Example of a French protective forest

In the last 10 years, a series of "hazard zone maps", covering municipalities in the French Alps, have highlighted the protective functions of the forests (Liévois, Evans and Dubois, 2016).

The municipality of Veyrier-du-Lac is located on the eastern shore of Lake Annecy in the Northern French Alps, where 4-km-long limestone cliffs overlooking the settlements frequently trigger rockfalls (Figure 19). In 2010, the risk plan was reviewed, and a new methodology was employed to assess the rockfall hazard using a 3D rock fall simulation model (Berger *et al.*, 2009). Two hazard maps for rockfall were established, taking account of the protective role of forests or not (Figure 19). The results highlighted the forests with an obvious function against rock propagation, and thus rockfall release.

Those identified forests are components of the natural environment and their protective function is highlighted. Therefore, these forests must be subject to appropriate silvicultural measures, such as described in the French mountain silviculture guides (GSM) (Gauquelin and Courbaud, 2006; Ladier, Rey and Dreyfus, 2012). This is emphasized in the risk plan, and concerns the "green zones" (Figure 20).

Figure 19 Limestone cliffs and forests with a protective function above the settlements of Veyrier-du-Lac (Haute-Savoie, France)

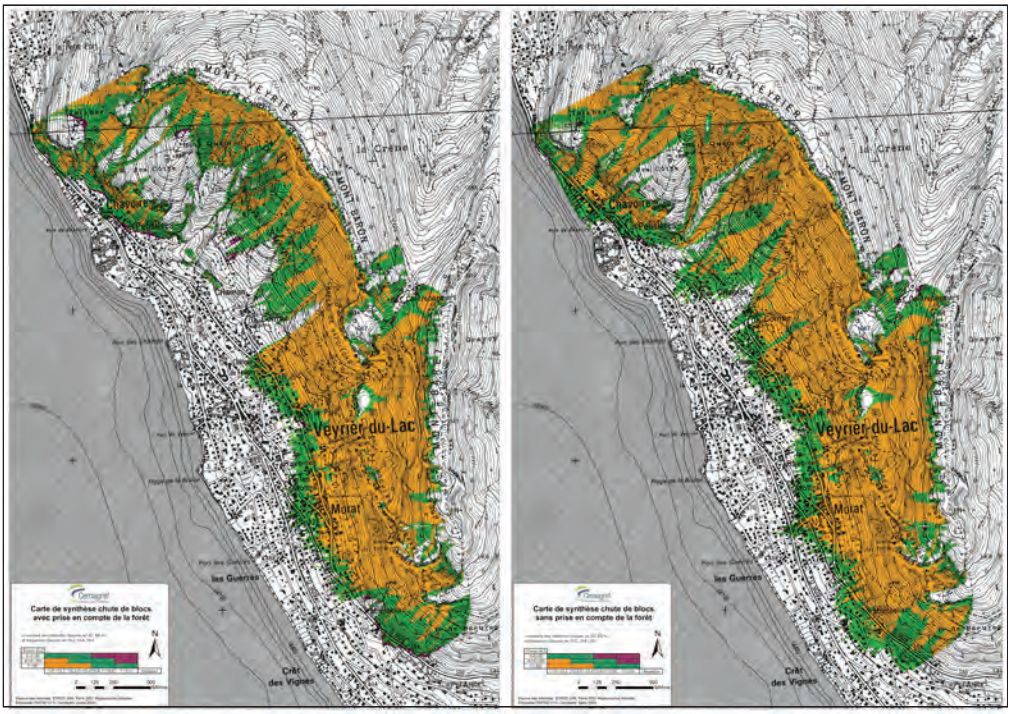

Figure 20 Rockfall hazard maps considering the protective role of forests (left), and without any protection (right)

They are based on trajectories in 3 dimensions of falling rocks and risks, and assist the risk prevention plan (PPR) revision for the municipality of Veyrier-du-Lac.

Explanation of map legend: risk (danger) level of rock fall processes, as a function of frequency [-] (classes: PA < 10-6; 10-6 < PA < 10-4; 10-4 < PA < 10-2; PA > 10-2) and energy [kJ] (classes: E < 30; 30 < E < 300; E > 300), with purple = low, green = medium, yellow = high.

Source: Berger *et al.*, 2009.

The resulting risk prevention plan (PPR) has taken into account the rockfall hazard maps considering the protective role of forests (Figure 20). In Figure 21, the forests with a protective function show up as "green zones", where specific silvicultural measures are prescribed, while the low risk zones (light blue) are identified with regard to the forests above.

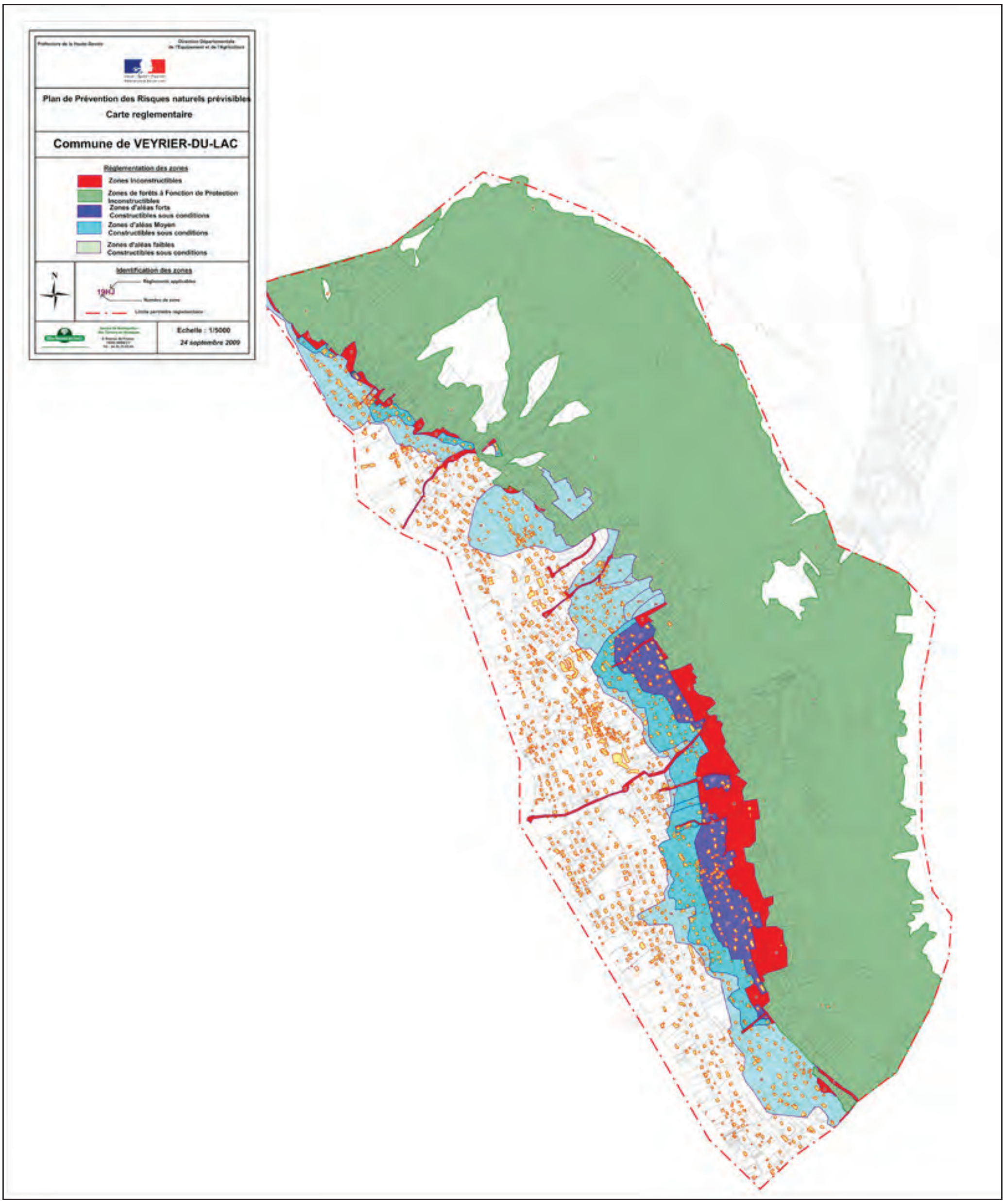

Figure 21 Resulting risk prevention plan (PPR)[11]

Red: no new buildings are allowed; Green: forests with a protective function (no building); Blue: high level of hazards – no new buildings allowed, or adaptation of existing buildings required; Light blue: moderate level of hazards – buildings permitted with adaptations; Pale green: low level of hazards – buildings allowed with adaptations.

Source: Prefecture Haute-Savoie, 2009.

[11] PPR: Risk prevention plan (plan de prévention des risques naturels).

Conclusions

As seen above, mountain forests, which provide protective functions against natural phenomena, have played an important role in the prevention of natural risks in France since the nineteenth century. It is now a question of ensuring the maintenance of these protective functions in the context of climate change. These concerns include the new dynamics of natural hazards to which forests will be exposed, the adaptation to climate change of the stands themselves and their management, and the evolution of the protective functions provided by forests. Besides the risks already considered (i.e. linked to soil and torrential erosion, avalanche initiation, falling boulders, among others), the possibility of new risks developing needs to be taken into account, such as those linked to fire or glacial hazards.

These issues have been clearly identified in France and studies are being conducted at different technical and political levels, such as in the framework of a roadmap project on the adaptation of forest management to climate change carried out by actors in the forest-wood sector at the request of the Minister of Agriculture and Agrifood.

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GERMANY – BAVARIA[12]

Luise Nadler[1], Richard Heitz[2] and Stefan Tretter[2]

[1]Bavarian State Ministry for Food, Agriculture and Forestry

[2]Bavarian State Institute of Forestry

Protective functions of forests in mountain watersheds

The legal definition of "protective forest" in Bavaria is according to Art. 10 Abs. 1 BayWaldG (Bavarian Forest Law) as follows:

Protective forest is forest:

- At higher altitude and on ridges of low mountain ranges and the Alps;
- On sites with risk of karstification[13] or erosion; and
- Which prevents avalanches, rock falls, landslides, floods and soil drift, and protects riverbanks.

Hence, the protective functions of forests in the Bavarian Alps include:

- soil protection and protection from erosion – 40 percent of forest cover;
- protection from avalanches – 40 percent of forest cover;
- protection of water catchments – 11 percent of forest cover; and
- other water protection functions – 35 percent of forest cover.

Where forests extend on rocky and shallow slopes just above infrastructure, such as roads and settlements, direct protection is very important from rock falls and avalanches by maintaining a dense forest structure.

Concerning mountain watersheds, protective forests in the Bavarian Alps fulfil similar functions as in other countries in the Alpine region. Protective forests delay and even reduce water runoff, purify water and balance the overall water regime. Trees lower the amount of precipitation reaching the ground by interception and stabilize soils by root penetration. Moreover, the remaining precipitation percolates into the humus and permeable forest soil, which stores and releases water with a delay. One square metre of mixed mountain forest ground can store up to 145 litres of water. Furthermore, within the forest, snow melts more slowly, thus stretching the period for meltwater runoff in spring, which helps to reduce flood peaks.

Protective forests in the Alpine region of Bavaria cover 147 000 hectares, which equals 56 percent of the total mountain forest area (Figure 22).

The overall tree composition of mountain and protective forests is spruce (*Picea* spp.) 58 percent, silver fir (*Abies alba*) 7 percent, Scots pine (*Pinus sylvestris*) 2 percent, larch (*Larix* spp.) 1 percent and, beech (*Fagus sylvatica*) 19 percent, while other deciduous trees comprise 13 percent. The average timber stock of mountain forest in the Bavarian Alps is 420 solid cubic metres[14] per hectare, which is 6 percent above the state average. With

[12] Note: all details in the text refer only to the forest area in the Bavarian Alps.

[13] Karstification is the process of calcite dissolution via the infiltration of water including CO2 from the atmosphere and soil.

[14] Solid timber is timber cut directly from the tree in length form. Due to its natural state, it still contains the knots and imperfections that you would expect.

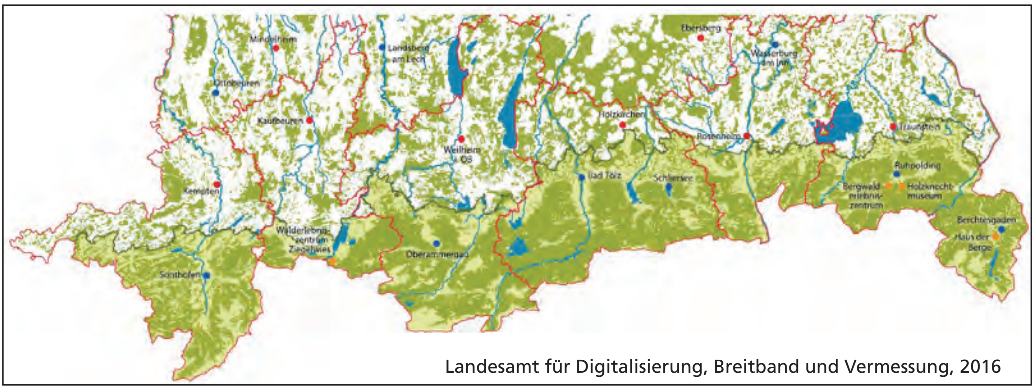

Figure 22 Total forest cover of Bavaria's Alpine region

Light green: growth area of the Bavarian Alps; Olive green: forest cover; Blue: lakes and rivers. (Legend refers to the southern part of the map, within the limits of the Alpine region)

Source: LDBV, 2016.

an average age of 100 years, these forests are 17 years older than forests in the rest of Bavaria (Third National Forestry Inventory, 2012).

Challenges and risks for protective forest

The major threats and dangers for the stability and resilience of protective forests are:

- lack of natural regeneration – especially of silver fir (*Abies alba*), yew (*Taxus baccata*) and broad-leaved trees due to difficult site conditions, game browsing and/or cattle grazing;
- climate change;
- natural disasters such as storms, bark beetle infestations and (with less significance) forest fires (Figure 23);
- snow gliding[15]; and
- loss of humus.

Major challenges managing these forests include:

- converting pure coniferous forests into mixed, uneven-aged forests with sufficient regeneration;
- motivating and assisting forest owners to manage their forests regardless of a possible negative contribution margin.[16] Managing mountain forests is oftentimes not profitable;
- balancing the interests and requirements of stakeholders, for example, foresters, conservationists, recreation seekers and hunters in mountain forests; and
- raising public awareness of the condition and essential functions of protective forests in Bavaria.

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[15] Snow gliding is a downhill motion of snow on the ground; can affect afforestation (uprooting of plants) and cause soil erosion. Once the glide motion turns into an avalanche movement, the process is called a glide avalanche.

[16] Contribution margin is a product's price minus all associated variable costs, resulting in the incremental profit earned for each unit sold.

Figure 23 Storms are severe threats to protective forests, as shown by the impact of the winter storm Kyrill (18–19 January 2007) on the western slopes of "Untersbergplateau" in Berchtesgaden

The state intends to approach these challenges with different initiatives, namely:

- state support programmes to promote climate-adapted forest conversion in general;
- elevated funding rates, such as for thinning, tree planting, bark beetle control and improving forest access in order to assist forest owners in managing their protective and mountain forests;
- participatory approaches and joint coordination processes with stakeholders, for example, in the context of the state programme on mountain forests (BWO)[17] (see below) to tackle conflicts of interest; and
- reinforcing public relations work and connecting with local communities and policymakers through a participatory approach.

Grazing of livestock (cattle, sheep, goats and horses) is still practised today in mountain and protective forests, although the forest grazing area has been significantly reduced by 70 000 hectares since 1958. The hotspots of traditional forest pasture remain in the Alpine regions in Upper Bavaria. As such, 50 000 hectares of mountain and protective

[17] German: Bergwaldoffensive.

forests are still encumbered with pasturing rights today, though the rights are only exercised actively on one half of the area. Sometimes illegal local grazing may occur, but it is negligible.

As mentioned, pasture use of protective forests can damage forest rejuvenation comparably to game browsing. Indeed, trampling can lead to the deterioration of fragile site conditions and result in local soil compaction.

Bavaria has a special law dealing with forest rights and obligations. The law contains common rules for forest pasture and gathering firewood. Furthermore, there is a special commission on grazing rights[18] for balancing the competing interests and handling the issues of forest pasture rights. Nevertheless, segregation processes are difficult, time-consuming and sometimes not successful due to complex points of departure and the involvement of numerous stakeholders. However, on the local scale, agreements can be made to temporarily segregate agricultural use from regenerating forests by simply using fences in order to help re-establish a functional protective forest.

Lastly, the Bavarian Alps are a touristic region of high importance. Recreational and touristic interests include, for example, an unspoilt environment and landscape, well-maintained hiking and mountain bike trails, hotels, diversified ski slopes and other winter sports activities and access to regional products. As a result, in certain cases these demands can lead to conflicts with land users and protective forest management.

Policy and governance

Bavaria has no general state strategy for protective forests. However, there exists a programme to restore protective forests[19] that can no longer fulfil their primary protective functions. This programme has existed for over 30 years and currently covers 10 percent of the Alpine protective forest area of Bavaria (around 14 000 hectares). In addition, the programme provides expert knowledge and financial and personal support to forest owners for the restoration of protective forests. Another programme aims at adapting private and municipal forests in the Alpine region to climate change, which is the state programme on mountain forests (BWO)[20] and uses a participatory approach to overcome challenges.

The Bavarian Forest Law provides a framework for managing protective forests, but there is no specific legislation. A legal definition of protective forests is given in Art. 10 BayWaldG. To prevent the clearing and conversion of protective forests, stringent legal restrictions (Art. 9 BayWaldG) are in place. Likewise, protective forest management aims to maintain the protective functions of the forest (Art. 14 BayWaldG). Indeed, protective forests fitting this legal definition are listed in an official protective forest register.

Public awareness for protective forests is high only in local communities that benefit directly from the protective functions. Unfortunately, most of the general public shows little interest in the wide range of forest functions and even major protective functions of forests. Therefore, the Bavarian forest administration aims to spread information about protective forests by public print media and internet platforms. In the case of special events, press releases are used to give detailed information on the local level.

[18] German: Weiderechtskommission.

[19] German: Schutzwaldsanierungsprogramm.

[20] German: Bergwaldoffensive.

The most important actors are the Bavarian Forest Administration and the Bavarian State Forest Enterprise (BaySF). Three special offices of protective forest management[21] provide on-site support in the framework of the Bavarian protective forest restoration programme. When natural hazards affect infrastructure and settlements, the State Construction Office and local water management offices are involved. Other important actors in protective forest governance include NGOs, i.e. in nature protection, regional authorities and local policymakers. Municipalities bear a small role in governance for protective forests because they only own and manage a small proportion of forests in the Alpine region.

There exist different forms of cooperation, dialogues, networks or participatory processes dealing with protective forests, mostly established in connection with the programme on mountain forests (BWO), and these take place on both regional and local levels (Figure 24).

Figure 24 Stakeholder meeting as part of the participatory state programme on mountain forests (BWO)

[21] German: Fachstellen Schutzwaldmanagement.

Management of protective forests

In Bavaria, private and municipal owners receive financial and personal support from the State, especially for thinning and afforestation. Even public forests can get subsidies for special measures such as the restoration of devastated protective forests.

The impact of game on protective forest stands can differ among regions and types of forest ownership. As such, intensive browsing by hoofed game (red deer, roe deer, chamois) can lead to a lack of natural regeneration or the loss of certain tree species during natural regeneration at the local level in some parts of the Bavarian Alps.

There is an official survey monitoring the impact of game browsing on forest regeneration all over Bavaria organized by the Bavarian Forest Administration every three years. The results are used as a basis for determining administrative shooting plans for hoofed game. In areas covered by the protective forest restoration programme, more intensive monitoring of browsing activity takes place, concentrating on planned and executed measures.

The Bavarian State Institute of Forestry (LWF) developed as of 2020 specific thematic digital maps for protective forests, including risk management tools. They are not available for general administrative uses as yet. However, local geo datasets used for planning and management exist for protective forest areas in need of restoration at the special offices of protective forest management.

The general condition and vitality of protective forests are monitored every ten years by the National Forest Inventory and the annual German report on forest condition[22] (StMELF, 2019). There is also a universal forest information system, which originated from the European project WINALP (Reger and Ewald, 2012), that combines site conditions and expected forest types, and thus forms an important basis for protective forest management.

Areas included in the restoration programme for protective forests are examined more closely by a variety of planning and monitoring systems. Every ten years, each restoration area is assessed regarding site and forest conditions, regeneration and measures necessary for improving or restoring protective forests. Furthermore, both temporary and permanent data collection monitors the success of management measures every three years, especially concerning forest rejuvenation. One year after planting in restoration areas, browsing activity is documented as well using standardized monitoring methods.

In contrast, the project-based state programme on mountain forests (BWO) only assesses the protective forest condition within a certain project area for planning suitable management measures.

Negative effects of forests for water management have hardly been observed, though in a few cases driftwood can cause problems for river management. Therefore, trees on riverbanks in risk areas sometimes have to be removed. Moreover, trees may break and get carried towards infrastructure in the course of avalanche detachment. However, only a few occurrences are known where this has led to safety problems or road blocking. In individual cases, single trees may collapse under snow pressure and have to be removed from permanent avalanche barriers in order to maintain the forest function.

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[22] German: Waldzustandserhebung.

Protective forests are usually continuous, hardly disturbed areas with natural structures and various types of habitat, hosting a range of specified, rare and protected species, which are native to mountain forests and the Alpine environment. Examples of such species include the capercaillie (*Tetrao urogallus)*, the lady's slipper orchid (*Cypripedium calceolus*) and Rosalia longicorn beetle (*Rosalia alpina*). Due to small structured site conditions, even thermophilous[23] open-country species can colonize naturally thinned forests. Therefore, protective forests are crucial for nature conservation in the Alps. In addition, protective forests fulfil a variety of other ecosystem services such as humus conservation and water and carbon storage.

Usually, regional nature conservation authorities provide statements regarding the management of protective forests, while NGOs are only involved in special cases. There are coordination meetings to discuss competing interests and, depending on the region and the planned measure, the following assertions may be heard:

- Always select tree species for planting in accordance with the potential natural vegetation;
- Minimize the reforestation of clearings, thinned forests and avalanche stretches to a necessary amount, meaning only in those forests with direct property protective functions;
- Reinforce grazing or browsing in protective forests in order to widen habitats for open-landscape species and promote small structure habitats. Therefore, measures which can potentially compromise conservationists' interests need to be discussed and checked thoroughly in advance.

There exists no universal planning instrument for all types of forest ownership. The Bavarian State Institute of Forestry (LWF) is developing a general planning tool for protective forests and risk management. Common management plans exist for state and municipal protective forests. For areas in the protective forest restoration programme, there is a multilevel planning process with planning every ten years, planning of measures every couple of years and a detailed annual plan. In addition, programme project areas on mountain forests (BWO) each have separate management plans.

Climate Change

The adaptation of vulnerable protective forests to climate change is promoted by the aforementioned project-based programme on mountain forests (BWO).

Scenarios for the loss of protective forest cover only exist in local simulations by the State Construction Office and water management offices, when the construction of protection fences and avalanche barriers is planned. Scenarios in case of severe climate change do not exist yet.

The Bavarian State Institute of Forestry (LWF) coordinates research on protective forests. Different institutions fund research projects, including the EU, the federal or State government and, more rarely, private sources.

[23] Adapted for life at warm places.

Best practice

There exist many local examples, especially in the context of the protective forest restoration programme, where maintaining and managing protective forests has improved the safety of communities by mitigating rock fall and avalanches. Two of the most successful and widely-known project areas are called “Weißwand,” just above the main road B305 between Schneizlreuth and Ramsau (Berchtesgaden) and “Hagenberg” above the “Spitzingseestrasse,” near the town of Schliersee (Figure 25 and Figure 26). Several avalanche corridors have been reforested by using a combination of constructive and biological measures, such as avalanche barriers, rock fall protection nets, planting and forest thinning to provide continuous protection against avalanches and rock falls for road users.

Figure 25 On forest sites at "Hagenberg" degraded in 1987 (left), a new protective forest regeneration programme has been successfully established to protect the main road underneath (right) (Figure 26)

After several floods damaged large parts of Garmisch-Partenkirchen in the 1990s and early 2000s, protective forests were restored within the mountain catchment above the town called “Kankerbach,” using mainly mountain pine (*Pinus mugo*) and Scots pine (*P. sylvestris*) to stop erosion and regulate water flow and runoff (Figure 27). Together with constructive measures from Bavaria’s most extensive torrent control project, the reforestation has helped minimize the risk of flooding (StMUV 2015a, 2015b).

Figure 27 New generation of protective forests in the water catchment area of "Kankerbach"

Conclusions

Although the protective functions of forests only have considerable importance in the Alpine (southern) part of Bavaria, major state programmes – such as the programme on mountain forests (BWO) or the protective forest restoration programme – show the awareness of government in this policy area. In spite of the obvious success of these programmes in protective forest management, even more efforts need to be taken to raise public awareness and increase the resilience of mountain forests to the effects of climate change.

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GREECE

Vereniki Louka[1] and Ioanna Masklavanou[1]

[1] Ministry of Environment and Energy, Directorate General for Forests and Forest Environment

General information

Greece is mainly a mountainous country, with a total vegetation cover of 64 percent, of which 25.4 percent is covered by forests, 25 percent by forest lands and 13.6 percent by pastures and other areas, making it the fourth most forested European country.

Characteristic of the Greek flora is the widespread occurrence of evergreen and hard-leaved plants such as the kermes oak (*Quercus coccifera*), terebinth (*Pistacia terebinthus*), *Arbutus* spp., wild olive (*Olea europaea*), among others, including many aromatic species of bulbous plants and therophytes.[24] Furthermore, at higher altitudes many areas are dominated by oaks, beech (*Fagus sylvatica*), firs (*Abies cephalonica*, *Abies borisii-regis*), pines (*Pinus halepensis*, *Pinus brutia*, *Pinus nigra*), sweet chestnut (*Castanea sativa*) or plane trees (*Platanus orientalis*).

Protective forests play a critical role as part of Greek ecosystems, considering that Greece is characterized by great morphological diversity, with various towns and villages spread among its forests (Figure 28 and Figure 29). This is the reason why an official definition was specified as early as 1969.

According to Greek legislation (Legislative Decree 86/10-01-1969), protective forests and land in general, whether cultivated or not, whose non-management is subject to special restrictions for the sake of public interest, are:

a) *forests on steep slopes, forest lands and pastures that protect their own soil;*
b) *forests intended for the protection of the soil and against landslides, extreme precipitation and rockfalls (i.e. including protection against the entrainment[25] of soil on the hillsides and slopes), as well as those forming the upper zone of forest vegetation on the hillsides;*
c) *forests used for the protection of soil against floods, torrents and rivers, as well as those used for protecting beaches against coastal erosion; forest stands along seashore sections, river banks and torrents are qualified to be so called;*
d) *forests for the protection of water springs, streams, roads, railways and inhabited areas, as well as landscapes of historical value, foundations or monuments of ancient or contemporary art; and*
e) *suburban forests, forest lands and other areas that can be reforested.*

Forests and land referred to in (a), (b), (c) and (e) are designated as protective, and those referred to in (d) as fully protective.

[24] Therophytes are annual plants that complete their life cycle in a short period when conditions are favourable and survive harsh conditions as seeds. They are typically found in deserts and other arid regions.

[25] Entrainment – the lifting and transporting (of soil grains) by the flow of a fluid or the wind.

Figure 28 Greece is a mostly mountainous country, where all forests fulfil protective functions. Black pine (*Pinus nigra*) afforestation in Arta region, Western Greece, for landslide prevention

Figure 29 Forests protect inhabited areas from natural hazards such as torrents, for example, using protective fir forest (*Abies borisii-regis*) in Trikala region, central Greece

Table 4 Protective functions of forests in mountain watersheds

Forest and other wooded land	Proportion of forest and other wooded land managed primarily for soil and water protection	Percent (%)
6 513 000 hectares	6 513 000 hectares	100

Source: Dr G. Nakos, Section of Forest Ecology, IMFE & FPT (NAGREF)

According to the categories mentioned, it is clear that some of the most significant protective functions of Greek forests are the protection against erosion and winds and their hydrological, climatic and hygienic effects.

Table 4 illustrates that the forest and other wooded lands are managed primarily for soil protection. It is important to note that soil protection is taken seriously into consideration in timber management of forest and other wooded land, due to the mountainous terrain in Greece (Nakos, 1983).

It is considered that 100 percent of forest and other wooded lands have soil protection as a main function, because the forest and other wooded lands, including those not under management, are exclusively on sloping terrain, thereby protecting against gravitational and wind erosion (Figure 30).

Furthermore, the mountainous character of the country, the geological and the climatic conditions combined with human influences, favour erosion and torrential phenomena. Thus, the forests in Greece, which occupy mainly the semi-mountainous

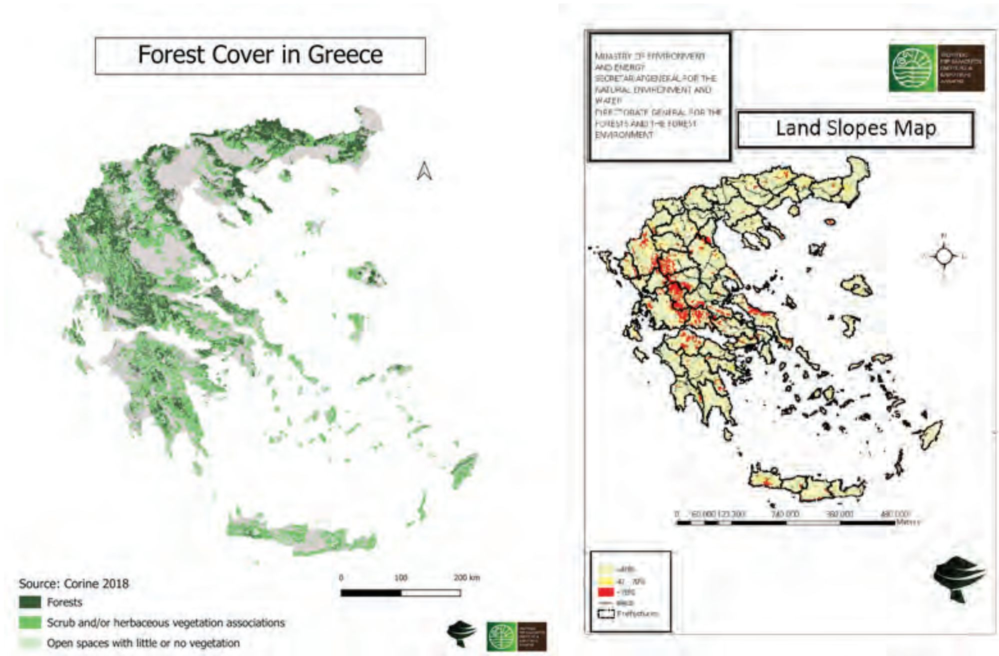


Figure 30 Forest cover and land slopes in Greece
Source: Ministry of Environment and Energy, 2018.

and mountainous areas, reduce the extent and intensity of these phenomena through their protective functions. In addition, forests enhance the storage of large quantities of water, which satisfy the needs of settlements, agriculture, livestock and industry. Consequently, soil protection and supporting the hydrological functions of Greek forests are the foremost priorities for their management (Albanis, Galanos and Boskos, 2000).

Management of protective forests

Soil erosion in Greece is extensive and, combined with the destructive potential of torrents, constitutes one of the most serious environmental problems of the Greek countryside. The extent and intensity of erosion are directly connected with the mountainous character, geological conditions, soil types, climate characteristics and principally with the history of the country concerning land use for millennia. The long intensive and negative human influences on the country's natural resources, combined with repeated forest fires, overgrazing, uncontrolled cutting, forest clearing and cultivation of sloping terrains without protection measurements, have resulted in the erosion of between a third and a half of Greece's agricultural and forest soils (Baloutsos, 1993). Thus, protection against soil erosion, natural hazards and afforestation of protective forests requires high financial investments.

Another major challenge for protective forests in Greece is the lack of proper management due to the reduction of funds for the necessary management studies. It has always been difficult to issue funds for scientific purposes, not to mention the increasing financial difficulties that have arisen due to the recent economic crisis.

The after-effects of all these issues are that forest fires cannot be easily controlled (Figure 31) and that pathogens are spreading rapidly, many of which are destructive to the ecosystem as they wipe out certain species. For example, the fungus *Ceratocystis platani* appeared in 2003 and since then has caused severe damage to the plane (*Platanus orientalis*) forests in north, western and central Greece. Additionally, the endemic palm (*Phoenix theophrasti*) forest of Vai, in eastern Crete (Figure 32), faces a major threat due to the red palm weevil (*Rhynchophorus ferrugineus*) intrusion on the island.

Finally, another challenge is illegal logging. Especially in mountainous areas, uncontrolled cutting is more intensive, especially during the economic crisis, as the increased need for heating led to a peak of illegal logging between 2012 and 2016. In order to overcome some of these challenges, several measures have been taken. Indeed, Greek law has always been quite strict when it comes to forest protection.

In mountainous areas, erosion control is achieved by constructing dams and other technical works, as well as by reforesting watersheds of some torrents. Furthermore, forest fire-affected areas require reforestation, especially in cases of recently reburnt pine forests or non-pine forests, where natural regeneration does not occur often (Figure 31).

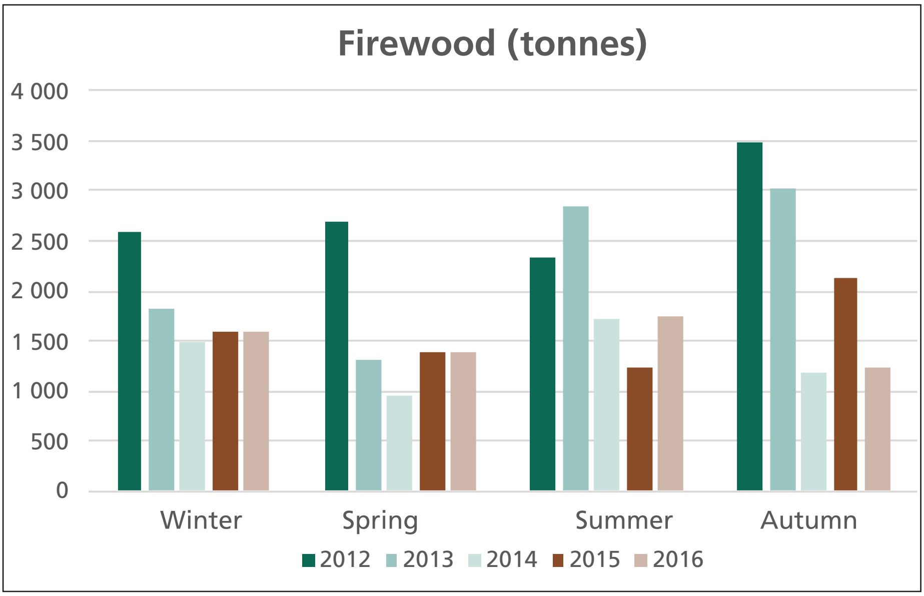
The nutritive constituents lost by the erosion of agricultural sloping soils are often temporarily replaced by adding the appropriate amounts of chemical fertilizers, with no additional burden on the environment. For this reason, the Ministry of Rural Development and Food periodically issues the "list of plant protection products and biocides (Ministry of Rural Development and Food, 2019).

Figure 31 After the disastrous forest fires of 2007 in Ilia, Peloponnese, extensive restoration works were undertaken, especially in the ancient area of Olympia

Log erosion barriers were placed on Kronios Hill (the hill above the ancient stadium at Olympia) under the supervision of experts from the Institute of Mediterranean Forest Ecosystems and Forest Products Technology.

Figure 32 The endemic palm forest of Vai; one of the most unique and frequently visited parts of Crete

Table 5 Seasonal distribution of confiscated firewood for the period 2012–2016



Source: Alexiou et al., 2017.

As far as pathogens are concerned, the process is more time-consuming, since scientific teams have to be assembled in order to research and compile the course of action required for tackling this issue.

Finally, to confront illegal logging, the Forest Service organizes patrols and takes all foreseen legal actions, such as imposing fines or confiscating firewood (Table 5), in order to limit the loss of trees.

Moreover, in several mountainous regions where the winter temperatures can be very low, firewood is provided by the Forest Service to local citizens at a significantly low cost (Alexiou *et al*., 2017).

Protective forest policy and governance

Protective forests are governed by articles 67–72 of Law 86/1969 (Forest Code) and article 4 paragraph 1 of Law 998/1979. The relative provisions distinguish between "absolutely protective" and "simply protective" forests. This distinction is based on criteria of ground topography, watershed protection and anti-erosion functions of the forests. To designate a forest as protective forest, a ministerial order needs to be issued.

The vital soil and water resources are protected by several forest law provisions and regulations. Relevant provisions include articles 104, 105, 107, 113, 294 of Law 86/1969, articles 4, 16, 38, 46, 47 of Law 998/1979, articles 12, 11 of Law 1650/1981 and Presidential Decree 437/1981 "On the study and execution of forest technical works."

To fulfil their protective function, forests should be managed, while observing specific and strict restrictions. Thus, it is forbidden in these forests:

- to change their land use and forest composition, i.e. to not-adapted species;
- to carry out intensive felling, which disrupts the cohesion of the stands and strips the soil; and
- to carry out any kind of felling without ensuring appropriate reforestation.

Furthermore, reforestation and watershed management of the torrents is enforced with a view to stabilizing and preventing erosion.

Since 1932, the Directorate of Forest Works and Infrastructure of the Ministry of Environment and Energy has implemented watershed management programmes in about 250 mountainous watersheds for the protection and development of their soil and water resources. Although the torrential problem in many of these watersheds has decreased, it continues to be acute. According to the data kept in the Directorate, it is estimated that only 25 percent of the total torrential erosion-source areas have been controlled so far. This relatively small percentage is due to low funding, organizing difficulties, bureaucracy, constraints, the time-consuming procedures of workers and technicians' recruitment, reactions of the people living in mountainous areas, as well as the customary and traditional rights of grazing and fuelwood felling (General Directorate of Forests and Torrent Control, 1964).

In November 2018, a Ministerial Decision issued in the Official Government Gazette (B 5351) established – for the first time in Greece – a national forest policy with a 20-year timeframe (2018 to 2038). This is referred to as the "National Strategy for Forests" and was created with the vision to develop and adopt the Mediterranean forestry standard, to ensure sustainability and to increase the forest contribution to the national economy through multi-functionality, adaptability, socio-economic role enhancement and finally, through taking into consideration the impacts of climate change. The strategy describes in detail the actions that can be taken to ensure the stability of the ecosystem and the sustainability of forests.

The local forest agencies are responsible for the control of all these measures, among others including regular patrols by teams that consist of both foresters and forest rangers. Furthermore, all forest agencies take part in various programmes and campaigns, in order to increase public awareness about the importance of forests. In schools, students learn through environmental courses, excursions or by environmental actions, such as planting trees. Every year, especially throughout the dry season, citizens are being informed through media, advertising, brochures and voluntary actions on the value, importance and role of forests, as well as the protection the forests need, in order to continue their ecosystem services.

Climate change

Climate change, combined with many years of bad practices and land use changes, has placed a large proportion of Greek forests in a critical condition. Forest fires have become more intensive, often undermining the capacity of forests to retain soil. As a result, as soon as the first major rainfall in autumn occurs, terrible flooding follows (Figure 33).

On the other hand, low precipitation, combined with high temperatures, favours the multiplication and spread of pathogens, resulting in mass deaths in a variety of species. For example, in central Greece, fir (*Abies cephalonica*, *Abies borisii-regis*) necrosis increases during periods of drought, as the defense mechanisms of the trees weaken and so they are more easily affected by insects. Also, in 2019 the increasing population of the pine shoot beetle (*Tomicus piniperda*), a vector for various pathogens, led to the necrosis of 350 hectares, which represents one tenth of the *Pinus halepensis* forest above the city of Thessaloniki.

Additionally, high temperatures increase the concentration of CO_2 in the atmosphere, which leads to forest stress and undermines their ability to store carbon (Regato, 2008). This storage function, which is quite beneficial, especially when it comes to suburban

Figure 33 Check dams built for torrent control in the Evritania region as otherwise heavy rainfall may lead to destructive torrents and floods

forests, gets severely damaged and affects all nearby areas. In Greece these effects are crucial, considering the fact that the two major cities, Athens and Thessaloniki, are surrounded by extensive mountain masses (Parnitha, Penteli and Hymettus in Athens and Seih Su forest in Thessaloniki). In fact, due to the mountainous morphology of Greece, all suburban forests act as protective forests, preventing erosion and torrential phenomena that would otherwise cause serious damage to cities.

Conclusions

It is clear that all forests in Greece are protective and thus the term is not often used separately. The need to find sustainable ways to maintain the Greek forests in a good condition has always been an issue for national policymakers, in order to protect various inhabited areas immediately affected by the consequences of a badly managed situation. All aspects of forest management need to be considered and all measures should be taken with the purpose of fulfilling these needs.

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ITALY

Alberto Del Lungo[1], Silvia Ferlazzo[2], Enrico Pompei[2] and Raoul Romano[3]

[1] DIBAF - University of Tuscia Viterbo
[2] MIPAAF Directorate of Forestry
[3] CREA, Centro Politiche e Bioeconomia

General information

In Italy, where mountains and hills cover almost 80 percent of the territory, protection is considered as one of the most important functions allocated to forests and forest areas. In the Alps and Apennines, the protective function has been identified prevalent for over 70 years. However, most of the forests fulfil protective and productive functions at the same time, and the concept of "direct protection" defines *the role that forests play in preventing the occurrence of natural hazards and/or mitigating their effects on people, human activities and infrastructure*.

The aim of the Italian forest policy is to strengthen protective forests through the adoption of strategies for the prevention and mitigation of hydrogeological risks and the implementation of sustainable forest management practices, in order to preserve the forests and, more broadly, their ecosystems. In this regard, forest stands with

Figure 34 Direct protective functions of forests in the Alps

Figure 35 Protective beech (*Fagus sylvatica*) forests in the Apennines (Collelongo [AQ] Abruzzo)

The tops of the mountains in the Apennines are often occupied by meadows, while beech forests play a protective role by reducing the risks of landslides and avalanches.

particular characteristics related to species, composition, density, texture and structure are considered to play important roles in protecting soil from erosion, thus contributing to reducing the risk of landslides and, ultimately, preventing hazards.

This concept is regulated by the Legislative Decree 34 of 3 April 2018 (Article 3, paragraph 2, letter r) that refers to the *direct protective functions of forest* as a wooded area which, due to its special location, performs a direct protective function for people, goods and infrastructure from natural hazards, including snow avalanches, rockfalls, landslides and debris flows. Thus, protective forests either prevent the event or mitigate its harmful effects. In addition, L.D. 34 2018 provides regulations and a definition of suitable silvicultural treatments, i.e. thinning, in order to maintain and eventually enhance the main functions of forests.

The financial resources to implement silvicultural treatments have to be identified in the application of co-financing measures related to the EAFRD (European Agricultural Fund for Rural Development) and in the measures 8.3 and 8.4 of the Programme 2014–2020 that provides funds for the prevention of natural disasters. L.D. 34 2018 (and the previous Royal decree-law n. 3267 of 30 December 1923 named "Serpieri Law") delegates to regional administrations the responsibility to identify potential direct protective forests growing in their territories, i.e. forests that protect slopes from rockfalls, avalanches

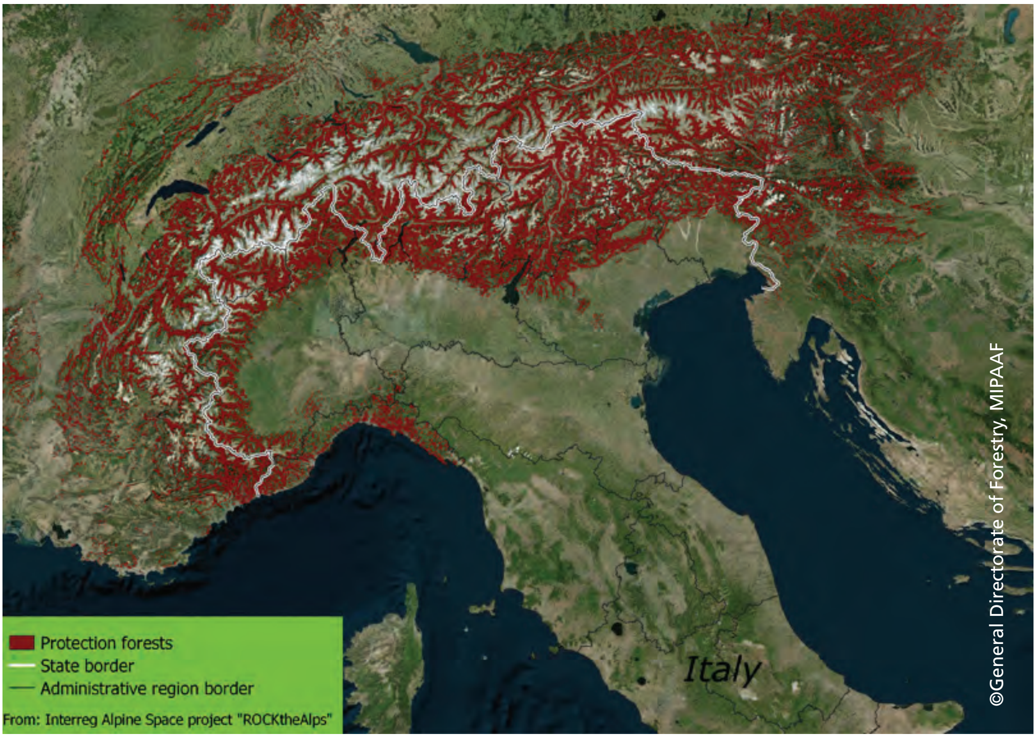

Figure 36 Protection forests in the Alps as defined in the Interreg project "RockTheAlps"
Source: RockTheAlps, 2016.

and debris flows. Moreover, the regional administrations should identify all the related "sensitive objects that they protect," such as territories in which there are temporary or permanent structures, infrastructures, people or human activities, and the safety of the population. Once identified, the regional administrations have to prioritize the protective forests within all their forest stands and define the forestry interventions and indications in order to sustainably manage and preserve them.

Protective forests, challenges and risks

The national statistics of the forest inventory in the country report to the FAO Global Forest Resources Assessment (FAO, 2015), notes that in Italy 8.124 million hectares of forests, or 87.4 percent of the total forests (Figure 36), are managed for the protection of soil, water and ecosystem services. However, the composition of protective forests differs widely along with the climatic, ecological and soil conditions of the peninsula. In the Alps, species of conifers such as larch (*Larix decidua*), fir (*Abies alba*), spruce (*Picea abies*) and several species of pine (*Pinus* spp.) dominate slopes and landscapes (Figure 34), while in the Apennines broad-leaved species such as beech (*Fagus sylvatica*) (Figure 35), sweet chestnut (*Castanea sativa*), several species of oaks (*Quercus* spp.), cherry trees (*Prunus avium*), several species of maple trees (*Acer* spp.) and alder (*Alnus glutinosa*) predominate.

As mentioned, protective forests require specific management practices to fulfil their protection targets, but the unsustainability of the economic management and the shortage of available resources reduce the possibility to properly treat and manage these forests. This results progressively in poor maintenance and exposure to increasing degradation, and consequently an increase of wildfires and hydrogeological hazards.

Climate change and climate variability are also major threats to protective forests. Changes in rainfall regimes and temperatures are posing challenges to which forests cannot adapt in a short time. Moreover, adverse effects foster wildfires and favour the spread of diseases such as ash dieback, caused by the fungus *Hymenoscyphus fraxineus*, which impacts ash (*Fraxinus excelsior*) – and pest outbreaks, including attacks by the pine shoot beetle *Tomicus piniperda* on coastal pine forests (*Pinus pinea*).

Every year, about 40 000 hectares of Italian forests are affected by disturbances, mainly wildfires. In recent years, other extreme natural events such as windstorms, late snowfalls and frosts have increased in both frequency and area affected. In October 2018, the windstorm "Vaia" hit north-eastern Italy and damaged a total area of 2 300 771 hectares in the regions of Lombardy, Veneto, Trentino Alto Adige (Figure 37) and Friuli Venezia Giulia. As such, Vaia caused the complete destruction of 41 491 hectares of forest, and an estimated total of 8 689 754 cubic metres of felled timber. The damaged territory included large areas of protective forests, though the exact area of protective forests hit by Vaia remains to be estimated.

Figure 37 Damage caused to spruce (*Picea abies*) forest at Paneveggio (Trento Province, Italy) by the windstorm "Vaia"

Other threats to the preservation of protective forests include uncontrolled grazing pressure by wild boar and large herbivores (for example, red deer and chamois), which continue to increase in number since there exist almost no predators, and hence their pressure on forests puts natural regeneration at serious risk.

Lastly, another risk for protective forests concerns conflicts with agricultural lands and activities. Even though, with the progressive abandoning of lands and the pressure of agriculture decreasing, the agricultural sector should always be considered among the main stakeholders of forests. In many cases, in the buffer areas surrounding natural reserves, it is necessary to negotiate rules and regulations in order to avoid and reduce pasture and farming activities. However, the pressure from cattle in protected areas remains too high. Management plans inclusive of agricultural and pasture practices are the main tool to reduce the impact of agriculture and livestock, because the plans involve all the local stakeholders and try to prevent conflicts with farmers, breeders and hunters, thus reducing the risks of illegal actions such as deforestation, forest fires and poaching. Furthermore, patrolling, watching and sometimes fencing critical areas can also provide important tools in the preservation of protective functions of forests.

Protective forest policy and management

At the national level, L.D. 34 2018 and the National Forest Strategy (being drafted, publication scheduled for 2021), provide the strategic guidelines for protective forests, while, at the regional level, the regional administrations incorporate national guidelines into their own legislation and adapt them to their territorial characteristics and needs. As such, regions define the required planning and management actions for protective forest areas and also implement planned actions. Hence, although L.D. 34 2018 defines the main framework for protective forests and the main management guidelines, its implementation is delegated to regional administrations.

Another relevant issue is the role of environmental policy on protective forests, which considers three main types of protective areas with different levels of governance: i) national parks governed by independent rules and regulations; ii) natural, regional and interregional parks, governed mainly by regional rules; and iii) natural reserves that are much smaller and may cover the territories of one or more municipalities. Taking into account that many protective forests are encompassed in natural reserves, municipalities can therefore be involved together with several other actors in the governance of protective forests. Nevertheless, municipalities are the main actors, as they are the primary stakeholders and are particularly involved in the governance of natural reserves and less of national parks. Since both national and regional policies on forest planning envisage the participation of all involved stakeholders, which include other than municipalities, also NGOs and civil society, all planned forest activities are shared accordingly.

While forests often provide a number of other functions, including the provision of non-wood forest products and recreational services, the pressure of people on forests has to be managed since it may lead to soil degradation, pose risks to forest regeneration and biodiversity, and disturb wildlife.

Information on raising public awareness includes training given in schools and in protected areas and sharing publications and videos. As such, park and forestry authorities, as well as NGOs and local administrations, are mainly responsible for raising awareness.

Unfortunately, GIS data available specifically for protective forests do not cover all the country. Although some regions, especially in the Alps, have set up georeferencing systems for protective forest areas, they are not connected at the national level. However, since the end of the 1980s, a national network of data has been organized to monitor the health status and structure of forest populations.

Importance of protective forests

Forests provide many ecosystem services, including soil protection, water regulation (Figure 38), and preserving biodiversity and wildlife. In addition, *biogenetic reserves* comprise those protective forests devoted to producing plant genetic material. The collection of seeds and cuttings, and the protection of seedlings of plant species *in situ*, help preserve the genetic diversity of tree species.

Protective forests are also considered as research laboratories for studying the development of forests and wildlife. In many cases, within protective forests, some areas are left to natural agieng, without any intervention or removal of dead wood, in order to analyse the evolution of the forest ecosystem without human intervention. In other protective forests, researchers are engaged in testing silvicultural treatments aimed at strengthening natural forest regeneration. The most advanced research involves studying the ecophysiology[26] of protective forests so as to understand better the exchanges of CO_2 between forests and the atmosphere, and thus strengthen the resilience of forests to climate change.

The institutions most involved in scientific research are universities, the research institute of the Ministry of Agricultural, Food and Forestry Policies

Figure 38 A creek flowing through spruce and firs in the Paneveggio forest. Protective forests allow for water regulation, which is an essential ecosystem service

[26] Ecophysiology is a biological discipline that studies the adaptation of an organism's physiology to environmental conditions.

(CREA – Council for Agricultural Research and Agricultural Economy Analysis) and the National Research Council (CNR), as well as NGOs and local authorities.

Climate change

Climate influences the structure and functions of forests and forest ecosystems, and plays an essential role in forest health. Climate change can also exacerbate many of the threats to forests, such as pest outbreaks, wildfires, storms and droughts. Furthermore, it affects, directly and indirectly, the growth and productivity of forests through changes in temperature, rainfall, weather and other factors. In addition, elevated levels of carbon dioxide influence plant growth. A recent example of climate change and climate variability triggering disasters was the windstorm "Vaia" in autumn 2018.

Future scenarios are not positive for protective forests, since climate change puts at risk their main functions of sheltering and protection against natural hazards. However, national policies are promoting interventions aimed at improving the adaptation of forests to climate change. The research is fostering new silvicultural treatments to support tree species which are more resistant to the effects of climate change, particularly droughts.

As reported by L.D. 34 2018, financial instruments to support protective forests include rural development policy measures (EU-funded EAFRD programmes). By 2021, protection and management guidelines for protective forests should be identified, together with the necessary national resources to enhance their functions. However, to date there is no identified unitary policy among regions, which represents a major constraint.

Good practice and additional information

The Piedmont Region, in collaboration with the neighbouring Alpine regions of Val d'Aosta, France and Switzerland, has prepared a methodology and a model to define forests with a predominantly direct protective function, and mapped a preparatory zoning action for silvicultural planning and management. The basic data for the application of the model are:

- a land digital model;
- a forest cover dataset;
- a geological substrate dataset;
- geographical information layers of the infrastructures and land use (BDTRE, 2018);
- data of the restricted areas bound under the terms of the "Po River and its tributaries Basin Plan"

In the beginning, the classification model was based on the elaboration of the digital land model comparing forest surfaces with those relating to infrastructure within a minimum sub-basin unit. However, over time the model has been greatly improved through a methodology complying with the EU Floods Directive (2007/60/EC) (2). Some basic themes have recently been replaced and more relevant information integrated.

This methodology, developed in Piedmont by the Regional Agency for Environmental Protection , allows the construction of a risk level, i.e. the ratio between danger and potential damage, that considers infrastructure, lithological features of the basins and, above all, updated census data, to discriminate between widely inhabited and non-inhabited areas (Arpa Piemonte, 2021). The standard method has been included in the new guidelines to draw up forest management plans, according to the Regional Decree 27-3480/2016. On this basis, about 150 forest management plans identify the direct protective forests and describe the silvicultural interventions to be implemented.

The advanced method is currently used in the "Extraordinary Post-Forest Fire Plan" which defines the restoration interventions after the forest fires of autumn 2017. It assesses and defines the priorities for the post-fire restoration interventions. Among the main advantages obtained were:

- the objectivity of the identification and perimeter of direct protective forests;
- the replicability of the method within the variation of territorial parameters, even with exceptional events;
- the rapidity of the territorial analysis methodology; and
- the ease of dissemination and use, as a result of open source software.

Conclusions

The report clearly shows the paramount importance of protective forests for the safety of living space, soil protection, the protection of water resources and the potential of areal development in Italy. The sustainable conservation of this protective function is at risk from a broad range of negative influences, many of them related to climate change, such as drought, wildfires, storms or pests, but also from damage caused by heavy pressure from wildlife (roe deer, wild boar) , pasture or overexploitation. Hence, there is urgent further demand for actions and management programmes on protective forests in Italy.

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NORWAY

Stephanie Eisner[1], Rune Nordrum[2], Bruce Talbot[1], Stein Tomter[1] and Knut Øistad[1]

[1] Norwegian Institute of Bioeconomy Research
[2] Norwegian Agriculture Agency

The Norwegian Forestry Act of 2005, in line with its preceding documents, defines protective forest *(vernskog)* as forest that protects other forested area against adverse weather conditions or that provides protection against natural hazards for other land uses, for instance, settlements, infrastructure and agricultural land. The definition additionally includes forested areas approaching the Alpine timberline, and along the coast that have a low potential for natural regeneration due to the climatic growth conditions. These forests are thus at risk of degradation under unsuited management. The forestry authority may, with the legal basis in the Norwegian Forestry Act, issue regulations that a forest shall be protective forest, if it has considerable protective functions as defined above.

The strong emphasis on climatic effects, as well as on stabilizing and restoring the tree line, dates back to the first forestry act of 1893, namely the "Act on the conservation of protective forests and against forest destruction." The nineteenth century is colloquially referred to as "the century of snow avalanches," and the large number of fatal avalanches during this period was associated with a widespread degradation of the natural mountain forest ecosystem and recession of the tree line, caused by wood overexploitation and forest grazing. The subsequent century was characterized by reforestation in coastal and mountain regions through natural regeneration of birch (*Betula pubescens* and *B. pendula*) forest, following the widespread abandonment of rangeland farming practices. In many regions, the current forest line remains significantly below its climatic potential.

Protective forest governance and decision-making

The Forestry Act (para 12) transfers the right to issue regulations on the management of protective forests to the individual counties (County Governor[27]), including the formal designation and delineation of protective forest. These regulations may establish rules and restrictions for management activities within protective forest, and a general obligation to notify of planned operations may be stipulated. Currently, protective forest covers about 4.6 million hectares, which corresponds to 38 percent of the total forest area of Norway. About 29 percent of all productive forest (annual increment ≥ 1 cubic metre per hectare) and 60 percent of all non-productive forest are classified as protective forest (Tomter, 2018). Figure 39 outlines the extent of protective forests as

[27] The County Governor is the State's representative in local counties and is responsible for monitoring the decisions, objectives and guidelines set out by the Storting (Norwegian Parliament) and government. In addition, the County Governor provides an important link between municipalities and central government authorities.

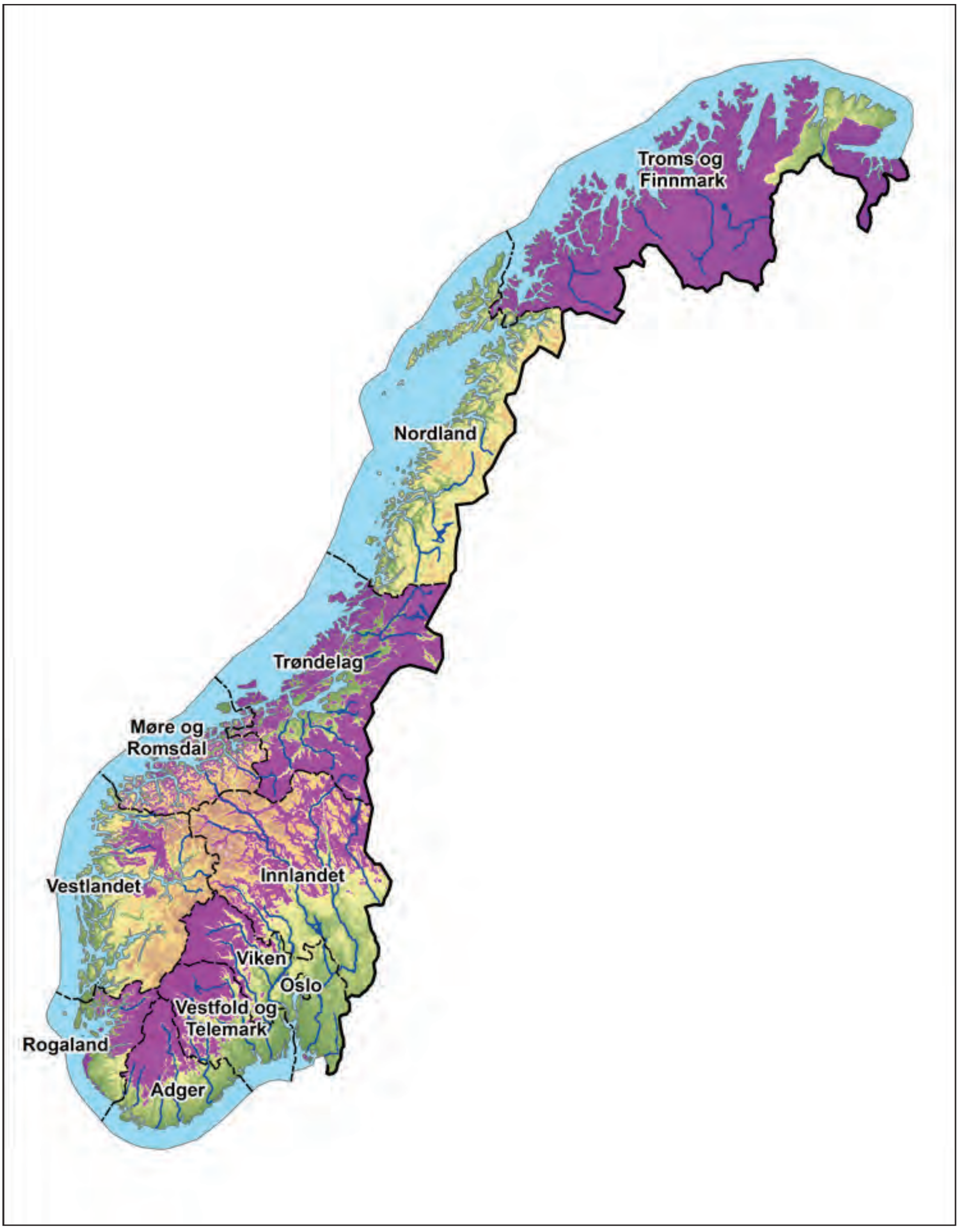

Figure 39 Areas prescribed as protective forest (displayed in purple) as reported by the single counties. No digital delineation is available for parts of Vestlandet, parts of Vestfold og Telemark and Nordland. The county of Oslo does not have protective forest. In the northernmost county of Troms og Finnmark, all forested area is declared protective forest

Source: NIBIO, 2021.

reported by the single counties. In the northernmost county of Troms og Finnmark, all forested area is declared protective forest, while the county of Oslo does not have protective forest. Digital protective forest maps are unavailable for parts of Vestlandet, Nordland and parts of Vestfold og Telemark, although these counties have issued protective forest regulations.

In practice, this process is carried out at the municipality level in moderation with stakeholder interests, i.e. forest owners and landowners, and public authorities at municipal and regional levels, such as land use authorities, planning and building authorities, environmental agencies and transportation authorities. In the first step, the forestry officer in each municipality drafts rules, or the revision thereof, for protective forest management under his or her supervision with the following elements: an outline of potential protective forest, description of its protective functions, general rules for forest management and operations, and circumstances under which the notification of planned harvesting is required. Based on this draft, the County Governor's office formulates local regulations or amends existing ones. These are then submitted to the municipal council with the possibility to suggest changes before formal adoption by the county.

A particular gap in the current governance system is that, apart from general forestry subsidy schemes, there are no subsidies or other financial instruments available that specifically target protective forest. The individual forest owner will not receive financial compensation or subsidies for the management of protective forest, even though restrictions may apply to management and/or technical operations.

In order to support the implementation of protective forest legislation in the single counties, the Norwegian Agricultural Agency (1992) published guidelines for protective forest management, which are currently under revision. With respect to climatic and regeneration aspects, a three-part zoning of protective forest with different restrictions on forestry activities is recommended.

Zone 1 is formally defined as the outermost part of the forest along the timberline at the transition to the Alpine tundra ecotone or coastal heath with trees of at least 3 metres in height and less than 30 metres distance between single trees. This zone should be at least 50 metres wide and be precluded from any timber harvesting.

Zone 2 comprises birch (*Betula pubescens*) forest and unproductive coniferous forest with at least 60 trees per hectare or trees of at least 5 metres in height. Single-tree cutting within coniferous stands may be permitted, given that regeneration is ensured. In deciduous stands, thinning or shelterwood cuttings may be carried out; clear cutting shall be restricted to sheltered sites and the plot size shall not exceed 0.2–0.5 hectares.

Zone 3 extends from the outer limit for productive forest to the lower protective forest boundary. Management and harvesting in this zone may follow usual practices with some restrictions: 1) Strategies for regeneration, either natural or through planting, should be scrutinized before carrying out any felling; and 2) So-called mountain forest felling (*fjellskoghogst*) should be prioritized over clear cutting or seed-tree cutting,[28] in particular in climatically exposed locations. This measure includes a combination of small-scale clear cutting (<0.2–0.5 hectares), patch cutting and selective cutting, depending on local climate, growth conditions, age distribution and species. Clear-cutting, seed-tree cutting or shelterwood cutting[29] may be carried out where mountain forest felling is not pertinent, but patches should not exceed 0.5–3.0 hectares, depending on local climate and growth conditions.

The recommendations on protective forest management listed above are reflected in requirement 10 (felling) of the Norwegian PEFC Forest Standard (2016), which demands that, *in mountain forests, emphasis must be placed on promoting and maintaining old growth characteristics. Therefore, when carrying out felling, selective felling forms (mountain forest felling) must be used as widely as possible in forests dominated by spruce, and small-scale clear cutting and smaller seed tree stands in forests dominated by pine.*

There is, to date, no national standard or best practice for the management of forest stands with considerable protective function against natural hazards. General criteria for forest management and structure to maintain or attain a protective function have been proposed by the Norwegian Geotechnical Institute (2013) and cover the most relevant natural hazard types, i.e. snow avalanches, rockfalls and rockslides, debris slides and debris flows. The report provides benchmark values for forest structure, such as species composition, stem density and diameter, crown cover and height, as well as forest and harvest patch sizes, differentiated by slope and hazard type. A large part of these recommendations is based on experience and best practice in the European Alpine region.

The Norwegian Water Resources and Energy Directorate (NVE) holds the mandate to manage flood, landslide and avalanche risks in Norway. As part of this mandate, susceptibility maps and hazard zone maps are provided for the most relevant natural hazard types, which can be used to identify forest stands with protective functions against natural hazards. National susceptibility maps are available for debris slides and debris flows, rockfalls and rockslides, and snow avalanches. The maps outline potential release and runout areas, without informing about occurrence probabilities. Furthermore, these maps were solely derived from digital elevation models, i.e. the local effects of forests or physical safeguarding measures are not taken into account.

More detailed risk maps are available at the municipality level, but they do not cover the entire country and only consider the locally most relevant natural hazard types. These maps outline risk zones for release and runout of events with return periods of 5 000, 1 000 and 100 years, respectively. Depending on the location, they potentially include all the above-mentioned hazard types, in addition to slush avalanches.[30] Assessments are based on field surveys and a combination of natural hazard models. The latter explicitly

[28] Seed tree method is a modification of clear-cutting where a few of the best trees are left standing to become the parent trees for the new forest.

[29] Shelterwood cutting refers to the progression of forest cuttings leading to the establishment of a new generation of seedlings of a particular species or group of species without planting. This silvicultural system is normally implemented in forests that are considered mature, often after several thinnings.

[30] An avalanche composed of slushy, very water-saturated snow. They usually occur in Arctic climates on permafrost soil when dry depth hoar frost becomes rapidly saturated with water in spring. Slush avalanches can occur on very gentle slope angles.

account for the effects of current forest structure (depending on hazard type volume, tree height, crown cover, stem diameter and density, and/or species composition) on event initiation, downhill movement and runout.

Forest stands that considerably affect model outcomes, i.e. hazard zoning, are explicitly outlined and marked as ”potential protective forest.” However, they may currently not be designated as protective forest. As a result, this implies that any changes in stand structure occurring naturally, such as self-thinning, windthrow, insect outbreaks, or induced by forest management, potentially require a re-evaluation of the current hazard zones. Figure 40 shows an example of local hazard zone mapping, which includes forest stands with considerable protective function.

Legacy effects render the management of stands with potential protective function challenging, especially on the Norwegian west coast, which is characterized by mountainous topography, high annual precipitation, intense precipitation events, and considerable snow accumulation at higher elevations. The region features large areas of regionally introduced, densely planted spruce (mostly *Picea abies*, occasionally *Picea sitchensis*). Most of these stands were planted in the 1950s–1970s and did not undergo subsequent silvicultural treatment, resulting today in a dense and even-aged structure with sparse to absent understorey,

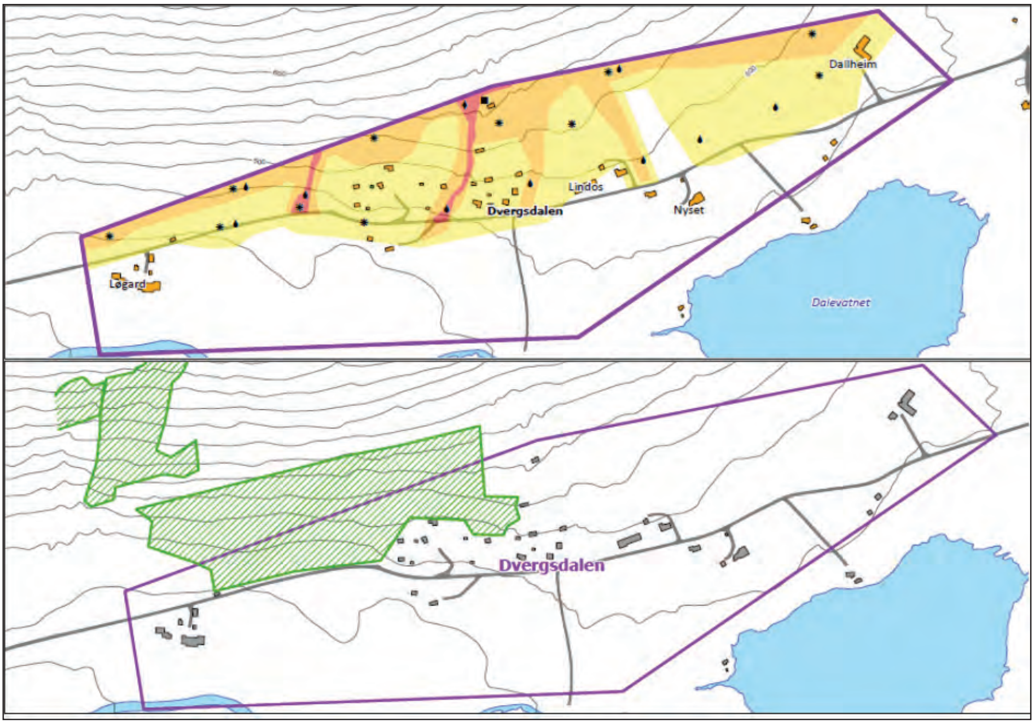

Figure 40 Example of combined local hazard zone mapping for snow avalanches, rock falls/rockslides, slush avalanches and debris flows

Yellow, orange and red shading corresponds to a return period of 5 000, 1 000 and 100 years, respectively. Forest stands affecting the hazard zoning are outlined in blue.
Source: NVE, 2021.

advanced self-thinning, and limited stabilization through natural regeneration. Targeted and long-term silvicultural conversion strategies are required, and still need to be developed, in order to retain protective functions of these stands, where applicable.

Another important challenge applying to the management of mountainous forest in Norway is very low levels of infrastructure, which make harvesting and timber transport cost-intensive. Mountainous forests in Western Norway have about 10–20 percent of the road density of mountain forests in the European Alps. In many cases, excavator-assisted clear cutting is the most, and often only, profitable harvesting method and it requires building new forest roads. However, both these aspects may lead to an increased risk of natural hazards. Indeed, there are several reported instances of landslides initiated on clear-cut slopes or along forest roads.

Conclusions

Current research activities under the auspices of the Norwegian Natural Hazard Forum specifically target the challenges around the management of protective forest and forest with protective functions, with the aim to develop:

- unified specifications to be used in the registration of forest that is important for natural hazard mitigation, and to lay the foundation for a systematic registration of such forest;
- long-term management strategies for these forests in order to retain their protective functions (Gampe, 2018); and
- risk indicators for the construction of forest roads on steep slopes in order to aid management and general forest road planning (Lileng, 2019).

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POLAND

Marcin Jachym[1] and Monika Tomczyk-Kida[1]

[1] Forest Research Institute, Poland, Department of Mountain Forests

Protective forest – general information and data

A protective forest is a forest that fulfils, exclusively or additionally, non-production functions related to the protection of land, water, infrastructure and inhabited areas, which are threatened by the effects of natural phenomena such as floods.

Forests fulfil diverse functions, with the main ones being:

- Soil and water-protective forests have a positive impact on the protection of soils against erosion and droughts, as well as protecting watercourses, water reservoirs and watersheds, while having a positive impact on the regulation of the water cycle in nature (Figure 41);
- Climate forests have a positive impact on the global and local climate, protecting the microclimate from urban and industrial areas (Figure 42);
- Recreational and leisure forests provide health-enhancing and recreational conditions for society and ensure the development of environmental awareness in society;
- Health resorts protect the condition of the forest and the surrounding areas.

In accordance with the provisions of the Forest Act of 28 September 1991 (Art. 15 *ustawy z dnia 28 września 1991 r. o lasach*), with subsequent amendments, and ordinance of the Ministry of the Environment on the detailed principles and procedure for considering forests as protective, protective forests:

- protect the soil against washing away or impoverishment, and also prevent soil and rock removal, or avalanches (in the watershed areas) (Figure 43);
- reduce the formation or spreading of windblown sands;
- are often referred to as protecting water resources;
- protect the surface and groundwater resources, and regulate hydrological cycles in catchment and watershed areas;
- are located where national parks are established in watersheds;
- form seed stands or refuge sites for animals and plants subject to species protection;
- have a particular meaning and natural-scientific significance; or
- are of particular importance for the defense and security of the State, for example, providing training grounds.

Protective forests are located:

- within the administrative boundaries of cities, at a distance of up to 10 km from the administrative boundaries of cities with over 50 000 residents, and in the protection zones around sanatoriums and health resorts;
- in areas requiring predominantly water and soil protection and windproof functions;

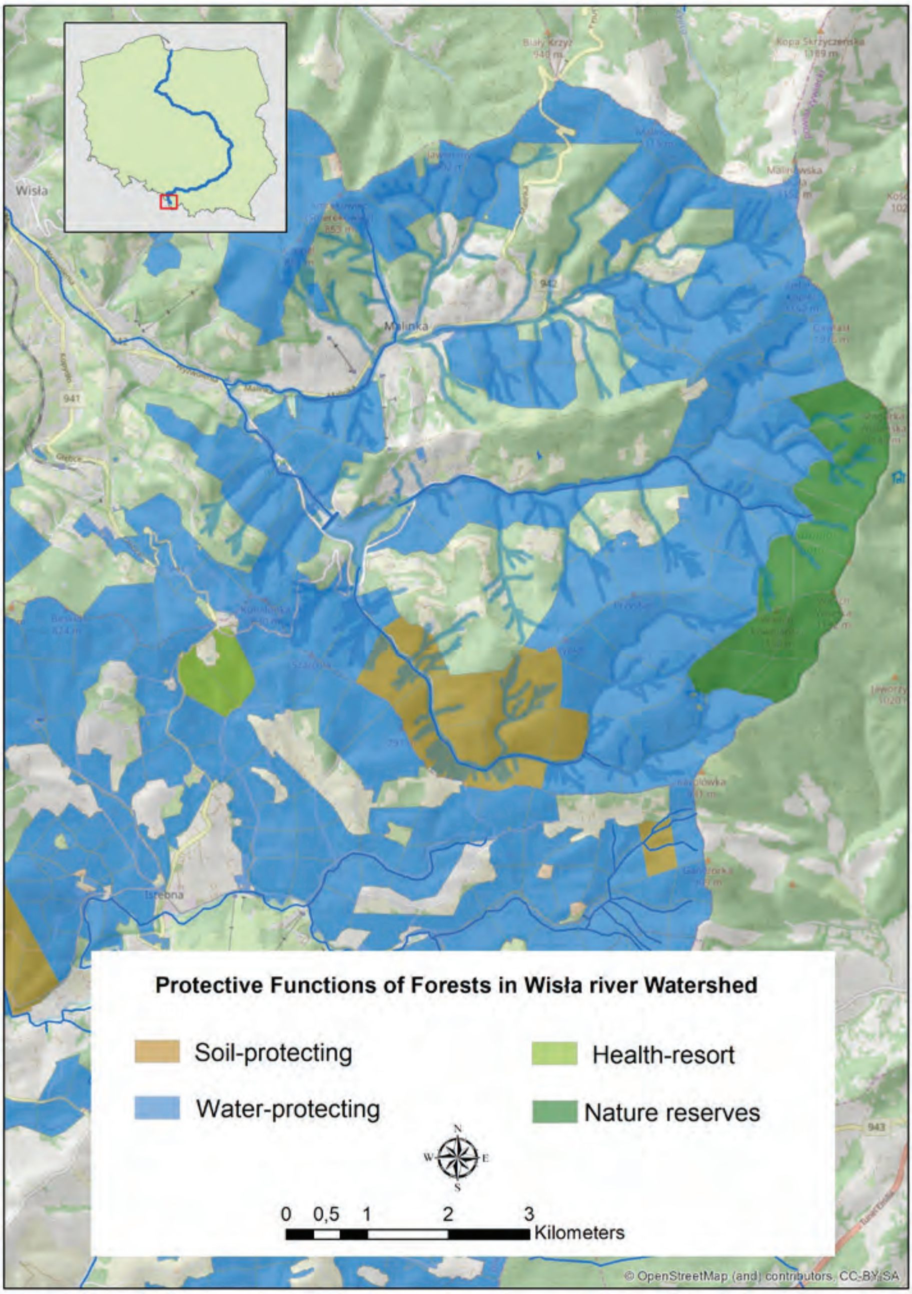

Figure 41 Protective functions of forests in mountain watersheds: an example from southern Poland
Source: Jachym, 2021.

Figure 42 Climate forest protecting the microclimate from urban and industrial areas – Niepołomice Forest district, Małopolskie province, Krakow steelworks, southern Poland

Figure 43 Forest with soil and water-protective functions at the artificial lake of Jezioro Solińskie (Lake Solina), Podkarpackie province, southeast Poland

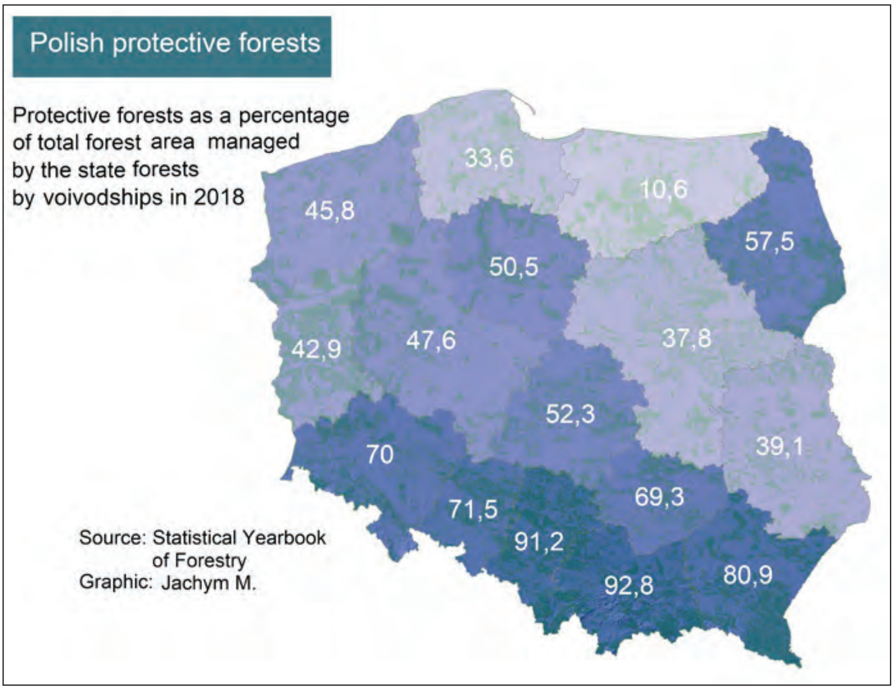

Figure 44 Percentage of protection forest in Poland in relation to the total forest area of the provinces in 2018

Source: Statistical Yearbook of Forestry, 2019; Graphic: M. Jachym

- in the higher forest border zones (in the watershed areas). For example, *Alnus alnobetula* (Ehrh.) K. Koch is found in the higher mountain locations of the Bieszczady Mountains in protective forests. In Poland, it is an Alpine species that occurs above the upper border of beech forests, colonizing overgrown pastures, where cattle grazing has ceased, as well as abandoned arable fields. It plays a similar role to *Pinus mugo*, i.e. it prevents erosion and consolidates slopes (Figure 44).

As of 1 January 2017, the combined area of protective forests increased to 3 811 000 hectares, which represents 53.7 percent of the total forest area. Furthermore, taking into account the forest area of reserves (103 000 hectares), the total cover amounts to 55.1 percent. Among the forest categories distinguished, the largest area is covered by water protection forests with 1 544 000 hectares, while the other categories comprise respectively: suburban (617 000 hectares), important for nature (572 000 hectares), damaged by industry (463 000 hectares) and soil protection (322 000 hectares).

The largest share of protected forests are the characteristic forest areas of the State Forests located in the southern part of the country in mountainous areas [Małopolskie province – with 92.8 percent protective forest stands, comprising mixed stands of fir (*Abies alba*), beech (*Fagus sylvatica*) and spruce (*Picea abies*), and Podkarpackie Province – 80.9 percent protective forest with beech and fir stands) and in areas under

Figure 45 Protective forest dominated by beech (*Fagus sylvatica*) and green alder (*Alnus alnobetula*) in the higher border zones (Połonina Caryńska, Bieszczady National Park, southeast Poland)

the influence of industry (Śląskie Province – 91.2 percent protective forests with pine (*Pinus sylvestris*) and spruce (*Picea abies*) in the mountains and mountain catchments] (Figure 45).

Challenges for protective forests

The main threats to the functions of protective forests in terms of vitality, resilience and stability are various abiotic and biotic factors occurring in the Carpathian and the Sudetes Mountains, including:

- deficit and disruption of water supplies
- wind damage, i.e. resulting in broken and fallen trees
- unfavourable forest structure, i.e. large loss of spruce (*Picea abies*)
- root diseases
- bark beetles.

Protective forests face additional challenges, such as the protection of surface and deep water, and water catchment retention, particularly in watershed areas and areas of underground water reservoirs. Moreover, spruce (*Picea abies*) forests are largely under pressure and difficult to reconstruct, as shown in the forests of Beskid Śląski and Żywiecki (Western Carpathians) in southern Poland (Grodzki, 2007).

Nevertheless, stand reconstruction has been successfully carried out for several decades, and as a result has increased the share of deciduous species. The principle of sustainable development is reflected in the implementation of ecological principles to forest management and the creation of the Promotional Forest Complex (PFC) “Forests of the Silesian Beskids” in the Outer Western Carpathians in the southern Silesian province (Blicharska *et al*., 2012). As demonstrated practically, the principle of maximally close-to-nature forest management has been implemented throughout the region. The “Polish Sustainable Forest Economy Policy” (Rykowski, 1998) programme is an important element of the national environmental policy adopted in 1991 and in accordance with international commitments, such as the “Earth Summit” conference in Rio de Janeiro (1992) and European Ministerial Conferences in Strasbourg (1990) and Helsinki (1993).

Water-related research projects have been implemented and funded by the EU (2007–2013, 2014–2020), Norwegian Funds, State Forests, the relevant Regional Fund for Environmental Protection and Water Management, and the National Fund for Environmental Protection and Water Management. In 2006, development and spatial concepts were developed for projects covering the lowland and mountain areas of Poland, namely for increasing retention capacity and preventing floods and droughts in forest ecosystems in lowland areas, and counteracting water erosion in mountainous areas associated with runoff of rainwater.

The aim of these projects is to slow down the outflow of water from mountainous areas by increasing the retention capacity of the catchment. As a result, this will minimize the negative effects of natural phenomena, such as in the form of floods, and the damaging effects of flood waters and droughts in mountainous forest areas. As part of these projects, activities have been implemented to increase the retention capacity of mountain areas, including the construction of reservoirs, re-naturalization of streams and wetlands, protection of slopes against excessive surface runoff and guaranteeing the maintenance of existing hydrotechnical infrastructure. The investment tasks included comprehensive treatments, which combined environmental, natural and technical methods.

Governance and education for protective forests

National policies regarding the protective functions of the forests are exercised through laws and ordinances. The most important document is the Forest Act of 28 September 1991 (with later amendments) Chapter 3, Protective Forests, Article 15–17. Moreover, the ordinance of the Ministry of Environmental Protection, Natural Resources and Forestry (Ministry of Environment) lays out detailed rules and procedures for recognizing forests as protective, as well as detailed principles for conducting forest management.

Recreation in forests is an excellent opportunity for forest education. Educating society about forestry aims at increasing knowledge about the forestry environment and spreading information about the principles of multifunctional and sustainable forest management. These activities are also intended to raise public knowledge and awareness about the principles of rational and responsible use of all forest functions.

As such, considerable resources are used for education by the State Forests for various projects. Indeed, this task is a result of the National Forest Policy adopted in 1997 by the Polish government and the "Guidelines for conducting forest education of society" contained in Regulation No. 57 of the Directorate General of State Forests on 9 May 2003 (Bureau for Forest Management and Geodesy, 2020). In this regard, the new core curriculum and system in Polish schools in 2017 was an important milestone.

For raising public awareness, it was important for foresters that, for the first time in the core curriculum in Polish schools, provisions were introduced which referred directly to forest education provided by the State Forests, thus encouraging the use of State Forests educational services and nature teachers. The core curriculum now includes new content on sustainable forest management, professions in forestry and the functions of forests. As forest education is constantly changing, new methods, techniques and challenges are consequently emerging, such as the use of modern technologies and social media, the introduction of a holistic approach and a global perspective. Thus, engagement with the public regarding raising ecological awareness in the field of protecting forests is implemented through:

- conducting educational classes in ecological education centres in forestry districts and other areas, educational exhibitions, forest competitions, fairs, among others;
- building educational and nature trails; and
- information notices and boards, i.e. on tourist trails.

Forest covers about 30 percent of the total area in Poland, of which almost 81 percent is used freely by the public. The majority of forests are publicly owned (80.7 percent), including those administered by the State Forests (76.9 percent). These represent areas owned by all citizens of the Republic of Poland. The protection of these natural areas is based both on the provision of a number of legal acts and on the internal regulations of the State Forests. As such, the principles of forest management are regulated in particular by the Forest Act, which outlines the objectives of the economy in accordance with the natural, social and productive functions of the forest.

Forestry management in Poland is subject to planning, and specialized companies, for example, the Bureau for Forest Management and Geodesy (BULiGL) and other private companies draw up ten-year-cycle forest management plans on behalf of the State Forests. These plans contain the so-called Nature Conservation Programme and are also subject to an environmental impact assessment. Most management plans have the so-called Forest Stewardship Council (FSC) certificate, which theoretically guarantees compliance with numerous social and environmental requirements. However, government administration bodies decide about the recognition of the forest, i.e. if it is protected or should be treated in a special way, while local government bodies can only express non-binding opinions.

The provisions of the Forest Act of 28 September 1991 (with later amendments) on forests recommend that the State Forestry Inspectorate, owned by the State Treasury and managed by the State Forestry Commission, which conducts sustainable forestry based on the forest management plan. This public body is also responsible for the condition of the forest. As such, sustainable forest management must take into account in particular:

- the preservation of forests and their beneficial impacts on climate, air, water, soil, living conditions and human wellbeing,[31] as well as on the natural balance;
- the protection of the forests, especially forests and forest ecosystems constituting natural fragments of native nature or forests particularly valuable due to the preservation of biodiversity, preservation of genetic resources, landscape values or the needs of education;
- the protection of soils and areas particularly vulnerable to destruction or damage;
- areas of special social significance;
- surface- and deep-water protection, drainage basin retention, especially in watershed areas and in areas of groundwater supply; and
- production on the principles of rational wood management, as well as the raw materials and by-products of forestry usage.

Since 2014, the Bureau for Forest Management and Geodesy (BULiGL), operated by the Directorate General of State Forests (DGLP), has provided an online geoportal with spatial data, taxation information, descriptions of environments and forest sub-compartments.[32] The data and IT system include not only the State Forests, but also forests in national parks, experimental plots and some non-State forests. Forest data are also available in the Web Map Service (WMS), enabling the display in external GIS software and geoportals. In addition, there is a tool that allows the structure of stands to be reported for any selected area. In 2016, a service was also introduced that allows downloading a digital forest map and a tax description database, along with economic guidelines for individual forest environments for any forest district. The functionalities are continuously being developed.

Forest condition is observed by the "Monitoring of forests in Poland" project, which is part of the state monitoring system of the environment that *inter alia* collects information about the condition of the forest and the processes occurring in it. Forest monitoring has been carried out since the late 1980s. This information is gathered on the basis of observations conducted cyclically or continuously in the network of permanent monitoring surfaces of SPO I[33] and SPO II[34] plots. Its task is to assess the health status and the condition of the forest environment in Poland. Nevertheless, regardless of forest monitoring, selected types of forest ecosystems are monitored as natural habitats, with special regard to Natura 2000 habitat protection areas.

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[31] Human well-being is a broad concept, one that includes many aspects of our everyday lives. It encompasses material well-being, relationships with family and friends, and emotional and physical health. It includes work and recreation, how one feels about one's community, and personal safety.

[32] A sub-compartment is an area of land that has similar land use, species, habitat composition, age, thinning and harvesting operations and needs to be managed as a single unit. Each sub-compartment has a range of attributes in relation to land use and, if forested, tree species composition and management.

[33] SPO I is based on a large-scale inventory system for the state of the forest, which was created based on the ICP Forests surface system – the European surface network. The layout of the observation plot network is for the assessment of forest damage in the European Union (Commission Regulation [EEC] No 1969/87).

[34] SPO II – 148 Permanent Second Level Observation Plots (SPO II) were created in pine and spruce stands, aged 50–60 years old, as well as oak and birch stands aged 70–90 years old. The 2nd Permanent Observation Surface consists of 400–450 growing trees.

Monitoring and challenges

The planning instrument for the conservation of forests in Poland is a protection plan. The document is prepared and implemented for national parks, nature reserves, landscape parks and Natura 2000 sites, and is the basic document for planning nature protection. For the Natura 2000 sites, the conservation plan is a founding document, and a protection plan is drawn up only if there is a need to specify the planning.

Damage caused by storms has become one of the most serious threats to forests in Europe's temperate climate zone. In addition, increases in temperature are causing changes in the natural occurrence of some tree species, leading to changes in forest composition and adversely affecting their growth. Therefore, climate change poses major challenges, which, apart from rising temperatures and devastating storms, also include fires, loss of biodiversity and the threat of invasive species.

On the basis of existing forest monitoring, it is proposed to create a system for monitoring climate change impacts, which introduces a number of significant indicators for individual regions:

- promoting species that are more adapted ands tolerant to climate change;
- breeding and promoting forests composed of a mixture of different tree species;
- planting species resistant to climate change in specific regions; and
- providing advance warnings of various natural threats and promoting effective ways of combating pest outbreaks.

Furthermore, interaction with the water sector plays an important role. The lack of water resources can reduce adaptation by eliminating species with increased water requirements. Therefore, forest reservoirs and watercourses should be restored, and existing swamps and peat bogs need to be preserved. On the other hand, the higher the forest cover in catchments, the higher the stability of water resources. As such, forest cover is important for climate change resilience and natural water retention, especially in the winter period. Indeed, the optimal solution for catchment management could be a system of mutual support of forest and water management, which requires a new approach to forestry management, so that forests are able to cover more catchment area in the future. In addition, forests growing on mountainous slopes and their soils fulfil an essential function by retaining a lot of water during storms and heavy precipitation events.

A recent project from 2008–2013 focused on the prevention of water erosion in mountainous areas associated with the downflow of rainwater and the maintenance of mountain streams and related infrastructure. The aim of the project was to increase the effectiveness of protection against natural phenomena in the form of water erosion, floods and droughts in mountain forest areas. As part of the project, activities were planned to increase the retention capacity of mountainous areas, protect slopes against water erosion, reduce lateral and bottom erosion in streams, and guarantee the technical maintenance of existing hydrotechnical infrastructure.

The project covered the mountain areas in the Sudetes and the Carpathians in southern Poland. Individual project tasks were located in 35 forest districts, belonging administratively to three regional directorates of the State Forests, i.e. in Wrocław (14 forest districts), Katowice (9 forest districts) and Krosno (12 forest districts). Investment tasks included anti-erosion development of mountain slopes, biological and technical development of streams, and restoration and construction of small retention facilities. The total area of the forest districts in the project was 513 537 hectares, including a forest area of 499 249 hectares. Anti-erosion constructions on the mountain slopes comprised the building of wooden beams and natural stone fences. Lastly, restoration and construction of small retention facilities largely applied to small water bodies with an area less than 1 hectare.

Particular attention was paid to strengthening the protective functions of mountainous forests, which in general terms consist of:

- soil protection against surface erosion by covering the soil with vegetation or forest cover;
- slowing down the water cycle in mountain catchments due to retention of rainwater (interception) by the forest cover and soil;
- changing the characteristics of high-volume precipitation, by reducing the maximum and extending the timeline, which results in reducing the flood risk; and
- creating a positive impact of the forest ecosystem on water quality in mountain streams.

Future planned investment tasks include mitigating anti-erosion impacts of logging trails on slopes with a total length of 52 km, and biological and technical development of mountain streams over a length of 173 km. So far, 129 water reservoirs in Poland have been restored and improved.

Conclusions

Forests play an important role in protecting biodiversity and water resources and mitigating climate change, in addition to their productive function. In recent years in Europe there has been a marked increase in the frequency and intensity of long-term hot weather in comparison to 1951–1990 (Kossowska-Cezak and Twardosz, 2017; Russo, Sillmann and Fischer, 2015). In Poland, the greatest positive anomalies for average monthly temperatures occurred in the summers of 1992, 1994, 2006, 2010 and 2015 (Kossowska-Cezak and Twardosz, 2017; Hoy *et al*., 2017; Wypych *et al*., 2017). Therefore, the main challenge in future forest management is to increase the stability and resilience of all forest stands to predicted natural disasters, as well as to strengthen the protective functions of forests.

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SLOVENIA

Simon Poljanšek[1], Matjaž Guček[2], Jurij Beguš[2] and Aleš Poljanec[2]

[1]Ministry of Agriculture, Forestry and Food

[2]Slovenia Forest Service

Introduction

Slovenia is located between the Adriatic Sea, the Alps and the Pannonian Basin, where three climatic zones meet and interweave: Alpine, Mediterranean and continental. Collisions occur between the polar air masses with warm and moist Mediterranean air, causing frequent extreme weather events. Furthermore, considerable diversity in altitude is reflected in abundant orographic precipitation and thus resulting in Slovenia being one of the European countries with the highest potential for soil erosion (Panagos *et al*., 2015). The main reason for the significantly reduced actual erosion in Slovenia are well-protected and biologically diverse forests, managed by mimicking natural dynamics (Slovenia Forest Service, 2008). Forests cover more than 58 percent of Slovenia's surface (Figure 46), of which more than three quarters has a slope of greater than 20 percent (NFP, 2007), and as such forests reduce rapid surface runoff and significantly lower the impact of torrents (Papež and Kobal, 2018). The main management objective in these steep areas is the protective function of forests, and thus forest structure and tree species composition are altered in ways to achieve optimal protection.

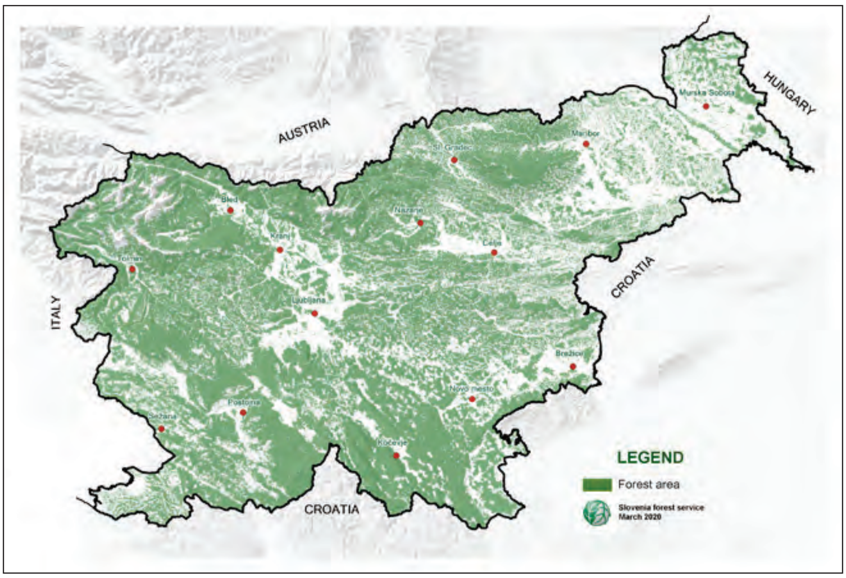

Figure 46 Forest map of Slovenia: 58 percent of the country is forested
Source: Slovenia Forest Service, March 2020.

The importance of the protective functions of the forest has long been recognized by forestry professionals. Already in June 1952, the first meeting of the Working Party on the Management of Mountain Watersheds (WPMMW) was organized with a focus on issues related to torrent control and avalanche protection. In February of the same year, Slovenia (at that time part of Yugoslavia) witnessed unprecedented winter events. In only three days, the now-capital Ljubljana received about a metre and a half of snow, while the highlands received about two metres, with even higher snowdrifts. The enormous amount of snow caused disastrous avalanches and devastated many forest areas (Gams, 1955). Following post-event analysis, a new cooperation was established between the Geographical Institute and the forest service. Despite meaningful events in the past and the recognized importance of protective forest functions by the Slovenia Forest Service (SFS), some challenges remain (Slovenia Forest Service, 2020). The main aim of this article is therefore to present the state-of-the-art in understanding the protective functions of forests in Slovenia, including management, research and challenges.

Forest area designated for protective functions

Forest management in Slovenia is regulated by the Forest Act (1993, and its subsequent amendments) and the National Forest Programme (NFP, 2007), a fundamental strategic document. As such, the protective functions of forests form part of all main legislations. The Slovenian NFP (2007) contains, among others, the main strategies for maintaining and strengthening the role of protective forests. Indeed, forest management in all forests, irrespective of ownership, is committed to respecting three main principles: sustainability, close-to-nature and multi-purpose forest management. The main tools for implementation of these principles are forest management plans, using participatory processes to address relevant public stakeholders, such as forest owners, municipalities, different organizations and the wider public. Furthermore, the increasing demand for a vast array of ecosystem services emphasizes the importance of multi-objective forest management. As a solution, the integration model of multi-objective forest management has been practised, presenting an essential management tool for implementing the concept of forest functions (Simončič and Bončina, 2015).

The Forest Act (1993, and its subsequent amendments) defines 17 forest functions that are classified into social, ecological and productive functions. The importance of each function is ranked according to three levels.

In the first level, the function determines the management regime. Second, the function influences the management regime and in the third level, the function has no significant influence on the management regime. Two forest functions are closely connected to the protective role of forests: 1) protecting forest soils and stands, hereinafter referred to as "indirect protective function"; and 2) protecting people, assets and properties, hereinafter referred to as "direct protective function". Additionally, the Forest Act (1993, and its subsequent amendments; article 43) declares that forests in extreme ecological conditions which protect themselves, their surrounding site and land below them, as well as forests with any other ecological function (for example, biodiversity conservation function)

Figure 47 Protective forest at the upper timberline in the Karavanks, consisting mainly of Norway spruce (*Picea abies*) and European larch (*Larix decidua*), and mountain pine (*Pinus mugo*) above

are in a special category, i.e. "protection forests." In fact, the majority of forests with indirect or direct protective functions are included in this category.

Indirect protective function

The indirect protective function, based on the *Rules on forest management plans and game management plans* (2010), is given to the forest stands protecting sites and the surroundings from all types of erosional processes. This is especially the case at extreme sites, at the upper timberline, on steep slopes, in dry areas and on shallow or rocky soils. Forests in areas influenced by erosion, landslides or avalanches, and in areas determined as protective in accordance with water regulations, also hold an indirect protective function. Such forests have a significant effect on downstream territories, thus beyond the forest area (Figure 48).

According to the regional forest management plans (Jonozovič et al., 2012), 190 941 hectares (16 percent of Slovenia's forest area) of forests have the first level of indirect protective function, out of which the following forest communities prevail: *Anemono trifoliae-Fagetum* var. geogr. *Helleborus niger* (14 percent), *Rhodothamno-Pinetum mugo* (11 percent) and *Ostryo-Fagetum* var. geogr. *Acer obtusatum* (9 percent). The second level of indirect protective function is defined on 309 039 hectares (26 percent of forest area)

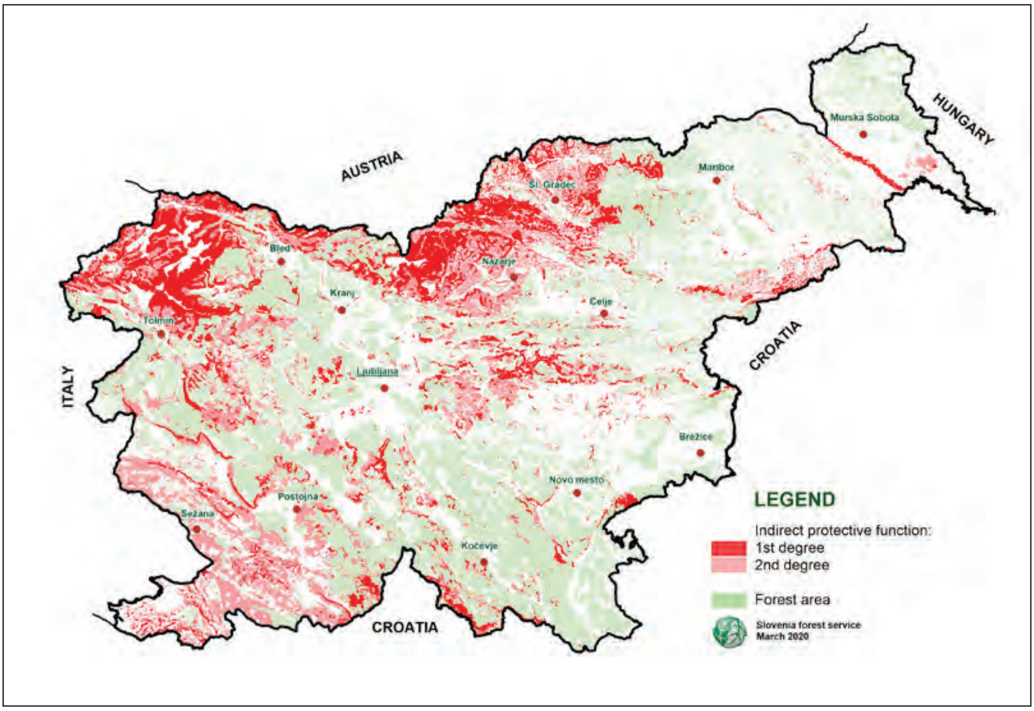

Figure 48 Forests with indirect protective function
Source: Slovenia Forest Service, March 2020.

(Figure 47), where *Seslerio autumnalis-Ostryetum* (18 percent), *Omphalodo-Fagetum* var. geogr. *Anemone trifolia* (8 percent) and *Castaneo-Fagetum sylvaticae* (7 percent) are most common (Guček et al., 2012).

Slope and altitude are the two most important and easily measured criteria for the determination of indirect protective function. More than two thirds of forests on slopes between 50 and 120 percent, all forests above 120 percent, and most of the forests above 1 400 m (more than 90 percent) and up to the timberline at 2 000 m altitude, including the dwarf or mountain pine (*Pinus mugo*), are assigned to have an indirect protective function. The largest areas of indirect protective function are therefore designated in the northern mountainous part of Slovenia (Figure 49).

Direct protective function

Direct protective function is assigned to the forests protecting settlements, infrastructure and other objects from natural phenomena and events, such as rock falls, avalanches, landslides or side winds, thus ensuring safe living conditions and the safety of infrastructure (Rules on forest management plans and game management plans, 2010).

However, the area of forests with a designated direct protective function is relatively small. Mostly it is near settlements and traffic infrastructure (Figure 50), but also in some forest patches and belts protecting agricultural land, infrastructure facilities

Figure 49 Forests fulfil indirect protective and hydrological functions (Slap Peričnik, Mojstrana)

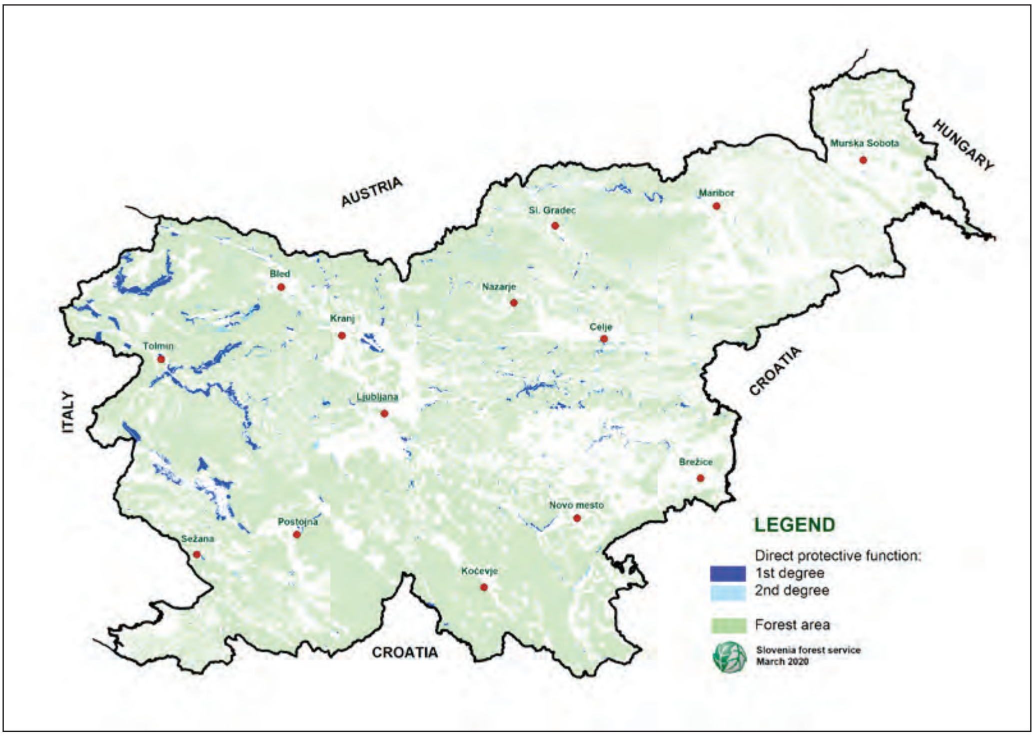

Figure 50 Forests with direct protective functions
Source: Slovenia Forest Service, 2020.

or settlements from strong winds, i.e. on the direct wind-exposed structural sides in the bora wind[35] area. Forests with the first and the second level importance of direct protective function together occupy only 32 495 hectares, which is less than 3 percent of Slovenia's forest area (Figure 51).

Protective forest

The decree on protective forests and forests with a special purpose (article 2, paragraph 1) defines "protective forests" as:

- forests that protect areas from sliding, rinsing and crumbling;
- forests on steep slopes or water banks;
- forests exposed to strong winds;
- forests that in the torrential areas retain water runoff and therefore protect the land from erosion and landslides;
- forest bands protecting forests and other land from wind, water, snowdrifts and avalanches; and
- forests in agricultural and suburban landscapes with an exceptional biodiversity conservation function, and forests at the upper timberline.

Figure 51 Direct protective functions of forest, as in this example in Tržič, Slovenia, where beech (*Fagus sylvatica*) dominated forests, mixed with Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) protect settlements and infrastructure

Protective forests (Figure 52) cover 98 762 hectares or 8.4 percent of Slovenia's forest area. Out of this territory, forest stands comprise 87.4 percent of the area, 10.5 percent is other forest land, mainly covered with mountain pine (*Pinus mugo*), and 2 percent is non-forest land. The average growing stock[36] in protective forest is 220 cubic metres per hectare, consisting of around 65 percent deciduous trees and 35 percent conifers. The dominant tree species in protective forests are beech (*Fagus sylvatica*) with 42 percent, followed by Norway spruce (*Picea* abies) 23 percent, European larch (*Larix* decidua) 6 percent, European hop-hornbeam (*Ostrya carpinifolia*) 6 percent, Scots pine (*Pinus sylvestris*) 3 percent and sessile oak (*Quercus petraea*) with 3 percent. The average annual increment is 4.4 cubic metres per hectare (with 1.4 cubic metres per hectare of conifers and 3.0 cubic metres per hectare of deciduous trees, respectively), which is significantly lower than the average in the whole of Slovenia (7.5 cubic metres per hectare).

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[35] Bora, originally defined as a very strong cold wind that blows from the northeast onto the Adriatic region of Italy, Slovenia and Croatia. It is most common in winter and occurs when cold air crosses the mountains from the east and descends to the coast; thus, it is commonly classified as a gravity wind. It often reaches speeds of more than 100 kilometres per hour and has been known to knock people down and overturn vehicles.

[36] Growing stock: Volume of all living trees in a given area of forest or wooded land that have more than a certain diameter at breast height. It is usually measured in solid cubic metres (m^3).

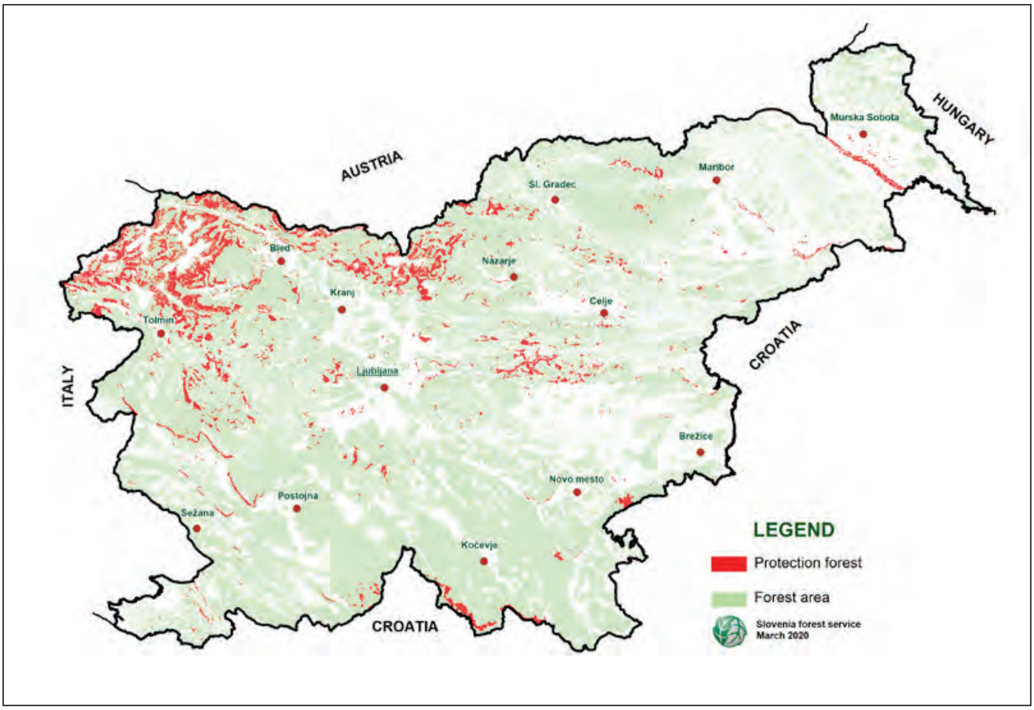

Figure 52 Protective forests in Slovenia
Source: Slovenia Forest Service, March 2020.

Management of protective forests

The management of protective forests is prescribed in the forest management plans at different spatial levels. These documents include guidelines and measures, but also restrictions, which limit management to interventions in order to improve the forest structure and tree species composition for direct or indirect protective forest functions, or other ecosystem services. Furthermore, the objectives and measures are defined based on the protection status. A small part of protective forests with highly important biodiversity functions is also included in the Natura 2000 network. In Slovenia, 71 percent of the Natura 2000 area comprises forests, with Natura 2000 management integrated into the forest management planning (PUN, 2015; Poljanec, 2019). In these areas, Slovenia is committed to providing a favourable conservation status for 11 forest habitat types of local importance and for forest plant and animal species of European importance. Accordingly, the protective function is harmonized with biodiversity conservation.

In some areas of protective forests, wild game can have significant adverse effects on forest stand dynamics. Thus, wildlife management is an important tool to reduce browsing impact. In wildlife management plans, measures for controlling game populations are annually planned in order to reduce the pressure on forest regeneration. As such, the browsing rates and success of forest regeneration are periodically monitored at two- to four-year intervals (Hafner *et al*., 2016).

Compared to other forests, forest management in protective forests is more challenging.

This is due to extreme site conditions, low profitability, dangerous working conditions, challenging ownership structures (for example, low motivation of forest owners to manage their forests due to economic inefficiency), and scarce skidding[37] and forest roads that are nonetheless necessary for maintaining an optimal forest structure.

The implementation of measures in forests with indirect and direct protective functions forms mostly part of regular close-to-nature silviculture[38]. However, there also exist specific requirements and restrictions such as the promotion of an uneven-aged small-scale stand structure, and a stable and diverse forest structure. There is a lower growing stock on high slopes due to the requirements of stable forest stands. Hence, high tree stumps are left standing, while logging and skidding on potentially erodible areas are prohibited. The prescribed measures also focus on tree damage reduction from extreme weather events (windthrows,[39] ice or snow breaks) or pests and diseases (for example, bark beetle calamities), as well as on fostering forest restoration and biodiversity conservation.

According to the Decree on protective forests and forests with a special purpose (2015), measures and actions not connected to the management of protective forests may be necessary, such as the creation of skid trails, forest roads and other infrastructure. However, these measures and actions should have no significant effect on the protective functions, and only carried out on the basis of an obtained permit, issued by the Ministry of Agriculture, Forestry and Food.

Research on the protective effect of forests

Research dealing with the protective effects of forest is an important part of adaptive forest management. Therefore, new knowledge on forest stand dynamics, different influential factors, such as changing climate conditions, management interventions, among others, are crucial for addressing future forest management challenges in protective forests. As a result, funds for research on protective forest, provided by the ministries and the governmental agency for research, have been intensified over the last 10 years. The research has focused on: the delineation of areas with protective functions; assessing the forest's protective effect against avalanches, rockfalls and debris flows; and silviculture measures for maintaining long-term protective functions. The majority of the research was conducted by universities, scientific institutes and the forest service. Indeed, the research has included studying qualitative processes and systematic investigations. It has formed part of activities under various national and international projects, for example:

- Manfred Project – Management Strategies to Adapt Alpine Space Forests to Climate Change Risks (Alpine Space Programme, 2007) (carried out by the Slovenia Forest Service, and Slovenian Forestry Institute);
- Applied research project Protective forests (2011): developmental characteristics, risk assessment, silviculture measures and technology of exploitation, carried out by the University of Ljubljana, Biotechnical Faculty;

[37] Skidding is the process by which any type of heavy vehicle is used in a logging operation for pulling cut trees out of a forest, so that the logs are transported from the cutting site to a landing, where they are loaded, and sent to the mill.

[38] Close-to-nature silviculture is a form of silviculture adapted to the forest habitat and stand conditions, and the role of the forest – and promotes natural structures and processes such as natural tree species composition, natural regeneration, soil productivity, nutrient cycling or biodiversity.

[39] Windthrow in forestry refers to trees uprooted by wind.

- Interreg Alpine Space project RockTheAlps (Harmonized ROCKfall natural risk and protective forest mapping in the ALPine Space) (RockTheAlps, 2016) – carried out by the University of Ljubljana, Biotechnical Faculty-Department of Forestry, Slovenia Forest Service, and Slovenian Forestry Institute; and
- Interreg Alpine Space project GreenRisk4ALPS with development of ecosystem-based approaches for the support of risk management activities in connection with natural hazards and climate change – carried out by the University of Ljubljana, Biotechnical Faculty-Department of Forestry, and the Slovenia Forest Service (Alpine Space Programme, 2021).

Promotional and extension activities dealing with protective forests

Promotion and outreach activities address relevant stakeholders in forestry with the aim to inform comprehensively about the importance of the protective functions of forests. To achieve this, we use different ways of outreach (personal contact and distant, individually and in groups), different methods (counselling, workshops, training, among others) and all possible information and education channels (media, internet, training, lectures, etc.). With these activities, we want to achieve two main goals: 1) the content of the statutory regulations and policies in the forest management plans have to be transferred to stakeholders; and 2) the scientific results are transferred to users, with an emphasis on the forestry experts in the forest service.

A good example is the workshop on "Forestry operations in protective forests with the emphasis on rockfall areas," which was developed within the RockTheAlps project (Figure 53). The main goal of this workshop was to transfer scientific results and legal

Figure 53 Field workshop about forestry operations in protective forests with the emphasis on rockfall areas

policy to those who need such knowledge in their everyday activities. This includes knowledge about rockfall problems, the importance of protective forests in the Alpine space and understanding about management of such forests, with an emphasis on practical forestry operations. The target groups of this knowledge transfer were forest owners, forestry operations contractors, municipalities and forestry professionals. The workshop was composed of theoretical and practical elements in the field, and forms part of the Slovenia Forest Service outreach activities.

Challenges in forests designated for protective purposes

In the past, a non-intervention strategy was widely accepted in protective forests and, in some cases, this still is practised. Despite some of the advantages (for example, no costs, no risks for forest workers, temporarily increased protective effects, potential habitat for rare species, among others), a non-intervention strategy diminishes the resilience of the stands against disturbances. Uncleared windthrow areas, for instance, may trigger bark beetle outbreaks and insufficient mid-term protection of disturbed and uncleared areas (Brang *et al*., 2006). Mainly due to limited management of protective forests in the past, today many forests in the Alpine space show an even-aged[40] and over-aged structure without sufficient regeneration (Brang *et al*., 2006; Diaci, 2012). Ageing of the forest stands and lack of proper management lead to higher susceptibility to natural disturbances, which could in the future represent a major threat for maintaining the long-term stability and the protective functions of these forests. Therefore, intensification of proper forest management represents, apart from climate change, the main challenge for protective forests.

Figure 54 Forests are important for the provision of drinking water and regulation of water regimes as, for example, in this beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) dominated forest near Kropa in the northern part of Slovenia

Another issue linked to inactive management of protective forests is the influence of forest management activities on torrents (Papež and Kobal, 2018). The

[40] By definition, an even-aged stand is one in which the trees are within 20 percent of a given age, relative to the rotation length. Rotation length is the period of time that forest trees are grown before they are cut and a new regeneration cycle starts.

combination of infrequent torrent supervision or control, extreme weather events and improper forest management in torrent areas can result in so-called logjams. A good solution could be an amended legislation, granting the Forest Service more authority to actively cooperate with the public water management service and forest owners to proactively remove timber from torrents (Figure 54).

The main impacts of agriculture in protective forests are livestock grazing and changing the land use from forest to agricultural use. According to the Forest Act (1993), livestock grazing in forest is not allowed, but may be permitted on exception in a silvicultural plan on the basis of criteria set out in the regulations on the protection of forests.

Forests with protective functions are also important from a social aspect, as most of them are located in mountainous areas, which are attractive for recreation, tourism and other outdoor activities. The most common forms of recreation are hiking, mountain biking and skiing. In fact, ski resorts are often located in areas of forests with indirect protective functions. As a result, that can be the reason for some disagreements on a local scale between the interests of recreation or tourism and the protective role of the forest. In most cases, these conflicts can be resolved locally.

Conclusions

The long-term stability of forests protecting human infrastructure and sites will become crucial in a climatically unstable environment (Poljanec, 2019). In recent decades, the climate in Slovenia has changed with novel trends observed in air temperature and precipitation regimes (Kajfež *et al.*, 2010), as well as climate change-induced higher frequencies of extreme weather events. As a result, these changes could lead to less resistance to pests and diseases of some key tree species (Poljanec, 2019). The main challenge in future forest management is therefore to adapt the forest structure and tree species composition. The aim is to increase the stability and resilience of all forest stands to predicted natural disasters, as well as to strengthen the direct and indirect protective functions of forests. Failing to do so could result in vast bare areas, as the frequency of stress events is shorter than the long period required for forest restoration. Consequently, due to reduced drainage and enhanced erosional processes, the likelihood of landslides and avalanches significantly increases. Recalling the year of 1952, the question arises what would be the knock-on effects of enormous amounts of snow in Slovenia today?

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SWITZERLAND

Benjamin Lange[1], Arthur Sandri[1] and Stéphane Losey[1]

[1] Federal Office for the Environment FOEN Switzerland

Introduction

Based on the assumption that forests protect against natural hazards, forest use was limited in certain forests in Switzerland already in the fourteenth century (Schuler, 2015). In 1876, the Swiss Forest Inspectorate Act came into force. This act was a reaction to various natural disasters in the nineteenth century, placed Swiss mountain forests under strict protection and laid down the principles of sustainable management (Federal Office for the Environment, 2013). The act also included a definition of protective forests and the Cantons were obligated to delimit forests with a protective function within two years. Since then, experts, researchers and practitioners have dealt extensively with protective forests, and the knowledge in protective forest management has increased substantially due to better understanding of natural cycles of forests and a deeper insight into natural hazard processes and the influence of forests on these processes.

In this article, we show which legal bases are relevant today for protective forest maintenance in Switzerland and how the Confederation, the Cantons and third parties, such as municipalities, infrastructure operators and forest owners, implement the management of protective forests as a joint task.

Protective forest policy and governance

Protection against natural hazards is a joint task of the Confederation, the Cantons and third parties, such as municipalities. The Confederation assumes an overarching strategic role at the national level, while the Cantons are responsible for operational implementation. This division of tasks is also reflected in the legislation. According to Article 77 of the Swiss Federal Constitution, the Confederation has to ensure that the forests are able to fulfil their protective function. Furthermore, the Forest Act of 1991 states that *The forest shall be managed in such a way that it can fulfil its functions without interruption or restriction (sustainability)… Where required by the protective function of the forest, the Cantons ensure a minimum level of maintenance.* The ordinance on forest also states that *The Cantons shall issue regulations for the planning of forest management and the forestry planning documents must describe, at least, the location conditions, as well as the forest functions and their importance.*

In the case of interoperational planning, the Cantons shall ensure that the population: (1) is informed of the goals and progress of the planning; (2) may be involved in a suitable manner; and (3) may inspect it. This procedure ensures that the Cantons can adapt the implementation of protective forest management to their specific structures and that the forest owners concerned can comment on forest planning.

A precise analysis of the legal mandate leads to the following questions:

- Where? This requirement needs to be spatially limited.
- Protective function? This term needs to be defined.
- Minimum level of maintenance? The minimum level needs to be defined.

A well-founded and uniform delimitation of protective forest would be decisive in answering the first two questions. In 2003, the Federal Government and the Cantons decided therefore to initiate a harmonized protective forest delimitation that is based on objective criteria. In a first step, a common ground was set by establishing a generally accepted definition: *A protective forest is one which protects against an acknowledged potential damage or natural hazard, or reduces the potential risks.* (Losey and Wehrli, 2013).

Delimitation of protective forests

To implement the protective forest delimitation according to uniform criteria throughout Switzerland, the Federal Office for the Environment has undertaken simulated hazard processes in relation to damage potential and to forested area. These simulations served as a basis for the harmonized protective forest delineation of the Cantons. For this reason, the project SilvaProtect-CH was launched (Losey and Wehrli 2013), which comprises four main steps:

1. **Modelling hazard perimeter:** Relevant hazard processes (avalanches, rockfalls, landslides and channel-related processes, such as debris flow, overbank sedimentation and driftwood accumulation) were modelled for Switzerland with data that are available in consistent quality for the whole country. On this basis, the spatial hazard perimeters were assessed.

2. **Determining the damage potential:** The damage potential was defined, based on digital data that are available in consistent quality for Switzerland. This damage potential corresponds to the infrastructure (for example, buildings, roads and railway lines), whose protection by technical measures is permitted by law and supported by subsidies of the Confederation.

3. **Evaluating damage-relevant process areas:** Hazard perimeters that may damage the protecting infrastructure were specified.

4. **Determining the damage-relevant process areas in forests:** It was evaluated which of the damage-relevant process areas evaluated in step 3 lie within forests and where the forest is able to mitigate the damage potential. For avalanches, only the starting zone (that portion of an avalanche path where a slide originates) was considered, since it was assumed that forests do not have significant protective effects in the transit and deposition area.

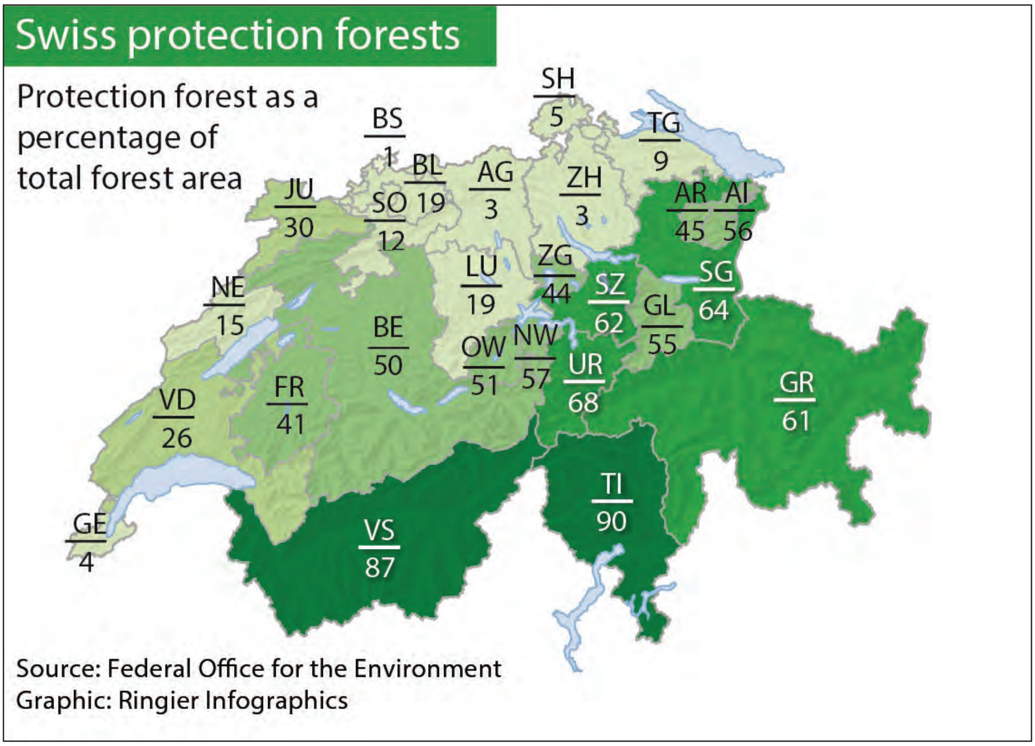

Figure 55 Percentage of protective forest in relation to the total cantonal forest area
Source: Federal Office for the Environment, 2021; Graphic: Ringier Infographics.

Based on these damage-relevant process areas in forests, the Cantons delimited their harmonized protective forest. This procedure ensures consistent and comparable protective forest delimitations of the Cantons. The cantonal protective forest delimitations show that approximately 50 percent of the forested area in Switzerland has a protective function (Figure 55).

The federal government also uses the damage-relevant process areas in forests to allocate federal funds to the Cantons. This involves calculating the proportion of each Canton in the total area of protective forest in Switzerland. Based on this so-called "protective forest index," federal funds are distributed to the Cantons.

Protective forest cover and natural hazards

As already mentioned above, rockfall, landslide, avalanche and channel-related processes were taken into account in the delimitation of protective forests. However, pure flood protective forests were not considered, as satisfactory modelling was not possible. Furthermore, it is not clear how the condition of the forest influences the process. Nevertheless, many of the former flood protective forests coincided with the channel-related protective forests and were therefore included in the delimitation of protective forests.

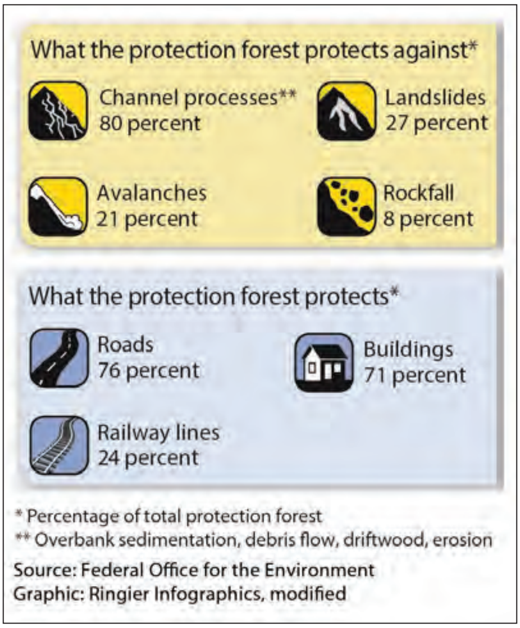

Figure 56 Process-related protective effect of the forest and damage potential
Source: Federal Office for the Environment, 2021; modified by Ringier Infographics.

The majority of protective forests in Switzerland, i.e. around 80 percent, protect against channel-related processes (overbank sedimentation, debris flow and driftwood accumulation). Protection against landslides or avalanches is provided by about a quarter to a fifth of the protective forests. Only a relatively small percentage of forests offer protection against rockfalls (approximately 10 percent). The most frequently protected damage potentials are roads, followed by houses and railway lines. Since protective forests can act against several natural hazard processes in the same area and protect several damage potentials, the percentages add up to more than 100 percent (Figure 56).

Programme agreement for protective forest management

Since 2008, protective forest management has been implemented within the framework of a result-oriented performance agreement between the Confederation and the Cantons.

This performance agreement consists of the so-called "protective forest" programme agreement, which is concluded between the Confederation and the Cantons over a period of four years. In addition to the underlying objective of protective forest management, this programme agreement also defines goals in order to ensure the infrastructure required for protective forest management and forest protection. In total, the Confederation provides around CHF 70 million annually for the Protective Forest Programme. Most of the funds are used for the maintenance of protective forests (around 65 percent), while around 25 percent of these funds are spent on infrastructure and 10 percent on forest protection. Based on surveys conducted throughout Switzerland, the average net costs (costs minus timber revenue) incurred for the maintenance of protective forests correspond to CHF 12 500 per hectare, including measure planning and success monitoring. The Confederation provides CHF 5 000 in compensation for each contractually agreed hectare of protected forest area treated, i.e. 40 percent of the average net costs. The federal contribution also covers 40 percent of the net costs for securing infrastructure and forest protection. The remaining costs for all programme objectives are borne by the Cantons and other beneficiaries, such as communes or infrastructure operators. In total, it costs approximately CHF 175 million annually to preserve the protective function of forests. If the forest owner does not simultaneously bear public responsibility for safety against natural hazards, there should be no remaining costs from the maintenance of the protective forest.

Quality in protective forest management

The programme agreement not only regulates the objectives and financial content, but also the quality indicators for how protective forest management should be performed. The core element in this regard is the enforcement aid entitled "Sustainability and Success Monitoring in Protective Forests" (German abbreviation: NaiS) (Frehner, Wasser and Schwitter, 2005; Sandri, Lange and Losey, 2017; Lange, Losey and Sandri, 2017). Within the framework of the programme agreement, this guideline is a legally binding instrument for subsidized silvicultural interventions in protective forests. As such, NaiS describes requirements and suitable instruments for protective forest management.

The guideline defines so-called target profiles that describe tree stand conditions (tree species composition, stand structure, stability and regeneration), which should have strong protective effects in the long term. This indicates that not only the protective effect, but also the sustainability of the stand, is included in the requirements of the target profiles. As an example, an increasing number of trees per area improves the protective effect against rockfalls. However, when the forest becomes too dense, the stability decreases and disturbances may reduce the protective effect. Thus, long-term protection is not ensured. For this reason, the target profiles subsume site- and hazard-related requirements. NaiS defines for each natural hazard and forest site type two target profiles: first, the long-term silvicultural target (ideal profile), and second, the benchmark for the need for action (minimum profile). While the target condition of the forest is specified in NaiS, the definition of the effective and proportionate measures leading to this target condition is left to the local experts. They are familiar with the local conditions and, therefore, responsible for the implementation of the treatments.

Determining the need for action is the most important procedure in the planning of sustainable protective forest management. This assessment is based on a comparison of the current state of a forest with the target profile, taking into consideration the natural forest dynamics. The minimum target related to natural hazards, as well as the site, serves as a benchmark. This is compared with the predicted probable development of the forest stand without interventions, which accounts for the natural forest dynamics.

Indeed, this comparison is made for all important forest stand characteristics. To simplify this comparison, a form was developed that enables us to determine the need for action in an easy and comprehensible way. As a first step, the site type and the relevant natural hazard are determined. Then, the minimum target profile for both the natural hazard and the corresponding site type is derived. The next step is to record the characteristics used in the minimum profile (species mixture, vertical and horizontal structure, stability carriers, seedbed, small and large saplings) of the forest stand.

Since a forest continually changes even without interventions, predictions are made for all the characteristics for the next 10 to 50 years. With this procedure, the natural dynamics of the forest can be taken into account when deciding whether an intervention is necessary. In making this decision, the expected conditions of all the characteristics in 50 years are compared with the minimum profile. If the predicted conditions are worse than the minimum profile, effective interventions should be considered in order to improve the development. Provided the recommended interventions are assessed as reasonable, there is a need for action.

This procedure ensures that protective forest maintenance is of comparable quality throughout Switzerland and that protective forests have a sustainable effect at a minimum cost.

The "Sustainability and success monitoring in protective forests" enforcement aid is not the only quality indicator of the "protective forests" programme agreement. The whole programme includes seven quality indicators that guarantee a sustainable protective forest. The quality indicators include requirements for forest protection, infrastructure, control mechanisms and the influence of wild game on forest regeneration.

Challenges

At this time, Switzerland's protective forest management system is working well and is recognized and appreciated by all partners involved, such as Cantons, communes, forest districts, forest managers and forest owners. The financing of services, minimum maintenance in accordance with the NaiS and the clear division of tasks between the Confederation and the Cantons are important success factors. Despite these largely positive experiences, there are challenges and questions that still need to be addressed.

Climate change

One of the central challenges is the influence of global warming on the protective forest. As temperatures rise, certain forest communities will change their tree species mix (Allgaier Leuch, Streit and Brang, 2017). Silvicultural decisions that affect the species spectrum of the trees should take into account the changing climatic conditions. This is a major challenge, especially since these decisions have to be made on the basis of scenarios. To obtain answers to questions about the effects of climate change on forests, the Confederation initiated a research programme entitled "Forests and Climate Change" in 2009. When carrying out the projects, the expected changes in some forest communities were also modelled, based on different climate scenarios. However, the question of how the findings can be applied to the guideline for protective forest management (NaiS) is currently under discussion and still needs to be answered.

Certain changes are also expected in the hazard processes due to global warming, even if we assume that the shift in tree species composition will be the greater challenge in protected forests. Avalanches at lower altitudes are becoming rarer, but are likely to remain a major natural hazard in subalpine areas at least until the end of the twenty-first century. Protection against rockfalls, shallow landslides and flooding is becoming increasingly important (Bebi *et al*., 2016), although the expansion of forests to higher altitudes could easily improve the situation locally. Furthermore, increased risks of disturbances, forest fires and bark beetle epidemics must also be considered.

Two important questions arise in connection with the management of protective forests: the influence of browsing by wild game on forest regeneration and the willingness of the public sector to finance the safeguarding of the protective effect of forests. If game density continues to increase, the ecological balance of the forest will not be secured in the long term due to a lack of regeneration. Therefore, solutions for this challenge need to be sought. Compared to technical protective structures, protective forests are in most cases much cheaper. From a financial point of view, there must be willingness at both the federal and the cantonal levels to make the funding available in the long term for necessary maintenance measures so that the protective effect of the forests is guaranteed.

Public awareness of protective forests

In 2010, the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) launched a research project to examine the Swiss population's attitudes and behaviour in relation to the forest. The survey was carried out in late 2010 and was answered by 3 022 representative respondents.

When asked which of the forest functions is most important, the majority of respondents answered that the forest is a habitat for animals and plants and provides protection against natural hazards. A 95-percent majority of those surveyed believe that public contributions for forest management are justified or somewhat justified. Federal and cantonal contributions should be used first and foremost for forest management. Forest maintenance is particularly important in protective forests. Thus, protective forests also receive the most federal subsidies by far. Indeed, the results of the survey confirm this assertion (BAFU and WSL, 2013).

Good practices

In principle, all protective forests in Switzerland are maintained in accordance with the NaiS quality criteria. It can therefore be assumed that protective forests are maintained in a target-oriented, effective and efficient manner. The results of random checks carried out by the Confederation support this assumption.

According to the quality criteria of the programme agreement on protective forests, the Cantons must set up and maintain so-called "indicator plots." The indicator plots make it possible to explore silvicultural issues and are used for success monitoring. Successful protective forest interventions have taken place on many of these indicator plots and can serve as good practice examples. One example is the Weiserfläche in Ritzingen in the Canton of Valais. This area has been the venue for regular meetings of protective forest experts active in practice, research and administration since 1986. The experts have examined and discussed the effects of past interventions and carried out analyses effectivity. A database with several hundred such indicator plots and corresponding documentation can be found on the homepage of suissenais.ch (in German and French only).

Conclusions

The management of protective forests in Switzerland has reached a remarkable level: protective forests have been delimited according to uniform criteria. With the enforcement aid NaiS, a guideline exists which is widely accepted in practice, research and politics. As such, protective forests are managed throughout Switzerland according to uniform criteria and of high quality. Moreover, the public authorities are prepared to provide the necessary funds for protective forest maintenance. Furthermore, in cooperation with research and practice, the basic principles of protective forest management are constantly being developed.

Therefore, the conditions set up for forest management are effective so that Switzerland's protective forests can continue to fulfil their functions in a sustainable manner, though climate change is a major challenge.

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TURKEY

Şenol Oktay Keten[1] and Ibrahim Ergüven[1]

[1] Ministry of Agriculture and Forest, General Directorate of Forestry, Department of Soil Conservation and Watershed Rehabilitation

Introduction and general information

Protective forests, known to be covered with maquis[41] vegetation and heath, differ from state forests as their purpose includes the protection of air quality in residential districts, the protection of railways and highways against sand and dust storms, and the conservation of riverbeds. In addition, protective forests confront the impact of erosion by rain or landslides. Furthermore, they comprise forests whose role is to protect national lands. As forests in Turkey are all state owned, protective forests are managed by the General Directorate of Forestry (OGM). Nevertheless, the General Directorate of Nature Conservation and National Parks is responsible for recreational and hunting functions in protective forests. Activities in protective forests are implemented by the OGM according to ecosystem-based functional planning and no profit is pursued (Figure 57).

Figure 57 View of Inkum protective forest

[41] Maquis is a shrubland biome in the Mediterranean region, typically consisting of densely growing evergreen shrubs.

Within this perspective, protective forests are managed to provide different benefits such as soil conservation, ecosystem services, recreational activities, production and protecting human health, among others. If protective forest conditions are suitable for the production of timber, silvicultural activities are permitted. In accordance with ecosystem-based functional planning, harvests, thinning and plantation activities are determined and notified to regional directorates. Funds for the activities' costs are sent to regional directorates based on area size and type of implementation. Monitoring of protective forests is also included in the ecosystem-based functional planning approach.

There are 55 licensed protective forests that cover 251 520 hectares (1.15 percent) of total forest area in Turkey. Protective forests are managed under the regulation of "Management and Separation of Protective Forests," which entered into force in 1984 and aims to comply with the articles about protective forests in Forest Law 6831. The regulation includes details that address the following subjects:

- management of protective forests;
- implementation of management plans;
- construction of roads, facilities and buildings;
- regulation of recreation and hunting;
- grazing and mowing;
- permitting mineral exploitation; and
- penalties for damaging protective forests.

Protective forests are separated into two categories consisting of permanent separation or temporary separation.

The conditions for permanent separation of forests are:

- places that have the possibility of disasters caused by avalanches, landslides or erosion;
- favourable for environmental health in residential districts;
- providing protection for railways and highways from sand and dust storms;
- preventing dams, lakes and riverbeds being infilled; and
- important for national defence.

In order to submit a forest as being protective forest, the forest must fulfil at least one of the conditions mentioned above.

The conditions for temporary separation are those forests:

- degraded in any condition;
- damaged by wildfires; and
- planned to be used in order to meet production needs.

The Ministry of Agriculture and Forest takes responsibility for protective forests by publishing the regulation. Protective forests are not separated by local or regional levels by the regulation. Nevertheless, the regulation is meant to be applied at the local level and ecosystem-based functional planning is also locally prepared. During the preparation of the plan for protective forests, OGM follows the regulation with high sensitivity. Within this scope, neither beneficiaries nor other agencies are involved.

Protective forests have many functions contributing benefits to people. They play a role in erosion control, conservation of water sources, preservation of endemic species, rehabilitation of natural resources, recreational activities, promoting human health, supporting livelihoods, and the conservation of wildlife and their habitats. Protective forests influence the rehabilitation processes of current ecosystems in a positive way. Therefore, protective forests have a substantial effect in terms of improving and enhancing forests and the environment in mountainous watersheds. However, the most important functions of protective forests are to protect people's lives, water resources, electricity lines, main roads and other infrastructure. Moreover, a healthy forest ecosystem has always been attractive for people to visit and enjoy, and that is why protective forests are essential for recreational purposes. Since Turkey has a wide range of different climate conditions and geological structures, protective forests also provide touristic functions.

Forest types in Turkey differ due to the changing climate characteristics from north to south and from east to west. Therefore, protective forest stands comprise a number of forest types and tree communities. For instance, protective forests in the North have mainly Oriental beech (*Fagus orientalis*) and Oriental spruce (*Picea orientalis*) species. Turkish red pine (*Pinus brutia*) and Taurus cedar (*Cedrus libani*) are common tree species in the South. In brief, tree communities in protective forests in Turkey consist of several oak species (*Quercus* spp.), Scots pine (*Pinus sylvestris*), black pine (*Pinus nigra*), Oriental beech (*F. orientalis*), Turkish red pine (*P. brutia*), Taurus cedar (*C. libani*), cilician fir (*Abies cilicica*), black alder (*Alnus glutinosa*), hornbeam (*Carpinus orientalis*) and Oriental spruce (*P. orientalis*).

These common tree species have both advantages and disadvantages in protective forests. Some examples are:

- Turkish red pine (*Pinus brutia*) is a light-demanding tree species. This is why it grows faster and reduces biodiversity in protective forests; on the other hand, it provides fallen pine needles which cover the soil and contribute to soil conservation;
- Oak (*Quercus* spp.) are found all over Turkey and protect the soil by covering a huge area in protective forests;
- Beech-dominated (*Fagus orientalis*) forests have a rich capacity for providing organic matter, which induces an increase in the infiltration capacity of the soil;
- The central part of Turkey lacks ground vegetation, yet the needles of the black pine (*Pinus nigra*) help reduce soil evaporation and increase water availability.

Challenges

Although wild game may disturb some forests in general, wildlife damage is not widely seen in the protective forests of Turkey. The General Directorate of Nature Conservation and National Parks has the responsibility for wildlife conservation. Within this scope, hunting permissions and prohibitions are given out by the General Directorate of Nature Conservation and National Parks in relation to wildlife condition concerns. However, the main damage in protective forests is caused by wildfires, snow, insects and human pressures. For the purpose of informing the public about protective forests, OGM reaches out to people by using leaflets, videos and social media.

Climate change has an obvious impact on protective forests as precipitation regimes have been changing year by year. Nevertheless, the most particular issue that impacts protective forests is soil erosion due to heavy rainfall and the increased amount of precipitation. Although there are some regions where precipitation has decreased due to climate change, generally precipitation has increased, and indeed climate change has even influenced some regions in a positive way. For instance, increased precipitation has contributed to certain plant species benefiting and improving ecosystems. Hence, it seems that climate change may have not only negative effects but also positive effects in Turkey.

One of the main issues associated with climate change is the greenhouse gases being released into the atmosphere. In order to reduce carbon emissions, OGM conducts plantation and soil conservation projects, and implements enhancement activities for the forest flora and understorey all over the country. The aim is to produce more carbon sequestration and carbon storage in soils and forests, thus contributing to decreasing atmospheric carbon levels and as such reducing the impacts of climate change on protective forests.

An example is Inkum protective forest, which was established as protective forest in 1964. The area covers 136.1 hectares, close to the city of Bartin in northern Turkey, and has different functions as a protective forest. Bartin has a popular beach beneath Inkum, which is vulnerable to both human impact and natural disasters. Therefore, the protective forest at Inkum safeguards the natural beauty of the beach by preventing erosional damage and protecting the public from floods and torrents that may otherwise originate from the area where the forest is located.

Further reading

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3. Concluding remarks

The members of the European Forestry Commission Working Party of the Management of Mountain Forests have found that protective forests and the protective functions that they provide are essential in responding to the current changing climatic conditions. Sharing knowledge of protective forests from various countries within Europe and their respective practices, legislation, history and experiences provides a unique opportunity to learn about the geographical and cultural differences. It also allows for better understanding of ways to increase the resilience of mountain forests and ensure the sustainability of their protective functions for society.

Protective forests provide ecosystem services such as controlling soil erosion and water retention, and even more important tasks such as mitigating natural hazards, including floods, landslides and avalanches. All these potential hazards may increase in frequency due to climate change, which in return increases the significance of these forests. However, there are limitations and challenges that these European protective forests face such as limited diversity of tree species, being over- or even-aged, and higher susceptibility to large-scale impacts that include forests fires, windstorms and pest infestations. Other challenges include difficulties in the implementation of integrated strategies due to largely privately owned forests, contradictory interests, as well as fragmentation of ecosystems.

These common challenges posed by climate change can be addressed by integrating mitigation and adaptation into protective forest management and moving from a reactive to a risk prevention approach. These actions include modelling future scenarios, changing the species composition of the protective forest stands and ensuring that financing is aimed at supporting climate-adapted forest conversion. Most countries also involved forest owners and even people not living in direct proximity of the locations in awareness campaigns of how the forests are protecting their lives and livelihoods.

In conclusion, the European countries involved in this report confirm the importance of protective forests. This review compiles various country reports in order to identify common challenges and approaches to deal with climate change through the management of protective forests, and foster further actions in transboundary and international cooperation.

For more information, please contact:

Forestry Division - Natural Resources and Sustainable Production
E-mail: FO-Publications@fao.org
Web address: www.fao.org/forestry/en

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