

Mountain Watersheds and Ecosystem Services: Balancing multiple demands of forest management in head-watersheds

Roberto Tognetti, Giuseppe Scarascia Mugnozza and Thomas Hofer (editors)



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PREFACE

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Due to steep slopes, extreme climate and severe weather events, mountain forests are fragile ecosystems. However, forested watersheds provide important goods and services and their management requires special planning and adequate measures to sustainably secure the productive, protective and cultural functions. Building climate resilience of head watersheds in mountain regions requires reviewing management strategies and approaches of mountain forests as a source of water for downstream users. Conflicting visions between upstream and downstream communities are increasing as a result of too simplified thinking about forest-water dynamic by the public and policy-makers. Hence, a better understanding of people and resource dynamics is needed to assess the multi-functionality of watershed services.

The European Forestry Commission Working Party on the Management of Mountain Watersheds (EFC WPMMW) has been active since 1952, promoting the conservation and rehabilitation of degraded lands through the rational use of water resources in mountain watersheds. The Working Party meets every two years to exchange information on the management of forests and watersheds, in the context of hazard, risk, and vulnerability in mountain regions, towards strengthening the resilience in mountain areas to climate change and disaster risks and preserving watershed's provisioning functions in terms of water, wood and energy.

The topic of the 30th Session that was held in Pieve Tesino (Italy) at the premises of the Centre for Alpine Studies of the University of Tuscia-Viterbo, 22–24 September 2015, was perfectly in line with the core objectives of the EFC WPMMW. The session focused on “Mountain Watersheds and Ecosystem Services: - Balancing multiple demands of forest management in head-watersheds”. Supported by the Autonomous Province of Trento (Italy), the local organizer was the European Forest Institute Project Centre on Mountain Forests (MOUNTFOR), which is hosted by the Edmund Mach Foundation (FEM) in San Michele all'Adige (Trento), and with the sponsorship of the Italian Ministry of Environment, Sea and Land Protection and of the Alpine Convention.

The session was attended by more than 50 delegates, lecturers and observers from the following countries and international organizations: Australia, Austria, Canada, Czech Republic, Finland, France, Italy, Japan, Poland, Spain, Romania, Switzerland, International Union of Forest Research Organizations (IUFRO), Alpine Convention, FAO sub regional office for central Asia

and FAO headquarters. An expert and stakeholder training dialogue was conducted in cooperation with experts of the Alpine Convention and the Ministry of the Environment and Protection of Land and Sea of Italy. The invited stakeholders used the opportunity to discuss the following topics with the experts present at the session of the WPMMW: 1) Forest, water, natural hazards; 2) Protective forests, and 3) Forests and green economy.

Ecosystem services comprise supporting, provisioning, regulating and cultural services and forests contribute to all these categories. The services provided by mountain forests range, among others, from erosion control, clean water to biodiversity and recreation. These multiple roles and the high sensitivity of head watersheds to environmental and socioeconomic changes encompass the need of balancing the different demands on forests through sustainable forest management. A shared understanding on how watershed management activities contribute to mitigating adverse impacts of these changes, as well as on the sustainable use of the ecosystem services provided by mountain forests is required. MOUNTFOR has recently fostered the COST Action Climate-Smart Forestry in Mountain Regions (CLIMO), funded by Horizon 2020 framework programme, which proposes a strategy to modernise the appeal and vision of mountain forests and build a “whole” green infrastructure at the continental scale.

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PROVINCIA AUTONOMA DI TRENTO



1. EXECUTIVE OVERVIEW

1.1 Promote sustainable development in mountain watersheds and ensure the long-term provision of forest ecosystem services

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1.1.1. Forest ecosystem services in mountain watersheds under climatic changes

Forests in general provide a wide range of ecosystem services (MEA 2005). Including supporting (e.g., nutrient cycling and soil formation), provisioning (e.g., fuel and timber), regulating (e.g., climate regulation and water purification), and cultural (e.g., recreational and aesthetic functions) services. Alongside these categories, the specific services provided by forests in head-watersheds comprise, among others, erosion control, clean water to biodiversity and recreation. The multiple roles and the high sensitivity of head-watersheds to environmental and socioeconomic changes encompass the need of balancing the different demands on forests by sustainable forest management (FAO 2013). A shared understanding of how watershed management contributes to sustainable provision of forest ecosystem services (FES), and to mitigation of negative impacts of changes, is required. This is also underlined by the increasing importance of the role of forests in various international processes, such as in the recently adopted Sustainable Development Goals (SDGs) of the United Nations (e.g., Manuelli et al.

2015). There, forests are not only mentioned in forest and forestry issues, but also in the context of water-related targets. Yet, the Forest & Water Action plan, which was launched at the XIV World Forestry Congress, in September 2015, defines a collaborative work plan that aims to consolidate and shape projects and activities related to forest-water interactions. The Action Plan marks a transition from discussion to action, in order to develop effective strategies for conserving, managing, and restoring water-related ecosystem services.

Climate change can be directly related to a mismatch between supply and demand of water by altering its quantity, quality, timing, and distribution (Figure 1). For instance, elevation-dependent warming can accelerate the rate of change in mountain ecosystems and hydrological regimes (IPCC 2014). Addressing fundamental eco-hydrological changes and their interactions create substantial challenges. Forest management can provide important means for adaptation. Indeed, forests in mountain watersheds are sources of clean water, sink of carbon and biodiversity, and provide the opportunity to assess the dynamics of water balance upstream and adjust water supply downstream. The importance of forests in mountain watersheds may increase substantially in the next few decades, as freshwater resources become increasingly scarce (Bakker 2012). In European mountains, climate and land use changes have already caused treelines to shift upwards (e.g., Palombo et al. 2014a). Yet, changes in farming systems and forest management have led to changes in land cover and species diversity (e.g., Pyrenees, Apennines, Alps, mountain systems in Central Europe, Balkans), with implications in watershed management and landscape complexity (e.g., Palombo et al. 2014b). Integrated watershed management aims at multiple uses of watershed resources, balancing human and environmental needs, preserving productivity and ecosystem integrity, while simultaneously protecting and restoring ecosystem services and biodiversity (e.g., Hofer et al. 2013).

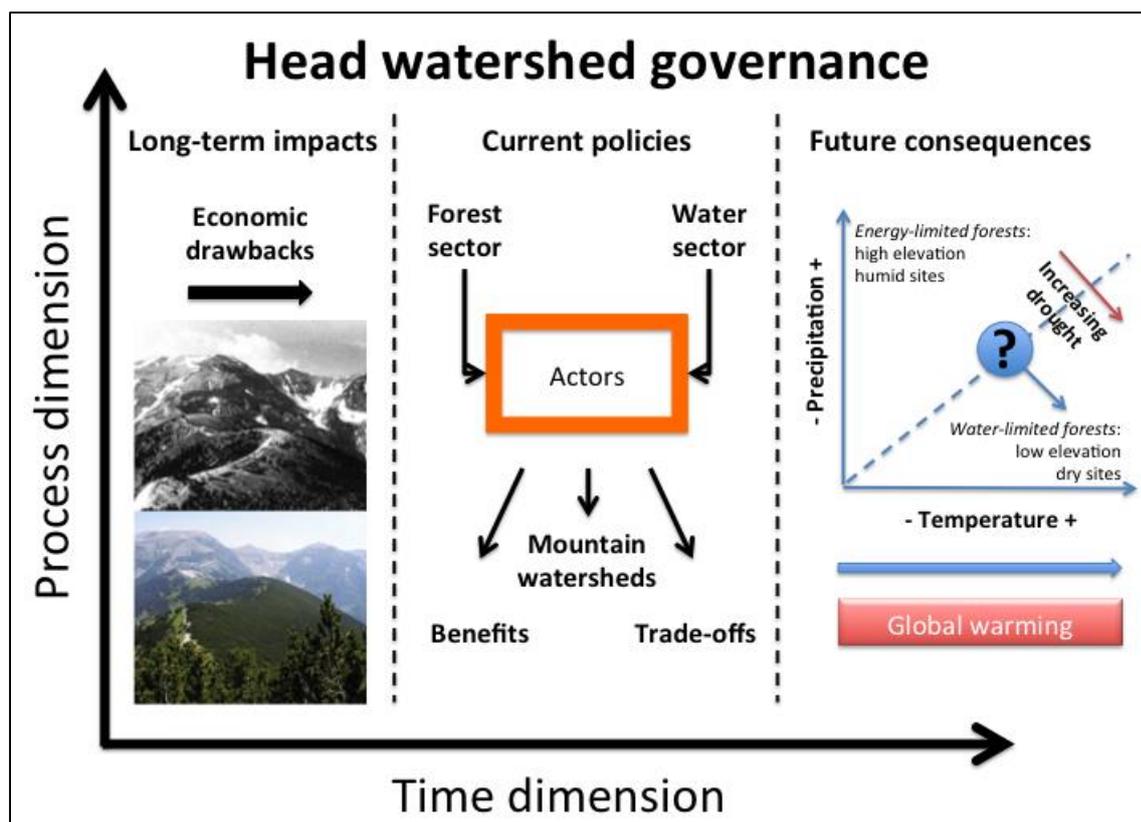


Figure 1. Sustainable development of mountain forests and watersheds deserves and requires a prominent position on the European and International agenda. Goods and services provided by mountain regions are subject to many forces of change, interacting in complex and uncertain ways. Research on mountain areas, particularly the Alps, provides the foundation for broad syntheses of existing knowledge. However, there is the need to incorporate applied research and governance analysis to disseminate the benefits of forest ecosystem services to stakeholders, finding equilibrium between economic development (e.g., innovative wood technology and renewable energy sector) and environmental conservation (e.g., reduction of soil erosion and control of invasive species). Conceptual models for scaling ecohydrological processes from leaves to trees to stands to watersheds, with emphasis on the ecological and hydrological controls on water fluxes, must be understood and quantified when transferring ecohydrological information across scales. Climate drivers are mediated by watershed-scale controls on ecosystem processes - maintaining mountain watershed health in the context of a changing environment may require focusing on forest management strategies to reduce the vulnerability to increasing stress, in order to secure the flow of ecosystem services.

Land use and climate change combine to threaten forested watersheds and the amount and quality of water they provide. In recent decades, warming and drought have been reported to increase tree mortality globally (Allen et al. 2010). In temperate regions, increasing forest density and tree growth, due to land use history and fertilization effects (due to elevated CO₂ and N deposition), may be counterbalanced by the rise in frequency and intensity of moisture deficit with a warmer climate. This may also imply upslope elevation shifts in tree species distributions, in proportion to the available land area (Körner and Ohsawa 2005). In Mediterranean semi-arid climate, forest thinning (light, frequent and localized) can reduce competition for resources (namely water), thus increasing growth and vigour of remaining trees, particularly in dry periods. Selective cuttings and assisted migration can change species

composition, complementing forest management and water retention practices to reduce the risk of tree mortality. Management actions may, however, become insufficient with severe droughts or to prevent forest fires, as well as if phenotypic plasticity and genotypic variability at the population level are not large enough.

As mentioned above, forests contribute significantly to ensuring a balanced water cycle, thereby reducing soil erosion and the risk of natural hazards (FAO 2010a, b). Natural hazards constitute a security risk in many mountainous regions in the world. Floods, mudflows, avalanches, slope movements and rock falls are threatening people, their living environments, their settlements and economic areas, transport routes, supply lines, and infrastructure. They constitute, thus, an important threat to the basis of livelihood (EEA 2010). Increasing settlement pressure, opening up of transport routes in the Alps, as well as strong growth rates in tourism have evoked a considerable spatial extension of endangered areas and damage potential. Forest managers are expected to anticipate these threats and respond to an increased demand of stewardship to ensure the sustained protection of forested watersheds and the provision of environmental services.

Forests have a sustainable and resilient role in the protection against natural risks, if they are managed in a site-adapted manner (Fares et al. 2015). They are the best-suited vegetation to reduce runoff and erosion processes, for rock-fall protection and protection against avalanches and positive effects, such as object protection effects. However, the long-term provision of these services is not guaranteed nowadays (Landmann et al. 2015). The amount and quality of protection services depends on forest and watershed resilience: when watersheds are threatened by environmental alteration and habitat degradation the provision of critical services can be compromised. Climatic changes at the global scale will greatly influence the variation of runoff patterns and the incidence of extreme events at the smaller scale, down to individual watersheds. Changes in the hydrologic system and associated disturbance regimes will likely have significant impacts on the provision of forest and watershed services, and water quality and soil resources accordingly.

Mountain forests contribute significantly in providing and maintaining clean water supplies. Climate and demographic changes may have a strong influence on mountain watersheds and water quality. To this end, ecosystem-based management is a key issue in order to implement management strategies that protect the values of forested watersheds for all stakeholders, preserving fresh water springs and local water resources (Furniss et al. 2010). A fundamental understanding of forests as complex ecosystems is important to identify and quantify the ecosystem services provided by forests, enhance the awareness of the role of mountain forests

in good watershed stewardship, and foster the definition of methods and criteria for the involvement of forest and water managers. Forests cover 41% of Europe's mountain area, and the share is increasing. These forests play key roles for regulating the water cycle and by protecting settlements and other infrastructures from natural hazards (avalanches, rock-falls and floods). Mountain forests also represent a great potential for biomass production and carbon storage, thus contributing to the implementation of the EU Forest Strategy and the Environment Programme. Climate mitigation options, such as biomass production for energy, might lead to increased demands for land and water in mountain forests, affecting forest productivity and biodiversity.

1.1.2. Mountain forests and watersheds facing increased risks and disturbances

Definition, identification, management and communication are the main challenges related to the protective function of mountain forests. Although a common definition for protective forests is widely accepted in Alpine countries, this is not formally recognized in the national legal framework (e.g., Italy). This makes forest planning and interaction with forest owners difficult. Protective forests should be actively managed to be effective in securing resilient watersheds. In many countries, however, the public institutions still have very little confidence in forest management as a tool to enhance ecosystem services. To improve public understanding, best management practices and guidelines realized in the context of cooperation projects are needed, as well as modelling as a key tool for the mapping of protective forests (according to hazard targets) and for the identification of suitable silvicultural treatments. Whether a protective forest should be managed or not is still a matter of debate. However, protective forests are not protected forests, and different function parameters should be considered. In the Alpine region (e.g., Italy, Switzerland, France), guidelines, documents and experiences have been produced, though these are not currently employed in the right way, because of the difficulties in involving all responsible actors, as well as transboundary and ownership issues. A protective forest cannot protect from all natural hazards and equally in all its successional stages. These forests should be stable and very close to the state of naturalness (Kohler and Maselli 2009). An efficient protection model, through proactive forest management, is important to maintain these forests; as an example, in Trentino, 30% of forests play a role of indirect protection downstream, while 50% exert a direct protection to towns. In Switzerland, where 80% of forests are protective, forest management is perceived in a positive way due to the revenue derived from forests

(timber), and investments in terms of management and communication are visible (B. Lange, personal communication).

The supply of goods and services can generate relevant conflicts between different stakeholders involved in forests management. It is, therefore, essential to carry on negotiations with the involvement of practitioners, enterprises and public bodies in order to define mechanisms of Governance, in line with opportunities offered by the Green Economy (Ariza et al. 2013). Income-generating prospects come from activities unrelated to the timber sector, e.g. based on non-wood forest products such as mushrooms, honey, fruits, etc. These activities are gaining economic relevance especially in local contexts, through innovative organization models. Employment opportunities are relevant in the field of forest management, as well as in the bioeconomy sector, especially in the management of forest biomass, if locally based in order to promote short supply chains. Mountain forests are also core contributors to physical and mental health and well-being, providing many social and environmental amenities.

In addition, mountain areas have great potential for producing renewable electricity from water, sun, biomass and wind. Besides opportunities, green energy infrastructures in mountain areas implicate risks and often result in unequal distribution of economic or social benefits among rural populations. Hydrological benefits from mountain forests are highly localized, as well as investments, and this contrasts with the global market for greenhouse gas emissions' reduction (Bennett and Carroll 2014). Again, the harsh climate, steep terrain, and natural hazards threaten energy infrastructures in mountain areas, and the pressure on mountain forests is even intensifying with global change. Renewable energy production can also have adverse effects on habitat fragmentation and loss, as well as change landscape structure and water flow. Nevertheless, healthy forested watersheds support a complex network of ecosystem services and offer the possibility to integrate environmental and engineering solutions (e.g., reforestation may limit sedimentation in a hydropower station's reservoir, thus reducing costs and damages to the infrastructure, also prolonging the life of the reservoir), with multiple benefits.

However, major issues in integrating environmental and economic issues arise from of the connection to land ownership. In this sense, large and public properties could be advantageous in comparison with small and private ones. Managing forests towards adaptation to changing climatic conditions and connecting ecosystem services with subsidies or incentives may provide with an increasing awareness of forest owners and managers on the profitability of forest ecosystem services. Indeed, there is poor attention from water management authorities on forest management practices, due to the lack in communication between water authorities and forest managers. Experimental mountain watersheds provide important opportunities to address the

water resource impacts of climate change, integrating ecohydrologic factors and socio-ecological issues (Kohler et al. 2014). To this aim, representative monitoring systems are needed, as well as effective methods of characterizing the biogeography and bioclimatology of watersheds, thus optimizing sampling strategies for various climate scenarios. Indeed, adaptive management requires to measure the initial state of the systems and to monitor trends over time to track system responses to management practices. In Mediterranean mountains, forest management should aim towards the re-naturalization of simplified forest systems to recover natural ecological processes and heterogeneous spatial structure, thus increasing their resilience and adaptability.

We need to understand the interactions between forests and soils, also considering understory species, or different forest management systems (Figure 2). In this sense, biodiversity should be viewed as an adjunct value in protecting the territory from natural hazards (more species diversity > more understory vegetation > less bare soils > less soil erosion). In patchy mountain landscapes, forest stands can compete for water use with other land covers, thus there is a need to comprehensive administrative boundaries, thinking on the role of forest in protecting from disturbances, while regulating water balance (Price et al. 2011). Forest and water issues require action at the scale of whole watersheds, given that the geographic scope of water management, biodiversity protection, and climate adaptation may transcend the legal and geographic reach of existing jurisdictions and institutions. Long-term experiments, including watershed manipulations at the large scale (embracing a whole rotation period), would enable the effects of stand and forest treatments (e.g., high forests vs. coppice stands) on water quality and species diversity to be determined in a reliable fashion. In the establishment of long-term experiments, early collaboration is an essential part of developing interdisciplinary relationships between scientists and stakeholders, to successfully tackle the ramifications of experiments and convert them into effective policy. The role of forest management and planning might be better addressed to the society, explicating the systemic management systems in the certification processes at the district level (involving a variety of products).

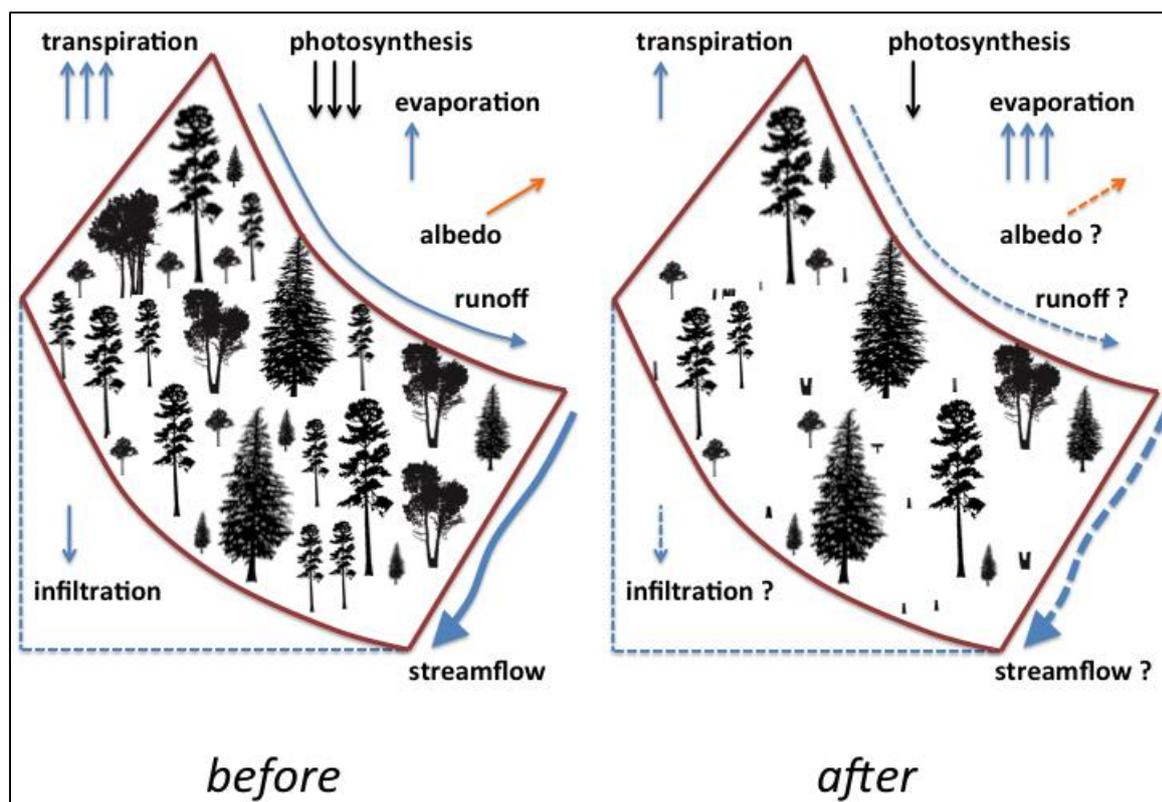


Figure 2. Forest management interacts with the stand structure through changing the tree species composition and the stand diameter distribution. Both processes affect the structure of the canopy and thus the organization in space and time of the trees. In dry conditions, thinning (light, frequent and localized) may modify gas exchange at the interface forest-atmosphere, thus reducing the competition for water resources. At the same time, favouring uneven-aged and mixed forests may combine biodiversity conservation, forest production, and watershed resiliency. Species selection and thinning strategies exert a control over canopy albedo. In regions with active forest management, forest owners need support to adapt management practices and improve harvesting techniques. In mountain watersheds, communities need support to secure forest ecosystem services, to develop criteria and indicators for sustainable forest management, and a range of guidelines and sound harmonized strategies in adaptive management of head-watersheds. The management of forest ecosystems requires planning for the long term - proactive adaptation, with the introduction of new species/genotypes, change of rotation times, and stand structure, has high costs, though forest conservation towards high stand resistance and stability may increase the risk of catastrophic loss.

The different role of forests in upland and lowland communities generates the first economic unbalance between mountain and plane populations, with affects the dislocation of ecosystem services and their beneficiaries (Price et al. 2011). Subsidies or incentives for local communities in mountain areas might promote sustainable management practices of mountain landscapes, avoiding overexploitation and limiting abandonment, more effectively than payment for ecosystem services (PES). These have been principally applied for private landowners and the amount of money related to PES has been irrelevant in comparison with the whole forest sector. Innovative forms of compensation to encourage forest management, especially in marginal areas and developing countries, are needed. Most environmental and social issues facing mountain forests and head-watersheds need to be addressed at several scales, simultaneously, and require governance arrangements at the landscape scale, across administrative boundaries

and land ownerships. Innovative collaborative governance arrangements of natural resources face management issues that may be better addressed by reframing the problem and incorporating broader value sets into decision-making processes. Multifunctional mountain watershed networks fall within the definition of green infrastructures as defined by the European Commission, as strategically planned networks of natural and semi-natural areas with other environmental features designed and managed in a way to deliver a wide range of ecosystem services (EEA 2010). Emphasis is placed on the ecosystem services that mitigate weather- and climate-related natural hazards.

1.1.3. Main outcomes from the Workshop and concluding remarks

With the aim of promoting sustainable development in mountain watersheds and ensuring the long-term provision of ecosystem services, the European Forestry Commission Working Party on the Management of Mountain Watersheds selected the topic “Mountain Watersheds and Ecosystem Services: Balancing multiple demands of forest management in head-watersheds” for its 30th session in Pieve Tesino, Italy. The following contributions give a detailed insight on the issues discussed during this event.

The first part of the workshop dealt with ecosystem services in mountain watersheds and supporting tools for adaptive forest management.

Ciolfi et al. described a methodological approach, based on the realisation and implementation of a Decision Support System (DSS) for eliciting, evaluating in a spatially explicit form and balancing ecosystem services, and integrating energy production (with focus on forest biomass). A participative approach was carried out, in which experts and stakeholders were involved in both the process of software design and in the application of the DSS for through the project. The software is released with an open-source license to encourage further development and to spread and share knowledge and science.

Pettenella and Poretaccio focused on the participatory approach in the local development of renewable energy, as a basic requirement decision-making. The participatory approach was based on a group of discussions led by one or more facilitators, helping the participants to focus critically on water use and forest biomass, generating information and ideas. People involved were primarily selected from the categories of stakeholders suggested by the experts. Analysis of scored values allowed for moving from an abstract perception to the valley scale. Basing a

participatory approach at the watershed level was useful, while depicting the reality that has to be managed.

Costantini et al. presented a set of soil-related projects, in which forest ecosystem services have progressively been considered important. Timber provision, water regulation, soil conservation, and landslides prevention were followed by services related to the increase of above- and below-ground biodiversity, ecological stability, and greenhouse gas mitigation and compensation. The management of peri-urban forest stands is of particular interest, because of the high economic and social values of the soil ecosystem services provided. The relevance of these environmental services is expected to increase in the near future.

Maesano et al. reported on the temporal variation of the annual carbon budget in a mountain forest ecosystem of Central Italy, to highlight the impact of seasonal hot spells and drought on carbon absorption and on net ecosystem productivity. The analysis of fluxes and meteorological data, in the period 1996-2012, showed clearly that warmer temperatures coupled with limiting precipitation results in a clear and significant decrease of carbon absorption. The measured trends showed that, over the summer, the study beech forest was able to respond and acclimate to changing climatic conditions, as far as drought was not prolonged.

Vizzarri et al. revised the environmental and socio-economic differences across representative mountain watersheds in Europe, focusing on forest management and planning issues, and their vulnerability. The authors analysed whether the current research outcomes are able to improve the implementation of the integrated management in mountain watersheds, and to what extent they are consistent with the emerging challenges facing mountain communities in Europe. Support tools for integrated forest management in mountain watersheds were envisaged for these complex social-ecological systems in order to promote the ecosystem resilience and local communities' engagement, in a sustainable way.

The second part of the workshop was focused on outlining the new challenges for headwater catchments and mountain forests, that are facing increased risks and disturbances.

del Campo and González-Sanchis analysed the complex relationships that exist between the forests and the hydrological cycle. Ecohydrological-based forest management was considered important to account for woodland encroachment and water scarcity scenarios, which require water quantification depending on forest structure or cover. With this approach, hydrological aspects of forests become part of direct benefits, and making forest management more focused on water saving, through proactive-adaptive silviculture.

Comiti et al. reported on the role of flood events, of different frequency/magnitude, on vegetation-wood-channel dynamics, including entrainment conditions of in-channel wood,

erosion rates of vegetation from channel margins and islands, transport efficiency of wood elements along the channel network. They also stressed how evolutionary trajectory of rivers may affect these processes, and thus the degree to which conceptual models derivable from near-natural systems could be applicable to human-disturbed channels. The current tools to predict wood volumes were discussed, considering alternatives for the management of vegetation and wood in rivers.

Sidle and Gomi focused on headwater catchments in temperate forest environments. Insights gained from investigations in temperate forest catchments can improve estimates of storm flow response from steep headwaters, particularly how spatially and temporally explicit changes in land cover and other forest management practices may affect storm runoff regime. Implications of research on ground disturbances associated with forest management were addressed for assessing soil erosion, landslide occurrence, aquatic ecology, nutrient cycling, and contaminant fate and transport in these steep catchments.

Schreier presented a comprehensive range of adaptation methods that are needed to protect watersheds, and to assure that environmental services can be sustained. Some of the effective ways to adapt to floods and droughts includes watershed-based initiatives to maintain and improve riparian buffer zones, designate areas for temporary storage of flood waters, focusing on improved green water management, promote wetland construction, and improve the infiltration and water storage capacity of soils.

Lingua et al. examined the importance of functions provided by the forest on its protective role. All forest stands accomplish this role, protecting the soil from surface erosion and affecting directly and indirectly the water cycle, regardless their location. However, when they are protecting actively or passively against a specific natural hazard we are referring to them as protective forests. The strategic importance of protective forests calls for increasing efforts in the comprehension of forest dynamics in mountain ecosystems and the development of efficient science-based decision making.

The workshop concluded with an ample prospect of national experiences on forest-water interactions in European head-watersheds. In general, management of mountain watersheds has moved from focusing on water resources and hydrology towards an integrated approach, managing the biological, physical, and social elements in a forest landscape within catchments. Holistic methods for managing mountain watersheds are complex and require interdisciplinary studies and adaptive approaches to cope with land-use and climate changes, considering how these relate to socio-economic and environmental development.

Major European head-watersheds and mountain forests were the object of contributions from Austria, France, Switzerland, Czech Republic, Poland, Finland, Italy, and Romania. Europe's mountains pull moisture from rising air masses, which they collect in watersheds, store and distribute, providing large amounts of runoff and water-related ecosystem services at all spatial scales. Changes in land use and climate may affect the provision of these services (FAO & JRC 2012). Mountain forest biodiversity may act namely for regulating services. A healthy head-watershed provides a sustained flow of desired environmental services over the long term, quickly recovering from disturbances. The future studies should support the following management strategies:

- Improve the consistency of ecological indicators to monitor the status and trends of mountain watersheds and forests.
- Assess the probable risk of head-watersheds and forest soils to natural hazards (pest outbreaks, heat waves, forest fires), and impacts on groundwater recharge.
- Measure changes in forest type, stand density, vegetation shift, and habitat retreat at the head-watershed scale, and effects on water capture and storage.
- Evaluate the benefits and trade-offs for the regulation of stream flows associated with multifunctional forestry in mountain watersheds.
- Address the impacts of forest management and use on water balance in mountain watersheds under changing environmental scenarios.
- Monitor the effect of forest treatments on the resilience of head-watersheds to erosion processes and nutrient leaching.
- Consider the effects of forest restoration and conservation management on water yield and soil quality in head-watersheds.
- Understand the relationship between multiple scales of climate variation and forest dynamics and resulting range dynamics at the watershed scale.
- Comprehend how large dynamics of tree distribution and abundance, and range shifts due to climate change, and relate to head-watersheds.
- Integrate large-scale projections, and regional downscaling, with intermediate-scale influences for reliable watershed planning and decision-making.

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2. ECOSYSTEM SERVICES IN MOUNTAIN WATERSHEDS: SUPPORTING TOOLS FOR ADAPTIVE FOREST MANAGEMENT

2.1 Ecosystems services, decision support systems and participative approach in planning: experiences and lessons learned in the Alpine Region

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2.1.1. Introduction

After World War II, the dramatic socio-economic change, which had already begun in the industrialised world, significantly increased, bringing radical change in lifestyles and a progressive weakening of those close, direct connections that for centuries tied human communities to natural resources, a form of dependency essential for the very survival of mankind itself. The results of such change are evident in the transformation of the landscape characteristics.

The Alpine Region did not remain unaltered from the enormous socio-economic transformation to which Europe was subjected, but specific effects and implications arose as a result of its particular situation as mountainous territory. The Alpine Range constitutes the Europe's principal orographic system, extending from France to Slovenia, involving seven countries, and

covering 190,000 square kilometres. The Alps are characterised by a great geomorphological and climatic diversity, but also by different histories, cultures and traditions.

People have always experienced an extremely strong, direct dependence on mountain ecosystems, and in particular, on forests. Although inhospitable and physically fragile, this environment has rendered it possible for local communities to survive thanks to their ability of profiting from landscape resources. Since long, human activities have, on the one hand, aimed at the production of food and raw material necessary to satisfy the needs of the local communities, and on the other hand, they have worked towards the construction of hamlets safe and protected from natural disasters. The mountain setting imposed diversified production strategies and appropriate forms of management with different intensities and well adapted to local circumstances. These management strategies guaranteed the continuity of production and had a stabilising effect on land even though within certain limits: all that resulted in the multiplicity of Alpine landscapes that we can still observe, where they have survived to the present days (Cantiani et al. 2013).

The new models of development, increasingly widespread in the Alpine area, disrupted the traditional modalities of interaction that characterised Alpine mountain societies and altered the relationships between mankind and nature. In a few decades, not only the balance in the ecosystems has been upset, but also that of the human communities, with severe depopulation effects in mountain areas. Among the many different problems that affect the Alpine region today, some are generating serious concerns, in particular: i) the vulnerability to climate change, due to the geographical position of the Alpine Range; ii) the effects of land-use changes; iii) the current economic-financial crisis (Cantiani et al. 2016).

In such a situation, new needs are being expressed by the communities and a new order of priorities of values often appears, whereas the Ecosystem Services (ESs), once demanded and appreciated, are today sometimes disregarded. More frequently, forestry professionals are quite isolated from the social context; at the same time, managers and decision-makers are confronted with new expectations and sometimes conflicting requests without the suitable tools to understand and manage these expectations. Will they be able to cope with such a messy and uncertain situation? Will they be able to adapt to change and shape a sustainable development for the Alpine areas?

In this paper, we describe a possible methodological approach, based on the realisation and implementation of a Decision Support System (DSS) for eliciting, evaluating in a spatially explicit form and balancing ESs. A great number of DSSs dealing with different topics is available in the literature. Some are used in modelling specific scientific topics while others are

effectively used in management to help decision makers (Wolfslehner and Seidl 2010, Zambelli et al. 2012, Sacchelli et al. 2014, Acosta and Corral 2017). The inclusion of spatial dimension that characterises the GIS based DSSs adds a large amount of information and makes the results of the DSS more understandable. Nevertheless, many of these DSSs, especially those that deal with environmental issues, are designed to represent in detail a very specific theme and they often lack a multifunctional approach (Garegnani et al. 2015a). Many DSSs are designed to produce results at macro-scale (national or macro-regional level) and they represent the phenomena using large pixel units (square kilometres or more). For this reason, they are not easily usable by local decision-makers and communities. In our opinion, the greatest limitation of the available DSSs is tied to the fact that very few of them are really publicly usable due to license restrictions or to actual availability from the authors (Steinigera and Hay 2009, Sacchelli et al. 2013). This fact limits the possibility to improve the DSS models and to share them. Therefore, we decided to develop a model with a multifunctional approach, designed to be applied not only at a macro scale but also at a very local scale and using an Open Source platform to overtake the cited limitations.

Such a DSS has been realised by DICAM-UNITN, EURAC and CREA-FL within the existing Alpine Space project *recharge.green* financed by the European Union, in which a model to integrate ESs evaluation and energy production was developed, with particular attention to forest biomass (Ciolli et al. 2015; Garegnani et al. 2015).

The DSS presented here is the evolution of the former “Biomassfor” model (Sacchelli et al. 2013, Zambelli et al. 2012) and, like its predecessor, is entirely based on Free and Open Source Software and released with a license that allows free use and redistribution of the source code. Nevertheless, we followed a completely different approach than that used in the development of “Biomassfor model”, that can be described as a top-down model. In this new DSS a participative approach was carried out: experts and stakeholders were involved in both the process of software design and in the application of *r.green.biomassfor* through the project. The DSS was successfully tested in the *recharge.green* project (www.recharge-green.eu/).

2.1.2. Ecosystem services

The concept of ESs is particularly useful when dealing with the relationship that links human and natural systems. ESs refer, in fact, to the entire sphere of benefits that human societies

obtain, directly or indirectly, from ecosystem functions, and shows how deeply human well-being depends on healthy ecosystems (Costanza et al. 1997).

Since the 1980s this concept has been largely discussed and studied and, in recent years, a big deal of work has been made in order to categorise ESs systematically. A great impulse to the conceptualisation came from the Millennium Ecosystem Assessment (MEA 2005) and the follow-up initiative The Economics of Ecosystems and Biodiversity Project (TEEB 2009).

Following the MEA assessment, the services are classified in four categories:

- 1) provisioning: the products humans acquire from ecosystems (e.g., food, timber and water);
- 2) regulating: the role of ecosystems in the regulation of ecological processes, (e.g., water and climate regulation);
- 3) cultural: the non-material benefits provided by ecosystems (e.g., recreational and spiritual values);
- 4) supporting: such as soil formation, photosynthesis and nutrient cycling.

Alpine ecosystems supply several goods and services useful both at local and global scale. Some services, in a recent past considered of major importance (e.g., timber/fodder production), are today considered less important, particularly in some geographical contexts. Other goods and services, on the contrary (i.e., regulating services), are more regarded. However, their supply may be threatened, mainly because of a high level of habitat loss and fragmentation. Moreover, in our post-industrial society, cultural and spiritual values happen to be particularly emphasised, over subsistence needs.

A sustainable development of the Alpine areas requires that priorities are clearly recognized and economic and ecological issues are carefully taken into account and balanced. To this aim, the consideration of ESs shows great possibilities, provided that it is applied to the right scale of analysis. The regional watershed scale makes it possible to address landscape management and planning issues with a sound and realistic approach (Cantiani 2012). Actually, at this level, local communities – people and institutions – may show a strong proactive approach to the natural resources management. In this context, in fact, management is heavily linked to governance mechanisms, being the focus of political debate and economic activity.

Whatever the approach chosen for the ESs assessment, either economic or non-economic, we stress the importance of a participatory process. This is actually an important prerequisite in order to supply credible and well-structured information to the decision makers.

An essential condition for the preservation of landscape and biodiversity, for the physical protection of land and for the conservation of all those values associated with local culture and traditions is to mitigate migration flows in mountainous areas, a common problem for the entire Alpine region. Actually, in order to make this possible, it is necessary that the population is involved in the land planning, listening carefully to their needs and expectations, and thoroughly understanding the values they attribute to the mountain ecosystems.

In order to evaluate the current status of ESs, to assess potential changes in their demand and provision, and to better address policy makers and improve decisions, we stress the importance of a suitable ES-based Decision Support System.

2.1.3. The ES-based Decision Support System realised

The DSS *r.green* aims to evaluate the spatial explicit potential of the four main renewable energy sources (i.e., Solar, Wind, Hydropower and Biomass). The DSS identifies and quantifies the areas suitable for the installation of renewable energy systems based on criteria of sustainability and land conservation. The aim of the developers is to highlight Alpine biodiversity, land use patterns and related ESs, and to model the carrying capacity of the Alpine ecosystems with respect to all aspects of renewable energy production and consumption. It requires a set of input data and can be applied at a multiple scale level. The core of the DSS *r.green* was programmed in GRASS GIS (Garegnani et al. 2015a, Grilli et al 2017b) taking advantage of python libraries and *pygrass*. GRASS is an Open Source GIS developed since 1984 (<https://grass.osgeo.org/>) and is supported by an international team of developers (Zambelli et al. 2012). GRASS procedures and modules are strongly reliable and tested and the software comes with a consistent and complete documentation, as it happens for those Open Source projects that are carried out in the frame of the Open Source Geospatial Foundation OSGEO (<http://www.osgeo.org/>). The DSS is organised in a set of add-ons (additional modules) that can be run independently. The main *r.green* modules are *r.green.wind*, *r.green.hydro*, *r.green.solar*, *r.green.biomassfor* that deal with each specific renewable energy, and *r.green.impact* that gives feedback on the impacts. Regarding Biomass, the main focus is on forest biomass, especially on forest residues and wood chipping. In fact, the logical structure in which *r.green* is developed was borrowed by the software *Biomassfor* that the DICAM-UNITN, CRA-MPF and GESAAF developed in the frame of the BIOMASFOR project, co-funded by the CARITRO Foundation in 2011. Each module is structured by a set of sub-

modules that represent a series of operational steps in an ideal flow of operations directly related to the level of exploitation that is taken into account. Each main module is composed by five sub-modules – theoretical, legal, technical, economic, recommended – as well as modules specifically oriented to the analysis of impacts and assessment of the ESs, although the general structure may slightly vary among the different modules. Taking *r.green.biomassfor* as an example, “theoretical” calculates potential energy from forest biomass in an area using the periodic (year) forest yield, “legal” estimates the energy available from forest biomass using prescribed yield, “technical” calculates the energy available from forest biomass that is actually exploitable depending on different mechanization level, “recommended” introduces bonds and biomass production limits, “economic” calculates the energy that can be produced with a positive net revenue of all the production chain. The model allows to estimate energy availability from woodchips taking into account variables tied to landscape morphology, extraction methods, roads infrastructures, production costs, costs for transport and wood sale. For example, changing the parameters can produce different economic scenarios or different positioning scenarios of a power plant. The *r.green* DSS, already available as a GRASS add-on, can be used through the link command of Grass console or running the standard GUI within Grass or finally through QGIS.

The Open Source DSS *r.green* was designed to incorporate the impact of ESs evaluation coming from a process of participation and involvement of local experts, stakeholders and public at large.

To achieve this involvement, it is necessary to carry out meetings and consultations as described in Balest et al. (2015a). The DSS was tested in the project *r.green* in different pilot areas: Mis and Mae Valleys in Veneto (North East of Italy), Alpi Marittime Natural Park in Piedmont (North West of Italy), Triglav National Park (Slovenia).

2.1.4. Model testing, applicability and potentialities

Although the models were run in all the pilot areas, the most accurate tests were carried out in each pilot area selecting only the “suitable energies”. In each Pilot area, the suitable energies were selected after a consultation of experts (Balest et al. 2015a).

The model *r.green.hydro* was mainly used in the pilot areas of Mis and Mae Valleys in Veneto and in the Gesso and Vermenagna Valleys in the Alpi Marittime Natural Park in Piedmont (Garegnani et al. 2015b). Different scenarios were performed and the outputs of

the module *r.green.hydro*, that is maps with energy production and relative costs, were discussed in several meetings with stakeholders in order to produce planning alternatives through a participative approach. The meetings allowed to identify feasible, sustainable and acceptable proposal of hydro power development (Garegnani et al. 2015b).

The model *r.green.biomassfor* was tested in three pilot areas: Mis and Mae Valleys, Alpi Marittime Natural Park and Triglav National Park (Ciolli et al. 2015).

In Mis and Mae Valleys and in the Alpi Marittime Natural Park different scenarios with different wood chip prices were combined with existing/planned bioenergy plant locations. Scenarios were produced (an example of such scenarios in Alpi Marittime is showed in Figure 3) and a first public event was organized to show the results to Regional administrators and stakeholders (Balest et al. 2015a). This started a discussion on the optimization of bioenergy plants and in general on biomass opportunities. Further meetings with Regional administrators, public and local stakeholders of the valleys were organised to discuss the scenarios and to modify them according to their indications. During the process, we were able to discuss the software feature and also to introduce some modifications following the stakeholders' indications. Finally, the DSS was used to produce alternative scenarios and to identify planning alternatives (Grilli et al. 2017).

In Triglav National Park, through a different approach, different biomass production scenarios were created and a comparison with the Wisdom model, previously used by the Triglav Park managers to produce scenarios, was carried out.

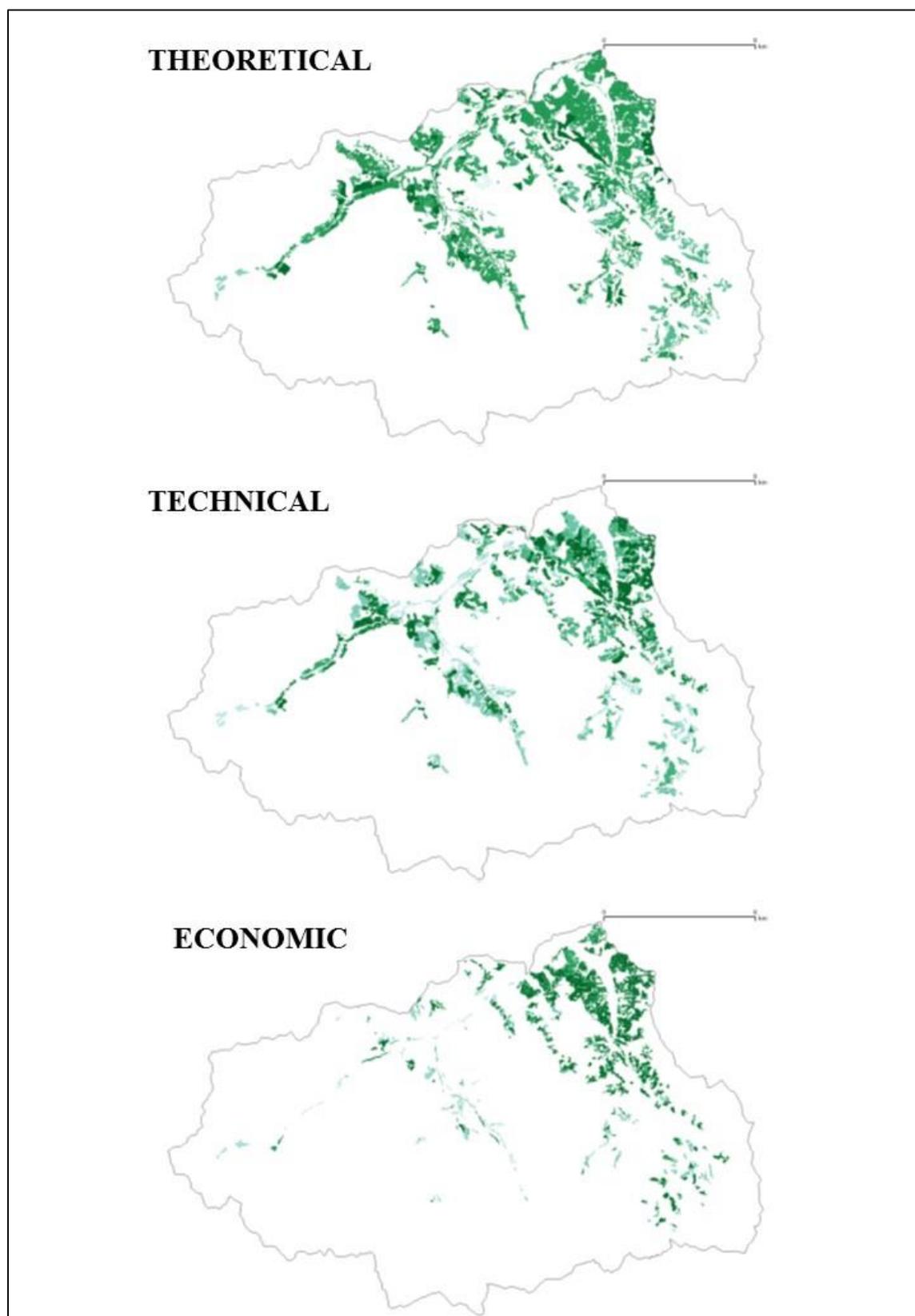


Figure 3. An example of the application of *r.green.biomassfor* to derive forest biomass potential scenarios in the Alpi Marittime Natural Park in Piedmont (North West of Italy). Three biomass scenarios are presented: Theoretical (40502 Mwh/y), Technical (25246 Mwh/y) and Economic (12862 Mwh/y) (Ciolli et al. 2015).

2.1.5. Conclusions and perspectives

The first tests of the holistic spatially explicit DSS *r.green* carried out in the frame of *recharge.green* project were successful. In fact, the DSS not only fostered discussions and produced scenarios that were judged plausible and useful but also produced results that were used immediately by local stakeholders and decision makers (Balest et al. 2015b, Grilli et al 2017).

Moreover, the involvement of stakeholders in DSS application increases social acceptance of the tools and decisions and reduces the potential conflicts between groups of interests.

Although the DSS is already usable, the complexity of the topics treated and consequently the complexity of the software suggests that there is a large space for improvement (Grilli et al. 2017b). The experience of the application in the project highlights also that it is useful to apply a DSS in a participative process since it gives a considerable added value; it is in fact important to take into account the feedback coming from the public in order to improve and tailor the DSS itself. In this way, also the development of the software takes advantage of the participative process and makes it more suitable to be used in further applications. The software is released with an open-source license to encourage further development and to spread and share knowledge and science.

The results of our research, carried out by means of the regional case studies illustrated, are expected to have not only a local, but also a broader relevance for the Alpine area. This is thanks to the fact that such results can be easily generalised and applied to similar contexts, wherever new models of development are desired as an alternative to those based on the waste of land and of its resources.

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2.2 Ecosystem services in mountain watersheds: supporting tools for adaptive forest management

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2.2.1. Introduction

The Alpine ecosystem provides several goods and services such as protection against natural hazards (i.e., landslides, avalanches and rockfalls), carbon dioxide sequestration, fodder, timber, tourism and recreation settings (hiking, biking, hunting, etc.), freshwater, biodiversity and renewable raw material for energy production (bio-energy) (Balest et al. 2015a, b). In the future water cycle regulation, biodiversity protection and renewable energies (RE) provision from Alpine natural resources will play an even more relevant role for the European citizens. The growing use of Alpine ecosystems for the provision of these services is in some cases generating new conflicts that call for the use of instruments to define and implement innovative solutions that can be socially acceptable, environmentally compatible and economically efficient. For example, a huge expansion of new facilities and infrastructure related to the use of renewable energies (like in the value chains related to biomass or to the power generation with micro hydro plants) may cause changes in the landscape and in the quantity and quality of goods and services traditionally available to local communities. Some of these changes can also enhance the production of goods, services and biodiversity in a positive way: for example, the increased demand for bio-energy may allow to carry out commercial thinning in old and semi-abandoned plantations with exotic species and may determine an increase in soil stabilization, the natural regeneration with the expansion of indigenous species, thus even an improvement of biodiversity. These impacts are in most cases dependant on “how” (which intensity, scale, equipment, species, ...) and not so much on “which” actions are implemented. However, in some cases, problems of trade-off and conflicts are always present, with the related NIMBY effects: the use of water for hydroelectric purposes reduces the amount available for other

purposes, with direct impacts on the aquatic environment; while wind turbines and solar panels on open areas can affect the visual aspects of landscape.

Alpine mountains, being biodiversity hot spots and providing scenic landscapes, are particularly threatened by the expanding RE supply. Preserving Alpine natural and cultural values whilst intensifying RE provision is expected to increase land use conflicts. In fact, cultural heritage is a result of the 'daily life' of mountain communities, as for centuries, thanks to their efforts and commitment, they ensured what we can now observe and enjoy.

In general, the consumption of natural resources allows marketable benefits, in the sense that the economic advantage for the exploiter is clearly visible and reflected in the market price and his related income. Damages to ecosystems produce an economic loss for the entire society that is not compensated, as long as the exploiter is not compelled to pay for his damage. This negative externality occurs because forests are providing mixed goods, some private (wood), some others public which are non-rival and non-excludable, and therefore without market prices that represent the total economic values of the resources; in this condition, it is not possible to reach an optimal balance between the demand and the provision of these services. Due to these characteristics, each form of natural resources consumption produces an unbalanced situation between beneficiaries (the private person or company) and the damaged ones (the whole society). An economic assessment of externalities can be a powerful tool for understanding the total resource value, the distribution of benefits and costs, the trade-offs among various alternative services (e.g., biomass used for energy vs. timber) (Hastick et al. 2015). This evaluation is often complex because most of the benefits and costs provided by ecosystems are indirect and result from complex ecological processes that often involve long time frames and nonlinear changes.

When an investment can be measured in economic terms it can be compared to other investments (e.g., is it more profitable to build a hydropower-plant or some infrastructure to prevent avalanche damages?) and to define the optimal size of an investment (e.g., the proper size of a biomass plant). Economics can be used for defining the net benefits (from both a public perspective and a private point of view) of the investment. In the case of an approach aimed to define public benefits and costs, not only market but also non-market impacts should be evaluated and this can make the assessment quite complex.

Moreover, the evaluation should not just be a neutral, technical operation made by outsiders: stakeholders, starting from the local ones, have to be involved in the process, and this implies the use of special approaches in stakeholders' identification and involvement where experts in communication and local governance systems should play a role. On a macro scale, when

dealing with issues of national or regional planning, economists and experts in political science may have a role in forecasting demand and supply development, prices and in setting the proper system of market regulation.

2.2.2. An assessment at the watershed level

In the frame of the Alpine Space Programme, the project recharge.green analysed the current provision of Ecosystem Services (ES) in selected pilot areas located in the Alpine arc, in order to understand which are the most interesting features that have to be preserved while exploiting RE. In order to better understand the costs and benefits of natural resources exploitation, an economic approach to ES valuation appeared to be effective, because it allows a profitability analysis where costs and benefits are valued with the same unit of measure. In the energy production context, considering the social costs of exploiting natural resources could highlight the existing trade-offs between RE and ES. Such information has been elaborated and released by a Decision Support System (DSS) developed by the partners of the projects, which aims to help decision makers in formulating effective strategies about optimal RE location, capable to preserve the environment and efficiently produce RE at the same time. The DSS consists of a computerized tool that helps users to identify solutions to a complex system, therefore enforcing decision-making process. In the case study, the collaboration with local authorities and stakeholders played a key role in the success of implementation of the DSS, since more accurate input data were used thanks to this interaction.

The results of the computer based DSS have been uploaded to a user-friendly platform, allowing users to observe on GIS based maps results from pre-selected scenarios while varying key parameters.

In the recharge.green project an evaluation of the impacts on ES due to power generation based on the use of water resources and woody biomass in the pilot areas of the watersheds of Mis and Maé rivers (Belluno Province, Veneto Region, Italy) has been carried out. The survey was based on the consultation of some selected local experts and of a sample of local stakeholders. The investigation consisted in a functional identification of the meaningful ES for the two pilot areas and in the identification of the potential areas for the implementation of plants for energy purposes.

A deepened bibliographic research has been carried out. Mainly through the online research, we gathered scientific articles, *ad hoc* studies and different types of publications related to the investigated ES such as guidelines and handbooks for the identification and the economic analysis of the ES and the implementation of Payment for Ecosystem Services (PES) schemes. When a merchantable value could be used in ES estimation, the databases of the official related organizations were consulted (e.g., the National Institute of Statistics online database for timber prices, the Forests and Carbon National Inventory for forest dry biomass carbon content). Unfortunately, the ES with some reference market were few, therefore a Benefit Transfer approach has been used analyzing several similar case studies in order to get proxy values attributable to our pilot areas.

Starting from the list of the ESs edited by the recharge.green project partners, and thanks to the survey conducted with the local experts, 10 categories of ES emerged for having a major importance for the pilot areas:

- Provisioning services
- Water related services
- Carbon sequestration
- Air quality
- Water quality
- Protection from hazards
- Habitat conservation
- Landscape services
- Recreational services

Each ES has been analyzed in order to find out the relevant components of the service. For example, in the first category (provisioning ES) we had to consider timber production, energy wood production as well as the non-wood forest products. Among the provisioning ES, we had to evaluate also hydropower generation, and we had to consider, for example, the quantity (m^3) of water that could be obtained and derived from the torrents and rivers examined, as well as the amount of electric energy that could be produced.

From the feedbacks given by the experts, the potential and suitable areas for the development of renewable energy plants have been mapped using a Geographical Information Systems. In particular, for both pilot areas, distinct localized zones have been identified respectively for the implementation of forest biomass energy plants and for that of mini/micro hydropower plants. With the aim to represent more realistic scenarios, the economic evaluation of the ES relevant

for the pilot areas has been carried on in the zones most favorable to accommodate plants for RE production.

Evaluation through monetary values, always conditioned by the quality of the data and the uncertainty of the estimate, had to be necessarily combined to qualitative analysis. There are several methodologies for evaluating the ES and their common characteristic based on the principles of welfare economics. We, therefore, referred to the basic concept of Total Economic Value (TEV) that represents the overall objective for the assessment of environmental economics.

The approach tested in the two pilot areas – Mis and Maè valleys – deeply fostered the participation of local communities and stakeholders. The process can be defined as: 1) voluntary: each stakeholder can decide if participating or not 2) inclusive: local actors interested in the project were involved, 3) transparent, thanks to the information given at various levels 4) efficient: as time schedule was well defined with respect to the planning stages.

Maps resulting from the DSS were shown to people who live in the two valleys: such results consisted in the first hypothesis of use of water and wood resources, analysed by the DSS in a scientific and objective way. Furthermore, the collaboration of the participants revealed to be helpful in the evaluation process of some services related to the use of water and wood. In fact, the process of communication of knowledge and self-experience resulted in more realistic cartographic information, previously built on institutional and scientific base. Finally, participants suggested a ranking in order to prioritize a series of 'values'¹, basing on their knowledge and personal experience, while answering to a questionnaire. In addition to technical and cognitive information, it was also possible to collect more general and "political" suggestions regarding the use of resources in the two pilot areas, thanks to a conscious, critical and animated discussion.

2.2.3. Stakeholders' participation

The participatory approach was developed through the 'focus group' technique. This is based on a group of discussions led by one or more facilitators who help the participants to focus critically on certain subjects – in this case the use of water and wood for energy purposes, to express their point of view, collect critical elements and analyse the shared opinions regarding

¹ In order to let the meaning of ecosystem service be better understood we used the term value to describe it. In fact, the several aspects and characteristics of the Valley environment would assume for each stakeholder a different value, according to his/her own experience and perception.

central questions on the actions of the project. The method bases on the idea that discussion among the participants of a group can lead to a larger amount of information, compared to conducting individual interviews, since the exchange generates new ideas. Generally, teamwork involves a limited number of people and can last about two hours. Focus groups were organized in two parts with a time interval of 4-5 weeks. Such period of time between the first and the second meeting was very useful as people had the possibility to process the raw information received, and to develop a possible debate from the reflections made by citizens/administration within their family/social contacts. People involved were primarily selected from the categories of stakeholders suggested by the experts during the interview. Participants of the first informative meetings organized in the valley in the previous months - were also invited. Finally, other local potential stakeholders were also intercepted through a distribution of posters and postcards in the information points and aggregation centres (town halls, offices of Mountain Unions, libraries, bars, etc.). The organization and management of the meetings was followed by an agency of facilitators. During the first meeting, the project was briefly explained to ensure a homogeneous mind-set among the participants, especially for those who had not been involved in the project yet. The results processed by the DSS about potential energy production from forest biomass and water have been shown. Afterwards, participants were asked to give their opinion about the energy scenarios and the opportunity to use or not these resources. In particular, suggestions regarding additional areas to be used for biomass or new lines/points for power plants were collected. In the same way, suggestions were collected about streams and typologies of power plant to be implemented for the use of water. During this meeting, we explained the findings about the interaction between ecosystem services and the use of water/wood. The University of Padova elaborated maps expressing distribution and values according to some bundles of services which values were difficult to be objectively given, such as recreational activities (hunting, mushroom picking, fishing), ecological quality of water, sports opportunities, woodlands and meadows, and explained how they were generated. Participants were then provided with maps and asked to contribute, starting from their personal knowledge, adding or revising information. Furthermore, we gave the possibility to send material, request further information or expose criticism, doubts, suggestions, to a specific mail address, before the second meeting. The second consultation, carried out in a single meeting, was focused on ensuring a "synthesis of the valley": for the Mis valley it was held in Sospirolo and for the Maè valley in Zoldo Alto. Many feedbacks on general aspects were collected. In confirmation of the importance that the anthropological dimension assumes in the assessment of ES, participants were asked to rank in order of importance (1 = extremely important and 7 =

least important) the values present in their valley, referring to their own experience, perceptions and preferences through a questionnaire. The categories of ES were expressed as values of the territory in relation to the activities and interaction between the community and the territory itself. Seven values were finally identified:

- Environmental
- Economic
- Touristic and recreational
- Social
- Emotional-sentimental
- Historical and cultural
- Aesthetic and landscape

Participants shared their ranking with the group, justifying and commenting their own choices and, when possible, drawing the different categories of maps on big blank maps: in this way, they could provide new elements to be considered for the analysis of ecosystem services in the valley. This participatory process (resumed in Figure 4) made it possible a ranking of ES for the two watersheds, based on the opinions of local stakeholders.

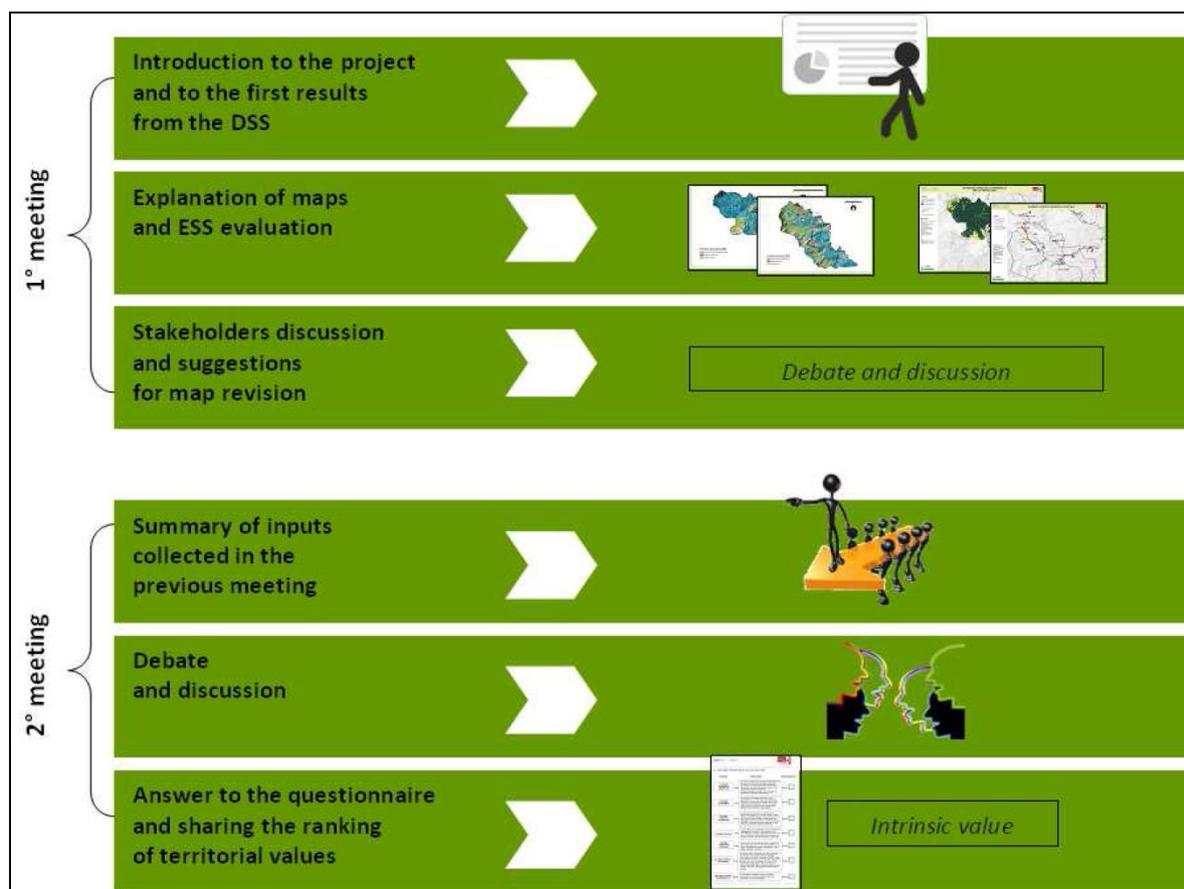


Figure 4. Description of the steps and phases of the participatory process adopted for the pilot areas of Belluno (Italy).

2.2.4. Results

The results obtained by the questionnaires delivered to the stakeholders were based on ordinal values of preference/importance. To sort the ecosystem values of the two watersheds, the correct method would refer to the values of mode and median². However, because of the available population of respondents was rather restricted, there could be matching values for different terms or it could not be possible to achieve, for example, a value for each class. To overcome these problems, it was decided to calculate the percentage of people who have attributed a certain class to each value, weighting the classification on the number of people who have expressed these values. The calculation sorted the values in descending order, starting with the most important ones: we considered which values were indicated by most of the respondents in the first three classes, then in the first two and then in the first class (excellence).

² Given a set of data, the mode is the value that appears most often. The median is the number that occupies the central position in an ordered set of data. The mean is the sum of a list of values divided by the number of values in the list.

Comparing these rankings with those resulting from the analysis of mode, median and average for each type of value, it was possible to obtain the final results for each of the two watersheds (Figure 5). This method considers separately two terms, having, apparently, the same value, and then compares them referring to other variables for determining the priority/weight.

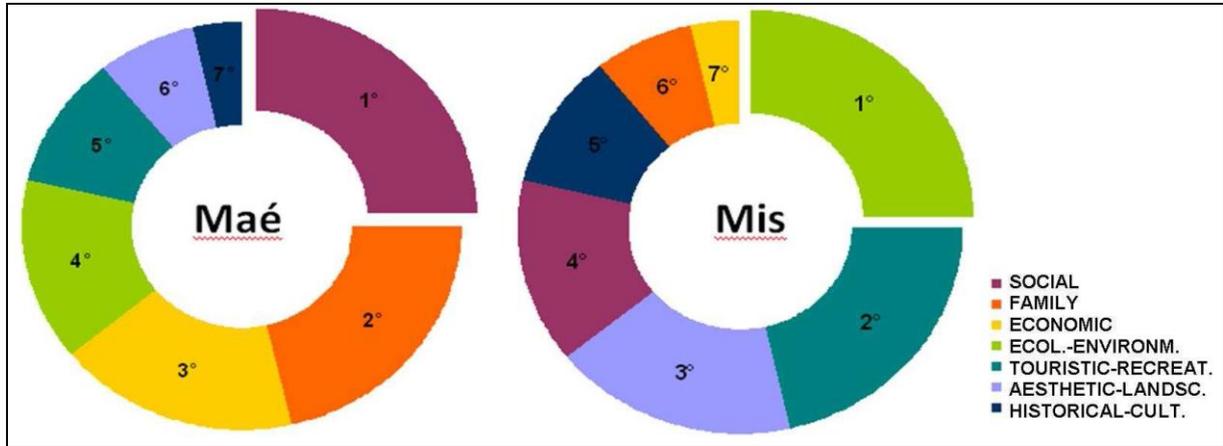


Figure 5. Results of the ranking of the Environmental Services in the two watersheds of the pilot area.

2.2.5. Conclusions

Adopting a participatory approach in evaluating investment on renewable energy infrastructures in mountain areas is a strengthening factor in the decision-making process. It is not only a matter of reducing risks, preventing conflicts and getting public support for the investments; participatory approaches based on the involvement of correctly informed stakeholders are a requested by the mixed, private-public, components of renewable resources such as water and forests. These are goods providing ES directly affecting the welfare conditions of local population that should be always involved in defining the proper balance between energy production and environmental resources conservation.

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2.3 Management of forest stands to enhance soil ecosystem services: a short review of recent and on-going projects in Mediterranean Europe

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2.3.1. Introduction

In the last half century, many studies about soil nature and ecosystem services have been conducted, covering different research issues, among them, soil mapping of woodlands and nearby croplands in the Alps (Ronchetti 1965, Sartori et al. 2009), soil conservation under reforestation (a.o., Gregori et al. 1999, Costantini 1993), soil biology (Gregori et al. 1991), and soil genesis as affected by climate change (a.o., Lulli and Bidini 1980, Egli et al. 2003).

Recently, a set of soil related projects, which are of particular interest for the management of mountain watersheds, have been carried out. They are: “Research on Italian Selviculture” (Ri.Selv.Italia) financed by the Italian Ministry for Agricultural, Food and Forest Policies (MiPAAF) during the 2001-2007 period, and three LIFE projects. One of them already completed, such as “Monitoring for soil protection” (SOILPRO – EU LIFE, 2010-2014), and two on-going projects, such as “Silviculture and biodiversity” (SelPiBioLife – EU LIFE, 2014-2019) and “Recovery of degraded coniferous Forests and climate change mitigation” (FoResMit – EU LIFE, 2015-2019).

All the projects are intended to provide technical solutions for the sustainable planning and management of different forest ecosystems at local or watershed level, from the Alps to the Mediterranean, with experimental plots established both in Italy and Greece. Therefore, they provide useful information and guidelines that may be applied all over woodlands of Southern Europe.

2.3.2. The Riselvitalia project

The project stemmed from a research request to work out a procedure able to support foresters and land planners in selecting the most appropriate destination of forests, including their protective role against shallow landslides, water runoff, and soil erosion. The Riselvitalia Subproject 4.3 “Models and indexes for sustainable forest management” dealt with assessing the protective role of the forest cover against hydrogeological disturbances and produced a GIS-based tool for forest planning (www.ricercaforestale.it/riselvitalia/). The propensities to all the instability phenomena and the role of vegetation in contrasting shallow landslides were evaluated by means of artificial neural networks (Scrinzi et al. 2006). Conversely, the protective functionality of vegetation against soil water erosion and direct runoff was assessed using original spreadsheets implementing well known algorithms, respectively RUSLE and SCS-CN (Gregori et al. 2006). The main task was to provide flexible solutions for different scenarios of forest management (e.g., timber, environment, recreation, etc.).

A mathematical approach was set up to combine cover functionality with land propensity, with respect to each of the instability phenomena analysed, in order to evaluate the following four indexes for soil conservation:

- 1) Equilibrium level: a rough estimation of the balance between propensity and cover protection.
- 2) Protection value: an assessment of the ability of the vegetation in controlling a particular phenomenon.
- 3) Constraint level: an indication of the degree of limitation with respect to timber-oriented management.
- 4) Action priority: a preliminary screening of land units requiring ameliorative practices.

Figure 6 shows the maps of both propensity and cover functionality, with respect to shallow landslides, assessed in a study area, located in the Sardinia Region (Nurri-Orroli Province, Italy).

In such a study case, given that the climatic aggressiveness is low (Gregori et al. 2006), the kind of lithotype and the slope degree played a major role, while vegetation type and management can counteract more or less efficiently the potential risk.

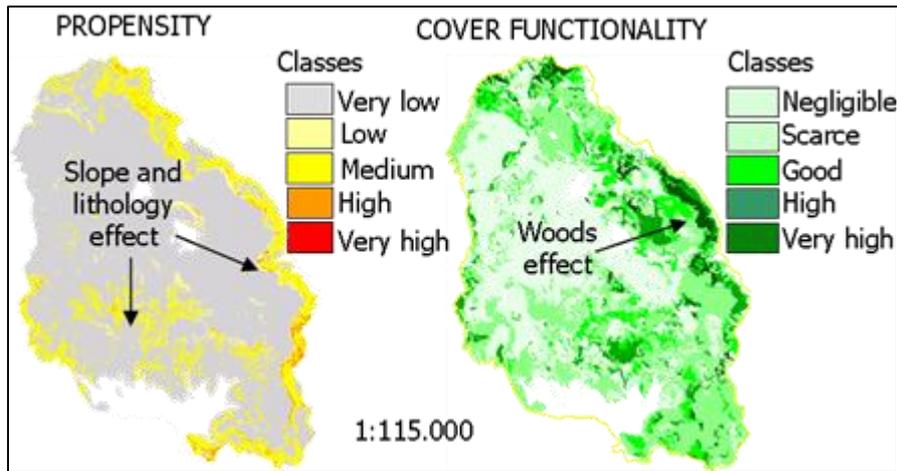


Figure 6. Maps of propensity and cover functionality related to shallow landslides.

Figure 7 reports the maps of the previous four indexes, calculated for the same study area, with regard to shallow landslides.

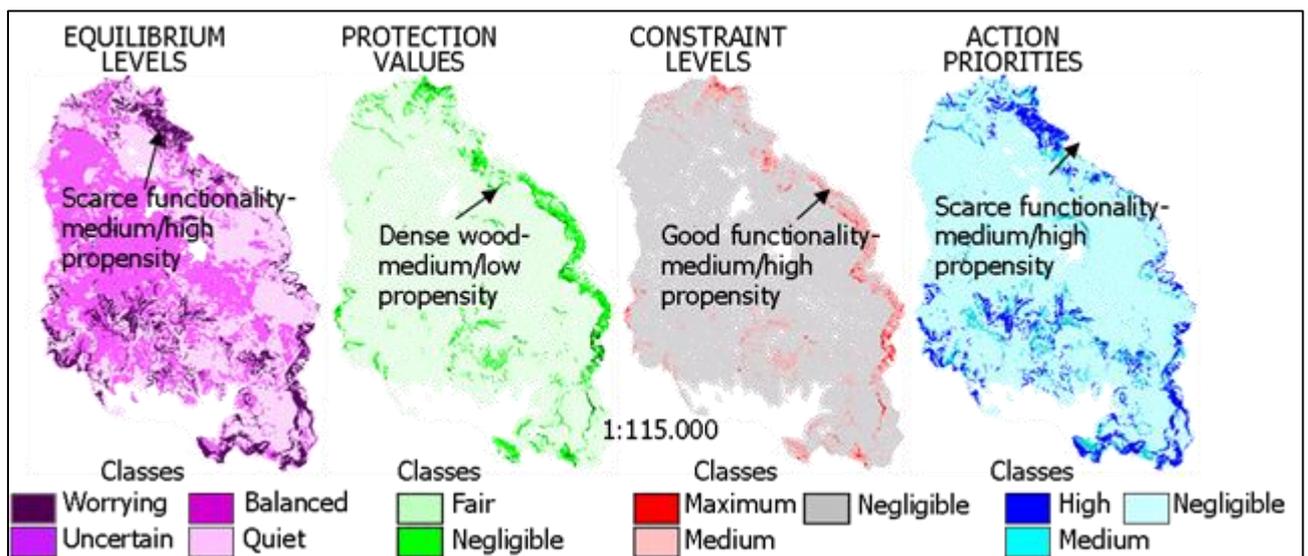


Figure 7. Maps of the four indexes with regard to shallow landslides.

The outcomes of the project allow the technicians to obtain an objective tool for identifying the forest lots with actual protective function and planning general conservation actions, particularly when specific goals have to be met (e.g., reservoir catchments) (Andrenelli et al. 2007).

2.3.3. The SOILPRO project

Assessing the risk of soil erosion caused by water at the regional level is important for current and future planning of land use and environmental actions to combat land degradation. The gravity of the risk not only depends on the rate of soil erosion by water, but also on other factors, primarily soil depth and workability of the underlying rocks and sediments, which may be used to replace the eroded soil (Fantappiè et al. 2015b).

The SOILPRO project interested two European regions, Sicily and Peloponnesus, and developed a web-based application tool (Soil Monitoring Software, SMS) to support local and regional authorities in their efforts to identify areas at risk of soil degradation, in order to implement soil protection measures as well as to monitor their effectiveness (www.soilpro.eu). The Regional Departments are interested to obtain maps of soil degradation risks with the highest possible accuracy, validated at the finest scales, to make the best localization of the areas where to apply soil protection measures (Costantini et al. 2015). The maps resulting from the project were approved by an official act of Region of Sicily (Regional Decree # 1835, 22 December 2011) and adopted in the implementation of the regional Rural Development Program. We produced the soil map (Fantappiè et al. 2011) and the physiographic map (Fantappiè et al. 2015a) of the region to estimate the rate of erosion by water ($\text{tons ha}^{-1} \text{ year}^{-1}$), by applying the Universal Soil Loss Equation model. Furthermore, the map of soil mass (tons ha^{-1}) to the effective rooting depth was combined with the map of soil erosion rate to obtain the risk of erosion by water, expressed in terms of years of complete loss of the soil cover. This map was intersected with a map of workability of the underlying bedrock to give advice on where the cost of soil recovery by deep ripping and rock grinding were very high. 8382.9 km² (32.6% of the Sicilian territory) were rated as at high or very high risk (<100 years to complete soil erosion, under the current land use and management), of which 1230.9 km² developed on bedrock with low workability and so very costly to be recovered (Fantappiè et al. 2015b).

2.3.4. The SelPiBioLife project

Pine species have been extensively used for land restoration in the Mediterranean basin and in other parts of the world, since the late 19th century. The traditional strategy for reforesting degraded lands in the Mediterranean was at first to introduce a fast-growing pioneer species, usually a pine species (Gil and Prada 1993), assuming that this species would facilitate the

introduction (either artificial or natural) of late-successional hardwoods (Barbéro et al. 1998). Indeed, the theoretical basis supporting pine utilization was its stress-tolerant and pioneer features, and their attributed role of facilitating the development of late-successional hardwoods in the long-term (Pausas et al. 2004).

Nowadays, most of these pine stands are performing their role of pioneer species, colonizing previously degraded areas and beginning the chain of ecological succession that supports a higher biodiversity and a more resilient and resistant ecosystem characterized by native broadleaved species. Nevertheless, this strategy was seldom completely applied because of the costly silvicultural post-plantation operations required, and the current disturbance regime.

According to the National Forest Inventory (INFC 2008), 31% of Italian pine forests in the Mediterranean zone show degradation symptoms and are damaged on a total of 462,568 ha. In most cases, pine plantations show degradation symptoms with many dead, fallen and/or damaged trees. The SelPiBioLife project is aimed at demonstrating the effectiveness of innovative silvicultural treatments to enhance soil biodiversity in artificial black pine stands (www.selpibio.eu/). Such innovative thinning methods are based on the identification of the dominant plants and removing of the plants around. The proposed methodology aims at creating small to moderate gaps in the tree crown layer (patch thinning) or at reducing the crown coverage density regularly (progressive thinning). Expected results are aimed to: enhance the overall soil biodiversity, enhance the pine succession and increase the economic value of the product, enhance the pine dendrometric stability, reduce the canopy cover and enhance the rate of light, water and temperature at the soil level. Thus, the overall effect should be an increase of the functionality of the ecosystem and of soil biodiversity.

2.3.5. The FoResMit project

The FoResMit project is implementing the recovery of degraded coniferous forests for environmental sustainability restoration and climate change mitigation. Forest degradation, resulting in a loss of biomass or in a reduced production, occurs through damage to residual trees and soils from poor logging practices, log poaching, fuelwood collection, overgrazing, and anthropogenic fire (FAO 1993, Flint and Richards 1994). Forest degradation, implying a decrease in canopy cover and regeneration, as well as forest fragmentation, will affect the annual increment of C sequestration, reducing the potential of these forests to act as a sink or transforming them into a source of green-house gas (GHG). Carbon emissions from

deforestation and forest degradation have been estimated to account for about 12-20% of global anthropogenic CO₂ emissions (IPCC 2000, 2007). Although deforestation is the main source, forest degradation contributes to atmospheric GHG emissions through decomposition of remaining plant material and soil carbon. These larger emissions are no more balanced by the C storage capacity in woody biomass and soil, due to unstable structural conditions of the degraded stands. Deforestation and forest degradation are important contributors to global GHG emissions, but if these processes are controlled, forests can significantly contribute to climate change mitigation (Pearson et al. 2017). Therefore, the current forest degradation needs an innovative management plan aimed to support and facilitate all the functionalities of a forest, in a context of climate change mitigation.

Even in the cases where there are no dead, fallen or damaged trees, peri-urban pine forests in the Mediterranean area are vulnerable to forest fires. These fires can destroy vegetation cover of protective peri-urban forests and other adjacent forests leading to erosion and in some cases to catastrophic debris torrent phenomena that can threaten urban infrastructures. Moreover, great amounts of CO₂ can be released in atmosphere through these fires. Thinning aiming at the reestablishment of native broadleaved vegetation will make the pine dominated peri-urban forests less prone and more resistant to wildfire. Moreover, through the sprout ability of broadleaves, vegetation cover of the area will be restored rather soon, thus protecting forest ecosystem from erosion and cities from catastrophes. As temperature and aridity rise as a consequence of global warming, forest fires will appear more frequently and their intensity will be greater. In this frame, broadleaved trees can be used as a mitigating tool through sprouting ability.

The general objective of the project is to define the guidelines of good silvicultural practices for the restoration of peri-urban degraded coniferous forests in Italy and Greece with native broadleaved species, improving the ecological stability and climate change mitigation potential of these ecosystems. The project aims at testing and verifying the effectiveness of management options for the conversion of degraded coniferous forests in meeting climate change mitigation goals. The project will provide data on vegetation structure, biomass increment, C accumulation in all relevant pools of vegetation and soil, and CO₂ and other greenhouse gas emissions, thus giving a complete picture of mitigation potential of management practices.

Traditional and selective thinning treatments will be applied and effects will be compared with unmanaged forest. The application of selective thinning is constituted by the following steps: i. selection of more productive trees; ii. choice in function of mechanical stability; iii. removal of dead plants; and iv. creation of small to moderate gaps and favouring broad-leaves species. The

objectives are multiple: increase C sequestration of plants (increase of NPP); increase C accumulation in soil; reduce GHGs emissions from deadwood decomposition; use biomass for fossil fuel substitution; restore ecological stability; reduce fire risk. The initial physical-chemical soil characterization is fundamental to validate the selection of test areas to reduce biases due to soil heterogeneity. After the implementation of silvicultural treatments, the FoResMit project will provide data on vegetation structure, biomass increment, C accumulation in all relevant pools of vegetation and soil (above and belowground biomass, litter, dead wood and soil, IPCC 2000) and CO₂ and other greenhouse gas emissions, thus giving a complete picture of mitigation potential of management practices (Figure 8).

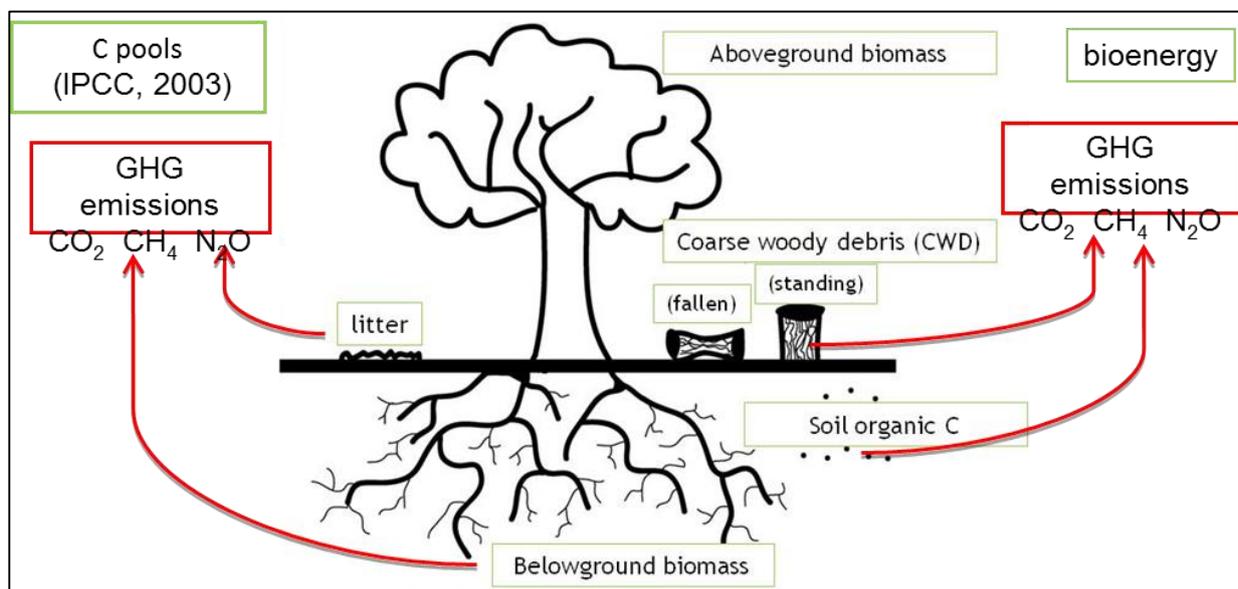


Figure 8. Monitoring actions of the Foresmit project.

2.3.6. Conclusions

The discussed projects confirm that soil forest ecosystem services are of utmost importance, and their relevance is expected to increase in the near future. Besides services related to timber provision, water regulation, soil conservation, and landslides prevention, other services are on the spotlight: increasing above and below ground biodiversity, improving ecological stability, GHG mitigation and compensation. In particular, the management of peri-urban forest stands is of particular interest, because of the high economic and social values of their soil ecosystem services.

Actually, the issue of finding the optimal trade-off between the conflicting interests of the different stakeholders – farmers, forest companies, communities, government, society, etc. – is

still a challenge. To this respect, the Riselvitalia and SOILPRO projects have provided local authorities and land planners with GIS-implemented tools that, however, needs some training to be adopted. On the other hand, SelPiBioLife and Foresmit aims to support a new silvicultural practice that is supposed to enhance several soil ecosystem services. In both cases, the economic sustainability of the treatments will be the object of a future investigation.

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2.4 Ecosystem services in mountain forests: the interaction of carbon and water balance in a beech stand in Central Italy

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2.4.1. Introduction

The availability of water resources is essential, not only for the vegetation distribution, but also controlling forest productivity. In fact, the availability of water is reflected in plants performance and, in case of water deficit, it determines the reduction or arrest of photosynthesis and growth, alteration of metabolic processes and, if prolonged, the possible death of the plant. In the Mediterranean area, most of the rainfall is concentrated in the autumn-winter-spring months, while the summer is characterized by long periods of drought, when the high temperature and low humidity conditions increase Evapotranspiration (ET) making the water deficiency particularly damaging.

Forest carbon (C) stock depends on the amount of carbon dioxide fixed by trees defined as the ratio of gross primary production less plants respiration; while the whole ecosystem C stocks and net sink effect depends also on decomposition processes. C-stock and fluxes, nutrients and energy fluxes are closely linked to stand age, specific composition and forest structure. In the Mediterranean region, climate (temperature and precipitation) and nutrients are the most important factors to explain the spatial and temporal variation of primary productivity and C-absorption by forest ecosystems (Matteucci et al. 2013). A valid tool to determine the exchange of C dioxide, water vapour and energy fluxes in different ecosystems and climatic conditions,

is the Eddy Covariance technique (EC), which was widely used in biosciences in recent years (Baldocchi 2003).

The sensitivity of Mediterranean forest species to water stress becomes very relevant under the consideration of environmental changes currently taking place (global change). According to models and scenarios, climate change triggered by the progressive increase of carbon dioxide in the atmosphere will cause for southern Europe an increase in average temperature, in the number and frequency of heat waves and a decrease of cold periods, all with varying degrees of reliability (IPCC 2014). In this respect, it is important to understand the response mechanisms of forest ecosystems to environmental factors and the impact that climate change could lead to it, particularly under extreme situations, such as e.g., at the upper or lower limits of forest vegetation. In those areas, the climate change could have a more significant impact than in other situations.

In Italy, the areal distribution of beech (*Fagus sylvatica* L.) includes middle and high altitude mountains (Hofmann 1991, Masci 1995). In almost all the Apennines, beech forests represent the upper limit of the forest vegetation. Due to the relevant interactions between C and water cycles and the potential impact of climate change on these cycles, it is therefore important to study the mutual relations between water balance and productivity in beech forest ecosystems located in the Apennines.

The objectives of this research note are to report on the temporal variation of the annual C and water budget in a mountain forest ecosystem of Central Italy and to highlight the impact of seasonal hot spells and drought on C-absorption and on net ecosystem productivity.

2.4.2. Materials and Methods

The study was carried out in Central Italy in the Abruzzi Apennines (Collelongo, AQ, 41° 50'58" N, 13°35'17" E, and 1600 m a.s.l.). The forest stand is a mature beech forest of about 3000 hectares under typical conditions of the Mediterranean-montane forest ecosystems. The main characteristics of the test site are shown in Table 1. The site is a long-term research site established in 1991 by the University of Tuscia (DIBAF Department, Viterbo) and it is equipped since 1993 with micro-meteorological instrumentations for the measurements of the C fluxes, water and energy exchanges between the forest ecosystem and the atmosphere using the eddy-covariance technique (Aubinet et al. 2000). Since 2004, the site is managed by the National Research Council of Italy (IBAF institute) and, in 2006, the Collelongo site became

part of LTER – Italy network (Italian long-term ecological research network), part of LTER Europe and ILTER.

Table 1. Main characteristics of test site (referred to 2012 survey).

Average Age [years]	120
Tree Density [n ha⁻¹]	800
Leaf Area Index (LAI) [m² m⁻²]	4.5 ÷ 5.5
Basal area [m² ha⁻¹]	40
Average tree diameter [cm]	26

The eddy-covariance system measures the gas and energy fluxes and is composed by a three-dimensional sonic anemometer (CSAT-3, Campbell, USA), an Infrared Gas Analyser (IRGA closed-path LI7000, LiCor, USA) and meteorological probes for measuring microclimatic variables as air and soil temperature, air humidity, net radiation and photosynthetic active radiation (PAR). All these sensors are installed above and within the forest canopy on a tower 26 m tall and connected to a data-logger (CR 5000, Campbell, USA). Furthermore, soil water content profiles are measured with Time-Domain-Reflectometry (TDR) sensors (CS616, Campbell). The equipment is powered by photovoltaic solar panels connected to a series of storage batteries and an energy power generator that automatically comes into operation to provide power to the whole measuring system in case of emergency. The experimental design characteristics are illustrated by Valentini et al. (1996), Matteucci (1998), and Scarascia Mugnozza (1999).

The forest productivity, the hydrological cycle, and the allocation of the absorbed C are quantified in the research site. For measuring the precipitation components, rain gauges over the forest canopy (P), stemflow (SF) and throughfall (TF) collectors were installed.

The general equation of a water balance is as follows:

$$P - (It + R + D \pm Ds + Evs + T) = 0$$

where P = precipitation, It = interception ($It = P - SF - TF$), R = surface runoff, D = subsurface flow and infiltration, Ds = changes in water storages retained into the soil matrix, Evs = soil evaporation, T = transpiration. This equation considers all components that bring water into the system, all the water flows that come out of the system and the change in water storage. In the research site, the R and D parameters are generally negligible, while the TDR method was used to measure the variation in the soil water content, every 15 days from 1996 to 2004 and

continuously since November 2004. The sum of the Evs and T parameters represents the total evapotranspiration. These components should allow closing the “simplified” water balance as reported by equation:

$$TF + SF = ET \pm Ds$$

Evapotranspiration is measured with the eddy covariance method, as described above.

2.4.3. Results

Canopy fluxes in the research site (beech forest of Collelongo) are measured since 1993 (Valentini et al. 1996) but the new data acquisition system is running since 2004. From point of view of climate, in the 1996-2012 period, the warmest month has been August while, in the same month, the cumulated Net Ecosystem Exchange (NEE, gC m^{-2} , negative values indicate that C is absorbed by atmosphere) has varied from approximately -130 gC m^{-2} (2007) to nearly -200 gC m^{-2} (2010) (Figure 9). These results indicate a decrease in C-accumulation with increasing temperature that impact both photosynthesis and respiration (Mazzenga 2017) and a significant negative relationship between average monthly temperature and cumulated NEE in August ($r = 0.52$).

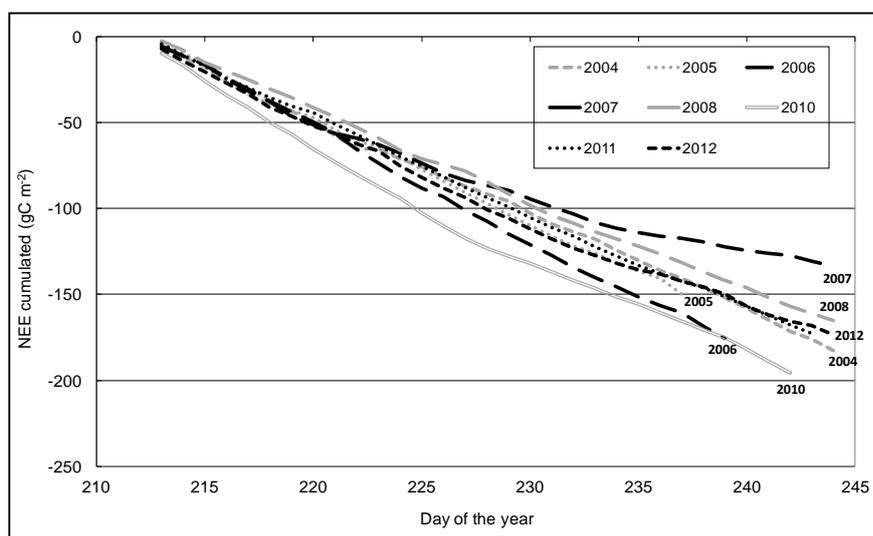


Figure 9. Cumulated Net Ecosystem Exchange (NEE, gC m^{-2}) measured by eddy covariance in August at the site IT-Col (Collelongo – Selva Piana). For convention, C-absorption from the atmosphere by the ecosystems is negative. Label for 2011 is not reported.

According to the data, in the warmest month a decrease of 10 mm in precipitation corresponds to 5 gC m^{-2} less C-absorption. High temperature plays a role in the correlation between lower NEE and drought. In fact, in three of the four years with lower C-absorption the mean

temperature in August was above the 1996-2012 average (16.3 °C), while 2004 and 2007 are very close to that value (16.2 and 16.0 °C, respectively). Furthermore, August of 2007 has been the driest of the series (2.8 mm), and was characterized by a relatively dry May and June (with a total of 138 mm vs. a mean for the 2004-2012 period of 210 mm). In fact, the precipitation sum of July and August is significantly correlated to the C-absorption ($r^2 = 0.58$). This is also showed analysing the data in two equivalent groups (4 data each, Table 2).

Table 2. Mean and standard deviation of August average monthly temperature, precipitation, Precipitation over Temperature ratio (P/T) and cumulated C-absorption (NEE) at Collelongo – Selva Piana. Data have been grouped in two equivalent groups.

T mean[°C]	P [mm]	P/T	NEE [gC m ⁻²]
14.4 (1.6)	47.6 (15.5)	3.4 (1.5)	-154.2 (11.1)
16.9 (1.0)	6.7 (4.0)	0.4 (0.2)	-133.4 (11.8)

However, it is worth noting that in the investigated period, totals of C-absorption (NEE) over late spring to summer (June to September) are not correlated to mean summer temperature, precipitation or P/T and the same is real for Gross Primary Production (GPP) and total ecosystem respiration derived from eddy covariance data. This finding may imply that, over summer, the ecosystem is able to respond and acclimate to changing climatic conditions, as far as drought is not prolonged. Nevertheless, annual totals of NEE in years with drier growing season generally show a lower C-absorption compared to wetter years.

In 1996 to 1997, a detailed study of hydrological variables was performed. Evapotranspiration (ET) budget data are presented in Table 3

Table 3

Table 3. Evapotranspiration and precipitation in site study.

Period	ET (mm)	Precipitation (mm)
28/06/96 - 27/06/97	401	1206
14/10/96 - 01/05/97	65	854
Growing season 1996-97	336	352
28/06-14/08/1996	171	36
28/06-14/08/1997	91	6
28/06-13/09/1996	229	164
28/06-13/09/1997	125	33
01/05-15/09/97	192	118

The annual evapotranspiration budget was calculated for the period from June 28th 1996 to 27th June 1997 in which ET was 401 mm, 336 mm in the growing season (28/06/96 to 14/10/96 and 01/05/97 to 27/06/97) and 65 mm in autumn, winter and spring until the start of the foliation (Table 3). The last fraction may be regarded as evaporation from soil and, in part, from the snowpack, while the spring-summer period is the sum of soil evaporation and plants transpiration. In the growing season precipitation was 352 mm, which should be sufficient to cover 336 mm of ET. However, even in this case, rainfall distribution should be considered. In fact, about 120 mm of precipitation were from mid-September to mid-October, 95 mm in the month of May while in the resting period, 854 mm of precipitation recharged the soil, preparing for the growing season, although that amount was not totally used from the vegetation. If we calculate ET for the growing seasons in the two years, we can see how important the inter-annual variability is. The highest C-absorption of the beech forest is between late June and mid-August (Matteucci 1998, Mazzenga 2017) and, in the same period of the study years, ET was 171 mm in 1996 and 91 mm in 1997, compared with a precipitation of 36 and 6 mm, respectively (Table 3).

The disequilibrium between supply and use of water resources continues until mid-September. Therefore, during the summer the ecosystem must rely on water reserves of soils in order to meet the requested transpiration. To verify if water resources were sufficient in total, a calculation was made for the growing season of 1997. In the calculation, the amount of water lost by the various layers of soil, as measured by the TDR, was considered together with the contribution of useful precipitation (the combination of SF and TF) and ET. The results are shown in Table 4.

Table 4. Comparison of ET, water lost from the soil and precipitation for the Collelongo site in the spring and summer of 1997.

Period	ET	Water lost from the soil (mm)		Precipitation (mm)	
	0-50 cm	0-70 cm	0-90 cm	Total	useful
17/05-06/09	184	109	175	209	61
28/06-06/09	76	47	75	94	27

In a water balance, the difference between available (useful) precipitation (UP minus interception) and evapotranspiration should be equal to the change in water content of the soil in the portion explored by the roots. Between May and September, this difference was equal to -131 mm, a value that makes up 75% of the variation in soil water content between 0 and 70 cm (175 mm), range in which there is the largest fraction of absorbing roots (Dore 1995). During the period when the leaf area index was at maximum level (late June-early September) UP-ET (-59 mm) represents nearly 80% of the variation in the first 70 cm. The results are very significant, as they are obtained by measuring the water balance components with different integration techniques and timing, opening up new opportunities for the study of the water balance in the ecosystem.

A lower C-absorption in years with lower water input should affect also growth, which is measured on site by dendrometric bands applied on 10 trees. In fact, as shown in Figure 10, for 1997 and 2000, the trend is very similar until to the 20th-23rd June. After that date, the trend is different: in 1997, when the water deficit has started earlier and lasted for the entire season, the percentage circumference growth is stabilized and then declined after the middle of August, while in 2000 the growth reaches a maximum between 20th June and 11th July and then decreases.

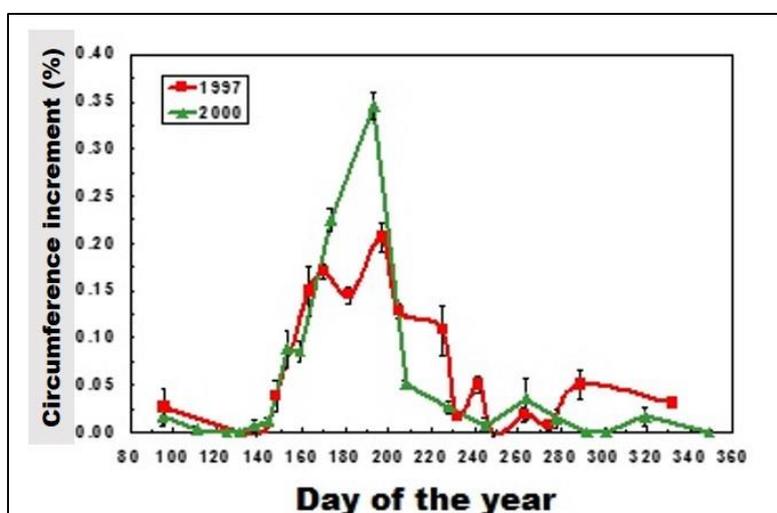


Figure 10. Annual trend in the percentage circumference growth measured on dominant trees in Selva Piana in 1997 and in 2000.

Between these dates, the soil water content within the entire profile (90 cm) is decreased from 32.4% to 20.9%, losing the equivalent of 90 mm of water, equal to an ET of 4.5 mm per day. Subsequently, the soil water content has reached values near the wilting point (WP), with consequent limitation of photosynthesis (Timarco 2001, Mazzenga 2017). It is interesting to

note that the beech forest is able to take advantage of the rainfall of the end season. In fact, in both years, growth responds positively to the rains of late August-September, even if more limited in 2000, when there was a major water stress. The apparent growth in the autumn is instead a rehydration process of tissues.

2.4.4. Discussion and conclusions

In the years of study, the climate has presented great variability, especially if precipitation is considered. Generally, the climate diagram of the site in the three summer months (June-July-August) presents a curve of the average temperature above that of precipitation, indicating the possibility of water deficit. The precipitation under the canopy is the main component of the water budget, representing about 90% of that above the canopy. The remaining fraction is represented by the interception. In summer, the soil water content is determined from irregular water supply and ecosystem ET, with often values lower than 15% in the first 20 cm of the soil and less than 20% in the entire profile (0-90 cm). Such conditions have occurred in at least three years out of four between 1997 and 2000.

The beech forest at Collelongo demonstrates short- to medium-term acclimation to relatively dryer years, indicating a capability of adjusting the C-water balance (Scartazza et al. 2013). Nevertheless, a thorough analysis of climate controls of Net Ecosystem Exchange over biomes included Collelongo in the group of sites where annual NEE was mostly controlled by dryness (Yi et al. 2010) and photosynthesis has been reported to be affected by drought (Mazzenga 2017).

At the beech forest of Collelongo, located in the Apennines of Central Italy, where the mountain temperate climate is frequently characterized by dry and warm summers, particularly in July and August, summer NEE is affected by warmer temperatures coupled to low precipitation bringing soil water content below a critical limit. Evapotranspiration responds to climate factors and is well correlated to soil and trees water status. The presence of water stress impacts both evapotranspiration and C-sequestration. In fact, there is a connection between decreases in maximum instantaneous values of net exchange, daily C-absorption and water status of the trees.

In the long term, warming climate and the increased frequency of heat waves could negatively affect the overall C-budget of Central Apennines beech forests, affecting their ability of acclimation to climate variations.

Overall, the study results stress that water availability is one of the major factors that influence the functionality and C exchanges in the beech forests located in mountain Mediterranean environments. Climate variability is expected to increase and extreme events, including drought but also late frost, will influence overall performance and stability of forests in Mediterranean mountains. In this respect, forest management should consider possible adaptive options in order to make these important forest ecosystems more resilient to climate change (Matteucci et al. 2013).

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2.5 Strengthening integrated forest management in European mountain watersheds: insights from science to policy

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2.5.1. Mountain watersheds in Europe: current issues and challenges

Forests, mountains, and water: beyond the hydrological services

The European mountains cover approximately 29% of the total area (of which 41% is forested; European Environment Agency 2010), and are considered important sources of water (i.e., water towers), biological diversity, and tourism and recreational opportunities, as well as key areas for conserving local traditions and cultures (European Commission 2004). Even though the mountain environments are widely recognized for their multifunctionality (for the Italian Alps; Notaro and Paletto 2011), they are often characterized by difficult ecological and social-economic conditions for the local development, and especially for the efficient (profitable) farming and livestock, productive grazing and forestry, and living. During the last decades, these aspects have been exacerbated by climate and land use changes (due to the abandonment processes), topographic conditions (e.g., slope, accessibility) and local economy (Briner et al. 2012), that in turn originated from a reduction of mountain ecosystems' resilience, and subsequently by an increasing of extreme events' occurrence (e.g., soil erosion, landslides, biodiversity loss, habitat degradation; Kräuchi et al. 2000). The depopulation and migration phenomena outside the mountain areas also undermined the mountain culture and identity, including the associated traditional uses (Musiał 2013). These constraints strongly limit the social-economic development of mountain landscapes, thus facilitating the marginalization of

activities, such as the agriculture and timber production, and the local impoverishment (Huber et al. 2013). Table 5 summarizes the main ecological, and social-economic constraints characterizing the mountain environments.

Table 5. List of the main ecological and social-economic constraints characterizing the mountain environments.

Constraint type		
Ecological	Social	Economic
<ul style="list-style-type: none"> • Steep conditions (increased slope) • Reduced ecosystem productivity, functionality and resilience (occurrence of degradation processes) • Increased extreme climate change-associated events and implications (e.g., hydrological risk, drought) 	<ul style="list-style-type: none"> • Scepticism with regards to innovation and new land management systems • Social segregation, and low access to education, healthcare, and other public facilities • Weak in cooperation (among people and between people and institutions) 	<ul style="list-style-type: none"> • Less intensive and remunerative agricultural and grazing activities • Lack of infrastructure and weak economic exchanges (in general) • Minor economic investments (low attractiveness)

Similarly, mountain watersheds are affected by human-induced modifications, such as those ranging from drought associated with global warming, to the reduction of agricultural productivity due to land abandonment (traditional uses in Central Italy; Palombo et al. 2013), and finally to the degradation of forests or other ecosystems (e.g., grasslands), including the loss of species and habitats (projected climate-originated impacts on biodiversity in mountain ranges; Thuiller et al. 2005). This is in contrast with the important role of forest ecosystems in providing water-related services to local communities. At first, forests improve the water quality by filtering out contaminants and trap sediments, thus substantially reducing the need

for treatments (and related costs) for drinking water (e.g., Postel and Thompson 2005). Moreover, forested watersheds are exceptionally stable hydrological systems (FAO 2003). Especially in mountain areas, forest ecosystems protect human settlements from natural risks, such as avalanches, rock-fall, mudflows, landslides, and other erosion phenomena (Eustafor and Patterson 2011). The forest vegetation is ultimately important to protect and maintain biodiversity in aquatic habitats (Aquatic Ecosystem Services; Creed et al. 2016).

The watershed scale seems to be particularly suitable for ecosystem management, especially to detect and monitor some key ecological processes (e.g., hydrological), including the linkages between the ecosystem functionality (of forests) and the associated benefits for local communities (i.e., ecosystem services, ES). Furthermore, at watershed scale, the risks derived from e.g. floods or landslides are better detected and monitored, as well as the implications of local communities' impact on ecosystem health and stability (e.g., the overexploitation or the abandonment of traditional uses of forest resources).

Integrated management of forest mountain watersheds

The integrated watershed management (WM) is the process of organizing natural and semi-natural resources in a way that the local development is promoted (i.e., through enhancing the ecosystem services provision), and that the balance between land use intensity and ecosystem functionality and resilience is ensured (Wang et al. 2016). The integration of adaptive management with the traditional knowledge may improve the WM effectiveness (Wang et al. 2016). In other terms, WM is called to balance local communities' needs with changes in land use and climate conditions, even considering (and adapting to) the related future uncertainties. Accordingly, adaptive forest management in mountain watersheds must consider the ES trade-offs, and the related effects on resilience of coupled nature–human systems over the time (processes and energy flows between alternative land uses, etc.; Sun and Vose 2016). Moreover, the forest management in mountain watersheds is called to balance the benefits obtained by the regulation of hydrological processes from forest ecosystems (e.g., in terms of water availability and flows) with other positive outcomes for local communities, such as e.g., biodiversity conservation and habitats protection, recreational opportunities, timber and non-timber forest products provisioning. Although the adaptive management is proposed as one of the possible solutions to bridge the gap between local communities needs and mountain environments constraints (Vizzarri et al. 2015), many studies outline the following obstacles and limitations concerning the WM implementation (e.g., Wang et al. 2016, Porzecanski et al. 2012): (i) lack of harmonized cooperation, and unified organization; (ii) weak stakeholders' equality,

involvement and consideration; (iii) fragmented policies and legislation; and (iv) absence of appropriate data and research opportunities. Finally, Vose et al. (2011) point out that research efforts are still needed to improve forest watershed management adaptation to climate change. Responding to these challenges and considering the need of reducing environmental risk by enhancing stability (i.e., resistance and resilience of stands in the face of disturbances) as one of the main objective of forest management, the following strategies have been implemented so far (Kräuchi et al. 2000): (i) stronger integrate knowledge of the complexity of human-environment relationships over the time (ecosystem processes and services) by implementing prolonged monitoring and experimental activities; (ii) intensifying the current research to improve the effectiveness of the management interventions (even with the support of modeling tools), especially with regards to ungulates or other external perturbations; and (iii) strengthening the network of mountain protected areas both at regional and global scale, to further detect and monitor the major mountain ecosystem changes.

2.5.2. State of research on forest management in mountain watersheds across Europe

Review approach

The literature review is to unravel how the current research (data and applications) may improve forest management in mountain watersheds in Europe. The review refers to a keywords-based search in the SCOPUS database (abstract, title, and keywords fields; www.scopus.com; Table 6). The literature search is focused on peer-reviewed and indexed articles in English language, published from 1960 to present³. Moreover, the review considers only those researches that are referred to watersheds (or catchments), and whose study areas are located in European mountain regions. Accordingly, the literature search was preliminarily divided into several groups, each of them specifically linked to a mountain region or massif in Europe.

³ The date at which the review has been carried out is different from the publishing date. As a consequence, the review results may differ between such two-time steps.

Table 6. List of search strengths and keywords used. In a next step, the set of articles found was sieved according to specific criteria of relevance (the percentage refers to the articles actually taken into account for the review).

Corresponding massif (region)	Search strength	No. of articles found (percentage of selected ones for next review processes)
Alps (including Prealps)	"Alps" OR "Prealps" AND "watershed*" AND "forest*" OR "forest ecosystem*"	55 (64%)
French mountains	"French" AND "watershed*" AND "forest*" OR "forest ecosystem*"	42 (19%)
Carpathians	"Carpathian*" AND "watershed*" AND "forest*" OR "forest ecosystem*"	12 (100%)
Apennines	"Apennines" AND "watershed*" AND "forest*" OR "forest ecosystem*"	5 (100%)
Central Europe (including Belgium, Austria, and Czech Republic)	"Central Europe" AND "watershed*" AND "forest*" OR "forest ecosystem*"	46 (100%)
Pyrenees	"Pyrenees" AND "watershed*" AND "forest*" OR "forest ecosystem*"	9 (100%)
United Kingdom	"United Kingdom" AND "watershed*" AND "forest*" OR "forest ecosystem*"	15 (87%)
Boreal	"Finland" OR "Norway" OR "Sweden" AND "watershed*" AND "forest*" OR "forest ecosystem*"	128 (73%)

Figure 11 depicts the synthesized search results. Each review result (i.e., article) was analysed via considering the following elements: (i) the consistency with the topic (i.e., forest management in mountain watersheds); (ii) the location of the study (mountain region); and (iii) the presence of contents related to suggestions/strategies promoting the research as support for forest management in mountain watersheds. Finally, it was evaluated whether the research would improve forest management in the study area (mountain watershed), both in maintaining the ecosystem functionality and resilience as well as in reducing the environmental risks. Results for other European mountain regions, such as Iberian mountain(s), Mediterranean islands (i.e., Cyprus), Balkan (i.e., Southeast Europe), and Atlantic Islands were excluded from the analysis.

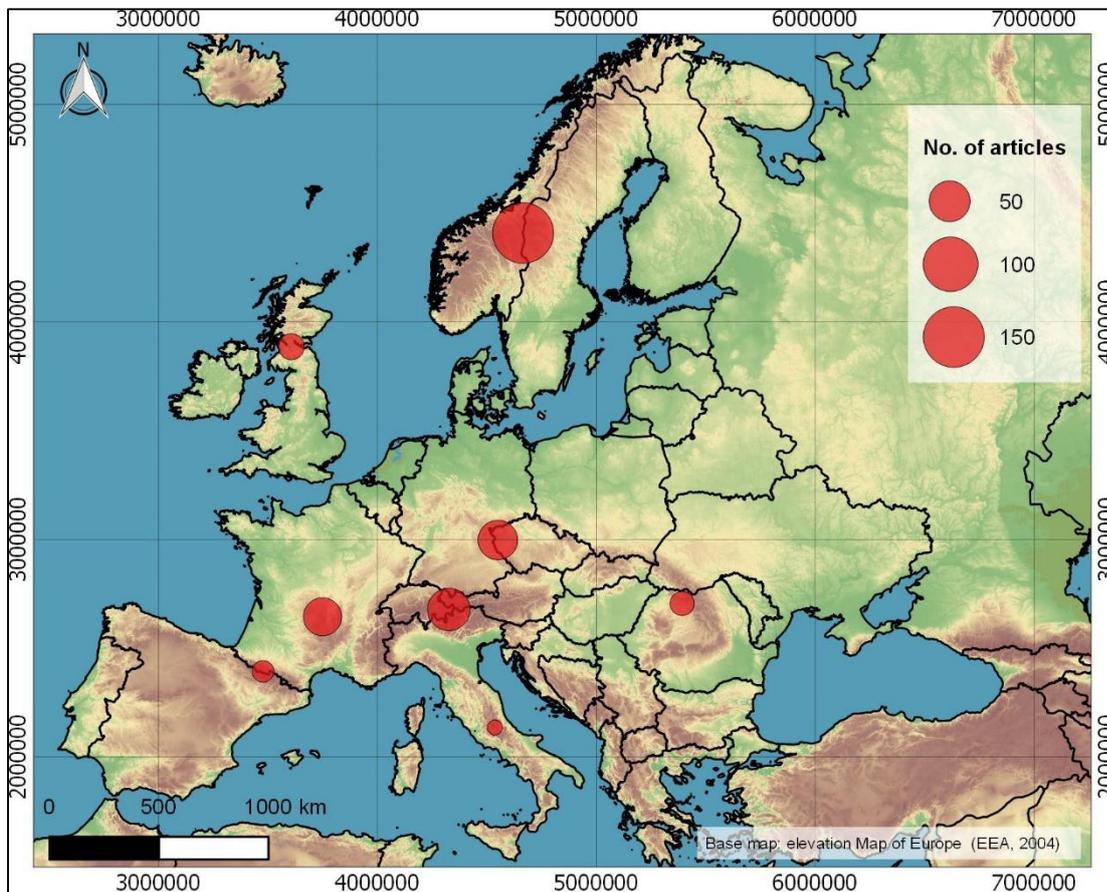


Figure 11. Map showing the differences about the main review results between the different search strengths for each investigated massif in Europe.

Maintenance of ecosystem processes, structures and services

Several available studies in many European forest watersheds are oriented towards further understanding how the abandonment of traditional practices influences the current ecosystem functionality (including biodiversity and habitats conservation) at watershed scale. Most of

these studies are located in Alpine and Boreal watersheds, and are focused on both (i) linking forest management with the conservation of plant and animal species, and (ii) describing how forest management may improve the adaptation of watershed ecosystems to external changes (mostly climate and land use). In the Alps, the abandonment of traditional practices is usually associated with higher lichen diversity (Nascimbene et al. 2013), increased soil nitrogen, tree species richness, and deadwood volume (Sitzia et al. 2015, 2012). Similarly, Garbarino et al. (2013) found that landscape heterogeneity generally increases where forests expand over abandoned pastures. On the French Alps, both the land abandonment phenomena and extensive reforestation actions are demonstrated to stabilize the slopes, as well as to restore the landscapes downhill (Piegay and Salvador 1997). In the Boreal region, some available studies emphasize the role of forest, and more generally, land cover on influencing the biodiversity downstream (species richness and habitat quality) (for Arctic char, Henriksson et al. 2015; for brown trout, Carlsson and Nilsson 2000). Forest regrowth is in fact associated with an increased ecosystem services availability, as in the case of the rewilding processes in Europe (Navarro and Pereira 2012). Nevertheless, the forest expansion following abandonment in mountain areas is in certain cases demonstrated to induce a biodiversity loss (Western Swiss Alps; Pellissier et al. 2013), the reduction of ecosystem resilience (e.g., increased fire risk in abandoned areas), and other negative social and economic implications (depletion of natural and cultural heritages, landscape homogenization, rising inaccessibility, etc.; Conti and Fagarazzi 2005). Other studies emphasize different impacts of forest vegetation on climate change mitigation. For example, Giesler et al. (2013) demonstrated that streams located in high-latitude environments (where the boreal forest is dominated by deciduous trees or possibly low-productive coniferous species) are carbon sources, in comparison with those located at lower latitudes. The importance of understanding the implications of ecosystem dynamics, including their interactions with the global warming (rain, snowmelt, and old groundwater), and on carbon sequestration is remarked by Smedberg et al. (2006) in Northern Sweden.

Reduction of environmental risks

The environmental risks in the European mountain watersheds are of both physical (i.e., floods, landslides and soil erosion) and chemical nature (particularly, eutrophication of ground/surface water and soil acidification processes). Land use and cover are demonstrated to have a great influence on the rainfall and runoff processes (Bahremand et al. 2006), particularly through affecting, e.g., infiltration and soil water redistribution (the influence of built-up areas on overland flow), evapotranspiration (different vegetation covers correspond to different

evapotranspiration rates; Calder 1993), and surface roughness (controlling overland and floodplain flow rates). Land use change affects pollution processes, as for example in the agricultural districts, where eutrophication usually alters the ecological quality of topsoil (high nitrogen concentrations in groundwater were measured in the watersheds dominated by arable fields in comparison to forestry catchments, where high ammonium concentrations were observed; Central Europe, Lawniczak et al. 2016). In mountain watersheds such as, e.g., the "Black Triangle" area across the boundaries of the Czech Republic, forest ecosystems strongly influence air pollution and water quality (Křeček and Hořická 2006). In fact, several studies demonstrate the key role of forests in mitigating both air and soil pollution, and especially in regulating the concentration of heavy metals (e.g., aluminium and mercury) and acid pollutants (in Central and Northern Europe, Schwesig and Matzner 2001; Pühr et al. 2000; Hongve 1999). In the same way, the forest stands play a crucial role for mitigating, e.g., the buffering and exchange processes and/or influencing the loads of dissolved compounds through the tree canopy (for the Bavarian Alps; Bäumler and Zech 1997). Forest cover is also important in controlling erosion processes in small basins (for Carpathians, Bednarczyk and Madeyski 1996), as well as in reducing snow accumulation and melting rates at high altitudes (for the Alps, López-Moreno and Stähli 2008). Nevertheless, it is important to note the complexity of the existent relation between forest ecosystems and water runoff.

Coupling research findings and watershed management perspectives in Europe

The state of research on forest mountain watersheds in Europe generally outlines the need to further implement management and planning approaches in a more comprehensive way. A prerequisite of the integrated management in mountain watersheds is represented by the goal of conservation and improving the functionality of ecosystems and their resilience. In fact, the research outcomes clearly demonstrate that healthy and stable forest ecosystems are able to improve landscape diversification, and reduce the environmental impacts (e.g., pollution and catastrophic events). Accordingly, forest management and planning at watershed scale should consider the effects of past external disturbances, such as, e.g., land use and climate change, on the current ecological asset, being able to adapt current strategies to ongoing changes. For example, forestry operations may mimic and facilitate natural processes (e.g., tree mortality, disturbances, re-invasion by native species), in order to restore the main ecosystem functions and processes, and include landscape and biodiversity perspectives in forest management (e.g., pine stands in South-western Alps; Vallauri et al. 2002). The implementation of integrated WM should also incorporate the analysis of the historical land use changes in order to simulate future

landscape changes and prevent possible natural disasters. This is the case of, e.g., July 2005 Siret River floods in Romania, which was favoured by the massive deforestation in the upper elevations of the Siret River watershed (Romanescu and Nistor 2011). On the other hand, the forest management is crucial to reduce the magnitude and frequency of natural disasters (soil erosion, floods, avalanches, landslides, etc.), and the pollution of soil and water. In fact, forest management is demonstrated to have a key role for regulating chemical cycles, through, e.g., reducing N leaching by favouring tree species that intercept lower amounts of pollution from the air, and by implementing harvesting strategies that reduce the risk of high nitrate leaching (Alpine and Apennine forest catchments; Jost et al. 2011). Possible approaches to improve the water quality may consist of, e.g., planting deciduous or mixed stands with high buffer capacity to reduce the atmospheric deposition (Jizera Mountains, Czech Republic; Křeček and Hořická 2006). In Central Italy, Borrelli and Schütt (2014) outlined that the susceptibility to erosion risk in two watersheds was aggravated by exposing the harvested forest area to heavy rainfalls without adopting, e.g., post-harvesting conservation strategies. In mountain watersheds, the risks linked to soil erosion and water contamination may be reduced by traditional forestry practices, such as, e.g., the use of clear-cutting thresholds, the use of horses in harvesting operations, and respecting riparian buffer zones, as suggested by Křeček and Hořická (2006).

Policy trajectories to 2020

Two main EU policies currently frame the integrated WM in Europe, such as the EU Water Framework Directive (EU-WFD; Directive 2000/60/EC), and the EU Floods Directive (EU-FD; Directive 2007/60/EC). On one hand, the EU-WFD was originally conceived to reduce water pollution, floods and droughts events due to anthropogenic pressure (e.g., land use change). However, Vogt et al. (2012) highlighted, for example, that such objectives are not fulfilled, especially if considering the eutrophication in agricultural districts. On the other hand, the EU-FD was aimed to avoid the risk associated with flood events at European level through creating flood hazard maps and flood risk maps, showing the potential consequences of different flood scenarios (Mazzorana et al. 2012). Nevertheless, the debris flows (e.g., mudslides, mudflows, or debris avalanches) are not currently considered in the EU-FD, although they represent a peculiar aspect for the environmental risk in mountain areas (Santato et al. 2013). More generally, the effective implementation of the integrated forest management in mountain watersheds in European countries should consider the following generalized policy trajectories to year 2020 (Ariza et al. 2013): (i) creating opportunities for new investments and compensatory measures for goods and services of mountain communities; (ii) supporting green

economies in mountain regions; (iii) strengthening research at regional and local scales; and (iv) promoting ecosystem-based management strategies that simultaneously consider the ecological, social, and economic dynamics, the potentialities for transboundary cooperation, as well as the sustainable use of resources. The same trajectories for EU policies have been proposed by, e.g., EUROMONTANA, which is one of the largest associations to promote the sustainable development in European mountains (EUROMONTANA 2013). At sub-national scale, these strategies are jointly promoted by the establishment of several agreements and cooperation actions among different stakeholders such as local communities, public bodies, and research institutions. For example, the Alpine Convention was established in 1989 in order to preserve the alpine environment by applying cooperation schemes and promoting the sustainable use of resources, as well as, among the others, improving the protective role of the Alpine forest ecosystems. Recently, the Contracting Parties (i.e., Countries; Germany, France, Italy, Slovenia, Austria, and Switzerland) and the European Economic Community ratified the “Action Plan on Climate Change on the Alps”, with the primary purpose to disseminate and recommend specific adaptation and mitigation measures ranging from the reduction of GHGs emissions to the effective implementation of the integrated approach in territorial planning (Alpine Convention 2009). Furthermore, as already mentioned, research plays a fundamental role in supporting the implementation of sustainable policies in mountain watersheds. Accordingly, predicting the impact of future-oriented policy and/or management approaches on the wellbeing of local communities represents a key strategy for the sustainable development in mountain watersheds. Several studies already demonstrated the importance of simulation tools to support the sustainable development in mountain areas (in Spain, Vidal-Legaz et al. 2013; in Switzerland, Huber et al. 2014). In the same way, the Research Centre for Inner Areas and Apennines (ArIA; <http://aria.unimol.it/>) was recently inaugurated to implement participatory and operative models to improve the preservation of the mountain heritage, and the sustainable development of the inner areas in Italy, according to the National Strategy for Inner Areas (UVAL 2014). Other research initiatives have been undertaken so far in other parts of Europe, such as, e.g., the European Academy of Bozen (EURAC research; <http://www.eurac.edu>), and the European Forest Institute Research Centre on Mountain Forests (EFI-MOUNTFOR; <http://mountfor.fmach.it>). In both cases, the research activities generated important outcomes for supporting the integrated management in forest mountain watersheds (social perception of forest ecosystem services, and management on the Alps, Paletto et al. 2013; and adaptive governance guidelines in mountain areas in Italy, Vizzarri et al. 2015).

2.5.3. Final remarks

This work mainly describes whether the current research outcomes are able to improve the implementation of the integrated management in mountain watersheds, and to what extent they are consistent with the emerging challenges facing mountain communities in Europe. In particular, the review exercise gives insights about the key role of forest ecosystems as well as their management and planning, in ensuring the functionality and resilience of mountain watersheds while facing external perturbations, such as, e.g., land use and climate changes. Moreover, understanding how the suggestions from the available single studies may be used as support for the current management of mountain watersheds in Europe, ultimately bridges the gap between the research and the policy side. This is demonstrated to be particularly important to support (with a certain robustness) the integration of already available EU policy strategies within the real forest ecosystem management in mountain watersheds. In particular, research and policy gaps still remain in the following fields: (i) further understanding of the ecological processes characterizing watershed systems, in order to better detect and simulate the future-oriented responses of the environment to external changes, including the biodiversity and ES availability; (ii) better integration of the stakeholders perspectives and needs within the watershed management, according to alternative sustainable development scenarios from local to regional scale; (iii) strengthening the EU policy and recommendations through taking into account the divergences among the forest mountain watersheds in Europe; and (v) incorporating the economic studies (e.g., investments' pathways) within integrated management of mountain watersheds, with the primary purpose to make the adopted interventions more effective, also with regards to the local communities' wellbeing. These aspects are also in line with the recent actions towards the "good status" of EU water and to reduce the flood risk (COM(2015) 120 final) and the "Warsaw Resolution 2 – Forests and Water" at European scale, as well as the "Shiga Declaration on Forests and Water" at global scale (FAO 2013). As conclusion, watersheds are complex social-ecological systems that need to be managed in a way that the ecosystem resilience and local communities are promoted, and the sustainability in management choices respected (Krievins et al. 2015).

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3. NEW CHALLENGES FOR HEADWATER CATCHMENTS AND FOREST RESOURCES: FACING INCREASED RISKS AND DISTURBANCES

3.1 On the need of an eco-hydrology-based forest management in water-limited forests

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3.1.1. Introduction

Mediterranean forests provide and regulate many non-marketed key ecosystem services such as protection against soil erosion and degradation, landscape quality, hydrological cycle stabilization, carbon pools, etc. (Scarascia-Mugnozza et al. 2000). However, there are challenges that may hamper the persistency of these goods and services in the near future. Global change is particularly important, especially when coupled with lack of management in human-shaped landscapes.

Lack of management is mostly a consequence of both abandonment of rural activities and economical unprofitability of logging in semiarid forests (Fabbio et al. 2003). This situation has led to an expansion and densification of forest and scrub as forest management practices in these low-productive forests are economically unsuitable; only public forests receive partial attention through fire-prevention silviculture or salvage logging after wildfires (Fabbio et al. 2003). For instance, in Spain, logging volume has dropped from 60 to 38% of annual growth in the last two decades (MMARM 2006).

Forest expansion may decrease the streamflow from upper catchments due to high rainfall interception. Some studies have reported a decrease in the average annual flow in some major Spanish rivers between 37 and 59%, partly explained by the densification of upstream forests

(Gallart and Llorens 2003, 2004). Usually, water scarcity in semiarid regions leads to overuse of groundwater resources.

Climate change is a key factor posing additional strain onto unmanaged semiarid forests, where an urgent adaptive management is instrumental to preserve a sustainable provision of goods and services (Fitzgerald et al. 2013). In sharp contrast with other biomes, semiarid forests are negatively affected by changes in the growing season and on soil water regime, resulting in loss of resilience, reduced growth, higher susceptibility to drought and water scarcity, wildfires, pest and disease outbreaks, dieback, etc. (Körner et al. 2005, Lidner et al. 2014). The Mediterranean region suffers from the significant impacts of climate change, such as an increase in the length of the dry season and lower soil moisture content, thus summing up more strain to water systems. All these issues have raised concern about the importance of forests and water interactions in the Mediterranean (Biro et al. 2011).

The lack of both appropriate socio-economic structures and incentive policies has prevented the development of markets for forest services. As a result, low-productive forests usually end up unmanaged and abandoned (Fabbio et al. 2003), which leads to an increase of the rural disaffection with forests and to a reduced resilience against climatic changes.

This work aims to highlight the need of an eco-hydrological-based forest management as the essential way forward to preserving goods and services of forests in semi-arid environments. Accordingly, the effects of forest management on the water cycle, on tree/stand growth and vigour, on soil properties and nutrient cycles and resilience towards droughts and wildfires are discussed in an integrative manner.

3.1.2. Eco-hydrology and forestry

Forestry is grounded on the sustainable use of natural resources, i.e. goods and services such as timber, water and soil conservation, wildlife, game, recreation, etc. However, traditional forest planning and management has been more focused on productive functions (especially timber), leaving the rest of the resources almost unattended. Typically, important decisions such as the rotation age, silvicultural system, site occupancy or type of regeneration are designed to maximize and sustain the yields of timber. This approach might not be profitable enough in the case of low-productive semiarid forests, where the concept of multiple-use resource management has gained increased attention during the last decades.

As water-limited environment, most of the ecosystem goods and services that could drive best management practices in semiarid forests converge in the field of eco-hydrology (Molina and del Campo 2012). Managing a forest for clean water, soil protection, carbon pools or other biogeochemical cycles, or resilience towards global change means managing it with an eco-hydrological orientation and foundation (Molina and del Campo 2012). Accordingly, semiarid forests need an urgent change of the management approach that puts key goods and services (i.e., more than timber) in the centre of the management decisions and includes as resources as diverse as possible.

Integrating and targeting eco-hydrological issues into forest management will prove the added value of adaptive silviculture in promoting tree and stand resilience, improve (or maintain) site productivity, enhance soil water content, reduce wildfire hazards, etc. Many studies have already demonstrated significant improvements in local hydrological cycles, plant sustainability and biodiversity after forest management (Callegari et al. 2003, De Cáceres et al. 2015, Millar et al. 2007, Molina and del Campo 2012). However, this type of silviculture is underdeveloped in many aspects compared to that traditionally oriented timber production. It is necessary to develop guidelines for a more efficient implementation of water-oriented forest management, which pursues the quantification and the manipulation of water cycle components in forests according to management objectives. In this sense, there is a need for an improved understanding on how the different elements of the water cycle are affected with forest treatments and what is the management margin that foresters have to take care of.

Besides enhancing productive functions, forest management may also contribute to reduce risk fire, increase ecosystem resilience, increase water yield, improve tree growth and vigor, increase landscape value, etc. These goods and services are assumed to be modified (in some cases enhanced) when performing forest management, but in most cases, they are not quantified (see Figure 12). The tipping point compared to previous management approaches is that all these functions should be explicitly considered and quantified into forest planning and management.

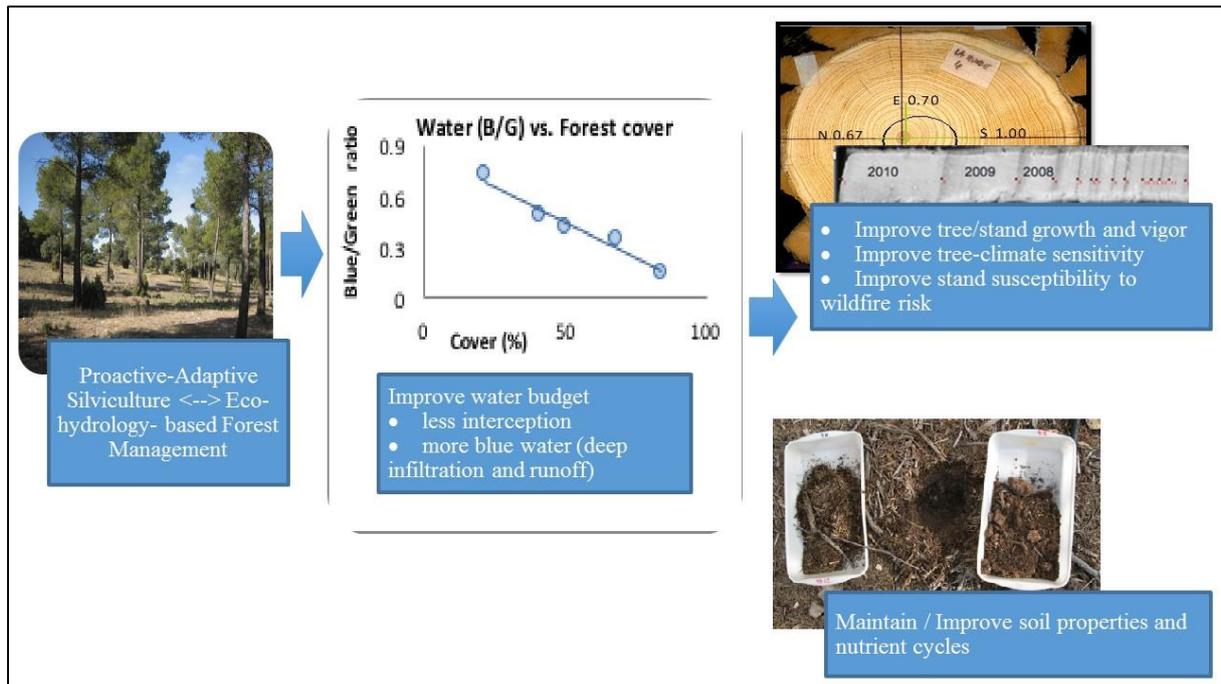


Figure 12. Scheme of the effects of eco-hydrological-based forest management. In semiarid regions, adaptive management might be focused on forest and water relationships, so guidelines for this silviculture must address how the physical structure of forests (cover, density, LAI, etc.) can be shaped according to the water cycle components being modified (rainfall interception, throughfall, transpiration, soil moisture and deep infiltration). Including the eco-hydrological aspects of the forest in the management approach would allow a more holistic and integrative approach better suited to the complexity of the forest at the interface between hydrology and ecosystem science.

3.1.3. Addressing an eco-hydrological-based forest management

Eco-hydrology-based forest management (proactive-adaptive silviculture), as exposed above, has to be an integrated approach that puts water in the centre of forest planning and management. It aims to steer and optimize forest and water interactions through forest management by considering an ecosystem-based approach. Thus, its application implies, besides the quantification of the possible timber products, a quantification and valuation of the eco-hydrological variables, which could be even more profitable than the production itself.

The desired future condition of the stand being eco-hydrologically managed has to be determined on a commitment between the effects of full site occupancy (best soil protection) versus more permeable forest structures allowing lower interception losses (more blue water) and fuel loads and less competence among trees (enhanced resilience).

3.1.4. Best practice example of eco-hydrological-based forest management semiarid forests in eastern Spain

In the following, there is an example showing the effects of the eco-hydrology-based forest management in experimental forests (cf. references section). The experimental studies represent examples of abandonment of semi-arid forests (Aleppo pine plantation, coppice forest of Holm oak and post-fire natural Aleppo pine regeneration), where control and thinning plots are compared in terms of hydrological performance, biological soil properties and nutrient cycles, tree growth and climate sensitivity and improved resilience to wildfire. The study cases correspond to forests located in the Valencian region (East of Spain), and have in common low-productive value and the water limitation.

Water balance

Eco-hydrology is especially important in arid and semi-arid systems where the feedbacks between ecology and hydrology can be particularly tight. Forests have a strong interaction with water helping to control most of its functions. Many studies addressed specifically the effects of forest management on water yields. The hydrologic performance of the experimental forests (stand scale) after forest management was affected in rainfall interception, throughfall, transpiration, soil moisture and deep infiltration (Table 7). The experimental results indicated a general enhancement of the hydrological cycle by favouring deep infiltration after treatments. At the same time, there was a general dismissing of stand transpiration despite the fact that tree transpiration increased after management. The results also indicated little competence between transpiration and the deep infiltration terms for the throughfall water, as they present opposite seasonal patterns. Soil and understory evaporation yielded low differences among treatments, which would mean that, in spite of clearing vegetation, the evaporation was not severely increased.

Nevertheless, in the case of the study with *Quercus ilex*, the positive effect of forest management appeared not to be significant during the driest year 2013-2014 (annual precipitation was only 271 mm, 58% of the expected value) (Table 7). This behaviour could be due to the higher vapour pressure deficit registered during this year, and the capability of *Quercus* spp. to extract water from deep soil layers. In any case, it is important to point out that water-oriented forest management could be less effective under dry situations, and a more detailed analysis would be required.

The general effects of the eco-hydrological forest management usually led to a significant increase of the blue/green water ratio, which implies a significantly increase of the water contribution from the forest to the catchment. The results obtained from these studies agree with many others that also analysed the effects of forest management on the water budget. However, although the experimental results are extremely useful to analyse and understand the effects of forest management in the water budget, there is still the need of including spatial and temporal variability in order to upscale and design a proper forest management strategy. In this sense, the use of modeling approaches becomes an important tool to include both variables. A process-based model (BIOME-BGC; Thornton et al. 2002) was used to analyse and optimize the hydrological balance of a whole Aleppo pine plantation across a wide temporal scale. The results showed a significant increasing of the water yield after forest management, but with a strong dependency on the annual precipitation. Nevertheless, these process-based models are difficult to operate because of the high number of parameters that are required, and do not consider spatial variability. Since forest management works at different spatial scales, mainly in the Mediterranean region (Fabbio et al. 2003), the use of a distributed model should provide more complete and useful results when designing an eco-hydrological forest management. As an alternative, there are less complex models, such as the parsimonious models (e.g., LUE; Pasquato et al. 2015), that require a significantly lower number of parameters, but still are capable of represent both spatial and temporal scales.

Table 7. The effect of forest management on the water balance, growth, fire risk improvement (respect unmanaged Control) and nitrification in several experimental plots. C: control (not thinned). T: Treatment (thinned). L: low intensity thinning. M: moderate intensity thinning. H: high intensity thinning. H98: high intensity thinning 10 years older. B/G: blue (deep infiltration + run-off) to green (total evapotranspiration, ET_{tot}) ratio. Fire risk improv: improvement of the modified KBDI index after thinning; ΔBiomass: total biomass increment from 2009 to 2010; Nitrif: nitrification; -: not registered.

Species, treatment, % cover after treatment and time lapse studied	Gross rainfall, mm	Interception, %	Stand Transpiration, %	Run-off, %	Deep Infiltration (>30cm), %	Soil/litter evaporation, %	ET _{tot}	B/G ratio	Fire risk improv. (%)	Growth: ΔBiomass (%)	Soil, Nitrif. (mg N/kg)
<i>P. halepensis</i>											
C_84%(25month)	1545	39.6	20.7	0	13.4	26.3	86.6	0.15		1.538	-
L_68%(25month)	1545	33.5	17.1	0	25.6	23.8	74.4	0.34	5	4.049	-
M_50%(25month)	1545	25.9	11.7	0	29.5	32.9	70.5	0.42	57	5.386	-
H_22%(25month)	1545	12.4	16.9	0	41.9	28.8	58.1	0.72	35	16.16	-
H98_41%(25mon)	1545	27.1	10.9	0	32.3	29.6	67.7	0.48	47	3.91	-
<i>Q. ilex</i>											
C63%(year12/13)	534	33	15	0.8	40	10	59	0.41	-	-	18.52
T30%(year12/13)	534	17	12	1.0	68	2	31	2.2	-	-	27.64
C63%(year13/14)	271	40	41	2.4	0	12	94	0.02	-	-	13.24
T30%(year13/14)	271	23	44	2.2	0	31	98	0.02	-	-	24.32

Soil properties and nutrient cycles

Eco-hydrology goes beyond forest and water interactions. Sustainable forest management requires maintenance of the biological, chemical and physical properties and processes of soils. In natural forest ecosystems, soil organic carbon stock is usually high and in equilibrium, but it may be diminished following disturbance (e.g., after forest management such as thinning treatments) by removing different amounts of biomass and timber. Minimizing the disturbances in the stand structure reduces the risk of C losses. However, some studies reveal that changes in forest management had no detectable effect on present forest soil organic carbon stocks and that microbial communities and nutrient cycling may even be enhanced by forest management. Eco-hydrological-based forest management has to address some of these indicators in order to assess its sustainability.

In the experimental sites, forest management increased soil organic C (not shown) and nitrification process (Table 7). Contrarily, no significant effects of forest management were observed in our plots in soil CO₂ emission and microbial activity (phosphatase and urease). Regarding the nutrient associated to the water fluxes, forest management appeared to increase the potassium runoff, while the fluxes of carbon, nitrogen and phosphorus were not significantly affected with the management performed in our plots.

Tree/stand growth and vigour

Increasing resource availability has effects on both the primary and secondary growth, as well as on total biomass (Table 7). In the experimental sites, pines showed an increased length of shoots per growth-cycle, needle length and needles per growth-cycle consequent to thinning. In the control plots, a reduction of polycyclism (the ability to produce several flushes in the same growing season) was observed. Secondary growth was highly limited in the pre-thinning stages of the stand, with basal area showing increments around 4.1 cm² year⁻¹, whereas thinned trees reached increments of 17.3 cm² year⁻¹; the increase was proportional to the intensity of the thinning.

Despite the fact that forest management affects tree growth, the nutrient content of leaves and twigs does not show this effect, and no significant differences in C, N, P or K were observed. On the contrary, tree nutrient resorption proficiency is slightly dismissed as N:P leaf litter ratio is reduced after thinning. Thus, trees of the thinned plot become more P spender and decrease P reallocation.

Improving forest resilience through forestry has two main directions

Improving both tree-climate sensitivity and wildfire susceptibility. Decreasing climate-related vulnerability of forests is one of the goals of adaptive forest management. In semiarid climates, a generalized warming and drying trend has been reported to negatively affect the growth of forests. The strong dependence of semi-arid forests to water makes them more sensitive to climate change, where variations in precipitation and temperature can substantially influence forest changes (Fitzgerald et al. 2013) that usually lead to forest dieback and growth decline. Studies on tree growth–climate relationships give evidence that forest management makes stands less sensitive to water shortages in drought-prone sites. Similarly, adverse meteorological conditions and dense forests stands increase fire risk. Climatic stressors such as extended periods of high temperatures or heat waves, low relative humidity and strong winds will in all likelihood alter the frequency, intensity, and the extent of fires. Changes in forest

structure due to partial removal of the forest is a fire preventive silviculture, as its implementation breaks the fuel continuity and availability (structural effect), and modifies the microclimate and the vegetation status (short-term dynamic effect). Thus, reduction of fire risk through forest treatments should be quantified in order to provide a more comprehensive understanding of the effects of adaptive forest management on promoting enhanced resilience with regard to climate change.

Eco-hydrological forest management might assist in adapting semiarid forests to climate change. In our plots, the effects of thinning (short and medium term) on pine Water Use Efficiency (WUE) and climate–growth relationships indicated that all thinning treatments improved the way trees used the soil water reservoir, but to different extents: WUE grew proportionally with decreasing forest cover. Likewise, these results have demonstrated that thinning makes trees less sensitive to water shortages, indicating that trees in the non-thinned plot need to rely more heavily on current year precipitation than those thinned, confirming that forest management increases the resilience of Aleppo pine trees to climate variations. Regarding fire risk, changes carried out in the forest structure due to partial removal of the forest canopy induced hydrological responses and consequently modified the water balance. A modified Keetch–Byram’s drought index proved to be sensitive to our silvicultural operations (Table 7) in terms of a decreased forest fire risk, thus linking to the other benefits related to tree growth and water balance.

3.1.5. Conclusions

Semiarid protective forests face the global change as a crossroads with many potential impacts and threats such as green/blue water impairment, wildfires, pests, dieback, growth stagnation, etc. Whilst the benefits of a timely proactive-adaptive silviculture are widely recognized, current challenges and needs of these ecosystems are connoted to the problem of lack of management and woodlands abandonment. To overcome this situation, non-marketed ecosystem services should be explicitly incorporated into forest management through new thinking and innovative approaches. Hydrology-oriented or eco-hydrology-based silviculture is just an example that creates opportunities to make silviculture more effective under water scarcity scenarios.

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3.2 Large wood transport during floods and its management in mountain rivers

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3.2.1. Introduction: a historical outline on wood in floods

In-channel large wood (LW) directly influences the physical, chemical and biological characters of aquatic ecosystems and is recognized to represent a key component in river systems by ecologists and geomorphologists. On the other hand, LW represents one of the main challenges for hazard and risk prediction in Alpine streams mostly because of its potential to clog bridges (Figure 13), culverts and narrow sections during flood events (Mazzorana et al. 2011, Lucía et al. 2015). However, our current knowledge of wood transport dynamics during large floods is very scarce because: i) large floods by definition are (locally) rare, and thus the occasion to study them is very limited; ii) geomorphologists and ecologists have been more interested in documenting wood-water-sediment-biota interactions, and large floods are interesting enough to geomorphologists primarily in terms of sediment transport, erosion and deposition; iii) engineers had focused in the past on the local scale (bridge, check-dams) mainly, and by means of highly simplified assumptions. Therefore, several questions that are fundamental for a rational LW management remain unanswered (Comiti et al. 2016).



Figure 13. Examples of bridges clogged by LW transport during the October 2011 flood in the Magra River catchment (photos courtesy of the Province of La Spezia).

Indeed, few studies have documented the effect of high magnitude flash floods on LW dynamics by collecting data on recruitment, transport and deposition volumes all information required in order to validate or develop new models for LW transport as well as to establish effective management strategies to mitigate the additional hazard induced by this process.

The first technical publications on flood hazards associated with large wood were triggered by a flood disaster at a hydropower reservoir which occurred in Switzerland in August 1978. In the same country, about a decade later (1987), widespread flood and debris-flow events led to the first detailed documentation of large wood transport (Bänziger 1989). During this period, extensive experimental work was carried out in Japan in order to investigate log transport in steep channels, mostly in the context of debris flows (Ishikawa, 1990).

Waldner et al. (2007) presented an inventory of the LW deposited after the catastrophic 2005 flood event which occurred in different Swiss catchments, following the previous work by Rickenmann (1997) in the same country. Recruitment processes were identified and quantified in detail in four alpine mountain river catchments with drainage areas varying from 73 to 1,140 km², whereby the total volume of recruited wood varied from 4,100 to 30,700 m³ per catchment. Marchi et al. (2009) analysed a 2007 flash flood in a relatively small catchment of the Slovenian Alps, where it was found that both hillslope processes and floodplain erosion were similarly responsible for LW recruitment, and highlighted how bridge clogging had been key in favouring hazardous channel avulsions. Ruiz-Villanueva et al. (2013) described the LW deposits during a flash flood event that occurred in 1977 in central Spain, and compared them to the results obtained from a 2D numerical LW transport model. Lucía et al. (2015) quantified LW dynamics during the exceptional 2011 flood (return period > 200 yr) in sub-catchments of the Magra River basin (Northern Apennines, Italy). The large wood dynamics were studied by establishing a large wood budget for two of the most severely affected tributaries. Most of it (70-80%) was

eroded from the floodplains or the banks as a consequence of channel widening processes, while the rest came from hillslopes processes (Lucía et al. 2015).

3.2.2. Large wood sources and transport during floods

Where does wood transported down a flooding river come from? How far upstream? Are hillslope sources more important than those along the river corridor? Similar to sediment transport, there are no general answers to these questions. According to Comiti et al. (2016), the variability in the floodplain vs hillslope contribution of LW during a flood to any given channel section appears to be mostly related to the following factors: i) magnitude of channel widening and bank erosion, which depend on many factors including hillslope sediment supply and basin lithology; ii) standing volume of forests both in the floodplains and on hillslopes; iii) landslide and debris-flow activity as LW delivery processes; and iv) hillslope-channel and within-channel connectivity. This last point is quite important since high proportions of LW recruited from the slopes can be retained either along the slopes directly (Lucía et al. 2015), trapped along narrow headwater bedrock channels, or deposited in the floodplains, without entering the flood flows in the main channel. Remarkably, in-channel dead wood was shown to play a very minor role in the flood-scale LW budget with respect to freshly recruited wood (Lucía et al. 2015).

There is a clear inverse relationship between specific LW transport volume (per unit of basin area) and drainage area (Comiti et al. 2016), as typically observed also for peak discharge and sediment yield. This trend probably stems from the fact that: i) cumulative LW recruitment volumes increases slower than basin area, because the larger the basins the less likely are widespread landslides and debris flows (providing large LW inputs) per unit of area, as a consequence of less probable extreme rainfall conditions over the entire basin and of the inclusion of milder hillslopes; ii) channel widening during floods is larger in the smaller (erodible) channels; iii) the larger the basins, the more LW is likely to get trapped along the channel network, mostly by artificial structures but partly also by standing vegetation (islands and marginal vegetation).

The key finding from the (few) well documented flood events is that once LW enters the flood flow, most of it can travel for many kilometres downstream if no artificial obstructions (dams, weirs, bridges) are encountered, to finally spread into alluvial fans or enter the higher-order channel. Local deposition does take place as forced by flow curvature at sharp bends, bank

obstacles, standing riparian vegetation, but its effect on LW budget is limited. In contrast, the trapping effects at bridge cross-sections (beside reservoirs) is of the greatest importance to predict LW transported volumes in a given channel reach, i.e. the along-channel connectivity is mostly limited by artificial elements (Figure 13).

Based on this evidence, Comiti et al. (2016) concluded that LW transport in rivers during large floods is generally strongly supply-limited. This implies that the same channel can produce transport from zero to thousands of cubic meters of wood further downstream, depending on the amount of LW recruitment (with the exception of very narrow streams unable to widen and thus where logs cannot move). Also, LW transport in large rivers during floods is clearly limited by the presence of artificially narrow cross-sections. Therefore, the estimation of the expected LW recruitment in the upstream basin/channel network, as well as the assessment of clogging probabilities for each bridge (or hydraulic structure), are the most important elements for the prediction of LW transport magnitude at any cross-section along the river network.

3.2.3. Conclusions: large wood management strategies

First of all, it is crucial to recognize that in mountain rivers LW transport is null to negligible for low to moderate floods. Therefore, for most of the time LW lies relatively stable in the river system contributing to bed stabilization, thus limiting sediment transport and creating bedforms (such as steps and scour pools) that provide habitats for fish and macroinvertebrate communities. Considerable in-channel wood transport and wood recruitment from slopes and eroded banks takes place only during high-magnitude, infrequent floods (generally >10-20 yr recurrence interval). Therefore, wood exerts its positive eco-hydro-morphological effects in rivers for most of the time, becoming a potential hazard only during much shorter flood times. Problems associated with LW transport during floods resulted in several guidelines for its management, from the European Alps (Lange and Bezzola 2006, Rudolf-Miklau et al. 2011, Comiti et al. 2012) to Latin America (Mao et al. 2013). However, the extremely high-energy and chaotic processes taking place during large flood events challenge our ability to effectively manage wood-sediment-water fluxes. Some basic conclusions can be nonetheless summarized as follows:

1. during floods, LW transport is supply-limited in most river systems, with the exception of both confined narrow channels in the headwaters (not subject to debris flows) and very low energy channels typical of lowland areas, where transport limitations do take

place. In the supply-limited channel segments, LW transported volumes are primarily determined by wood recruitment;

2. wood recruitment is determined by floodplain erosion (channel widening) and hillslope instabilities (landslides and debris flows) at varying degrees of relative importance, depending on basin characteristics (geology, morphometry, forest types and management). Deadwood already present in the channel seems to play a minor role (at least in European mountain rivers);
3. hazardous levels of LW transport in mountain rivers seem to occur only during high-magnitude events, generally having recurrence intervals > 50-100 yr. Wide gravel-bed rivers feature instead more frequent LW transport, but in these channels LW is rarely a problem during ordinary flood events;
4. LW-related flooding was documented to occur only associated with infrastructures (bridges and weirs) not properly designed to cope with this process.

Building on these evidences, some basic principles for the management of LW in river networks can be proposed, following Comiti et al. (2016):

- a) the fact that “fresh wood” (alive vegetation recruited by the flood) is by far dominant during a flood compared to deadwood already present in the channel questions the importance of LW clearing actions. The removal of LW from river channels or its cutting into smaller pieces has long been adopted as a traditional way to reduce hazards related to deadwood;
- b) in addition, not only LW clearing, but also riparian vegetation cuts may have a low effectiveness in the mitigation against large floods in mountain rivers, as it was shown in all available studies that massive LW input from hillslopes can be from very relevant to dominant in terms of transported volumes. Periodic vegetation cuts may bring about some benefits to prevent flood hazard only in those catchments where LW recruitment from slopes is expected to be negligible;
- c) the most sustainable and efficient strategies to minimize LW-related hazards are those being effective on both the reduction of bridge/weir vulnerability to clogging – where technically feasible – and on the trapping of LW upstream of critical sections, by means of dedicated retention structures.

For decades, wood-trapping structures have been built in the Europe and in Japan, first by adopting vertical and inclined buttresses as well as grids (Bezzola et al. 2004), and more recently using also cable and rope-net barriers (Rimböck 2004). However, the efficiency and the functional success of such protection measures depend on many factors, which include LW

volumes and rates, timing of LW transport during the flood, individual LW size, interaction between bed, LW and sediment in the proximity of the structure, location and orientation with respect to the flow, geometry, and local flow characteristics. Recent approaches tested in flume experiments propose spatially separating the wood and sediment retention functions, and ideally also the outlet structure for a controlled flood discharge (Schmocker and Weitbrecht 2013).

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3.3 Hydrologic Processes in Forest Headwater Catchments: Implications for Policy and Management

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3.3.1. Introduction

Headwater catchments with drainage areas less than 1 km² are important components of mountain ecosystems, yet their unique function and contributions to basin-scale flow, sedimentation, and nutrient transport are often not considered in forest management policies (Gomi et al. 2002). Without appropriately considering headwater dynamics in the context of larger basin-scale responses, it is impossible to consider the linkages between sources of water, sediments, and nutrients and their downstream propagation. Furthermore, without these spatial and temporal linkages, it is difficult to identify and track the effects of anthropogenic or natural stressors in the environment on downstream aquatic or human receptors. By nature, these stressors are spatially distributed and temporally variable within headwater catchments, thus facilitating synergistic interactions and non-additive propagation of fluxes (Figure 14). Because of these complex non-linear and interactive responses, there is a need to assess the cumulative effects of both natural and anthropogenic disturbances in headwaters on downstream water quality, sediment movement, and flow regime (Sidle and Hornbeck 1991).

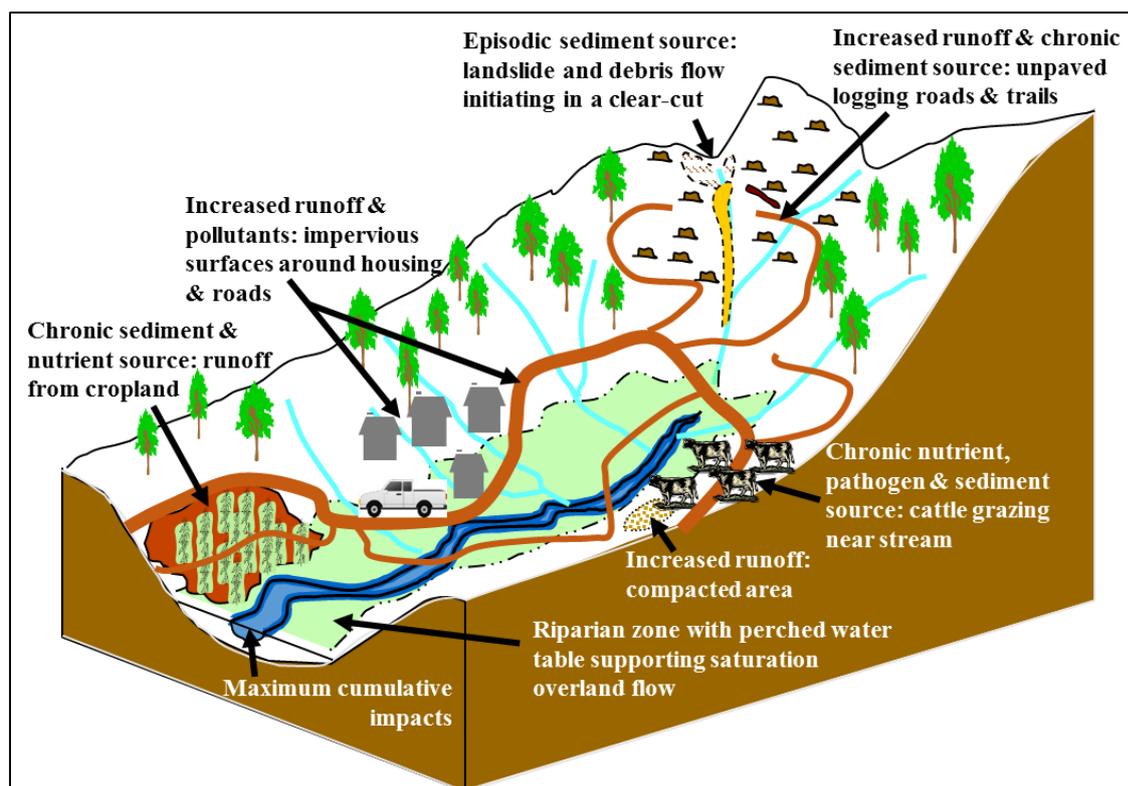


Figure 14. An example of how land uses within a catchment can generate cumulative effects related to streamflow regime, sedimentation, and nutrient/pollutant fate and transport.

Catchment assessments have typically focused on different downstream endpoints, but have not embraced the connectivity of endpoints to sources, let alone the cumulative effects of multiple sources in space and time. As such, most of the catchment assessment approaches that have been used by policy makers and managers do not consider the unique hydrologic behaviour of headwaters and their downstream ramifications. An example of the potential contributions of distributed land uses within headwaters, as well as lower catchment reaches is given in Figure 14. This illustrates the interconnections of various episodic and chronic land use effects on peak flows, sediment production and transport, and nutrient and contaminant fate and transport. Clearly, monitoring flow regime and water quality at the outlet of the larger catchment (i.e., end point) will not elucidate the spatial and temporal effects of land uses within the catchment on these ecosystem responses.

This paper outlines the unique characteristics and hydrological processes in forest headwater catchments that drive water, sediment and nutrient fluxes, with an emphasis on temperate mountain environments. This summary of processes is followed by an assessment of how forest management practices in headwaters affect these fluxes, with emphasis on steep ecosystems. Finally, policy implications related to the management of steep, forested headwaters are discussed.

3.3.2. Unique Attributes and Hydrologic Behaviour of Headwaters

Headwaters are areas where water originates in the uppermost channels and have been described based on inherent processes, drainage area, and channel structure (Gomi et al. 2002). Headwaters are differentiated from downstream reaches by their closer coupling with adjacent hillslope processes, greater variation in discharge per unit area, and different approaches to sustainably managing these sites (Figure 15).

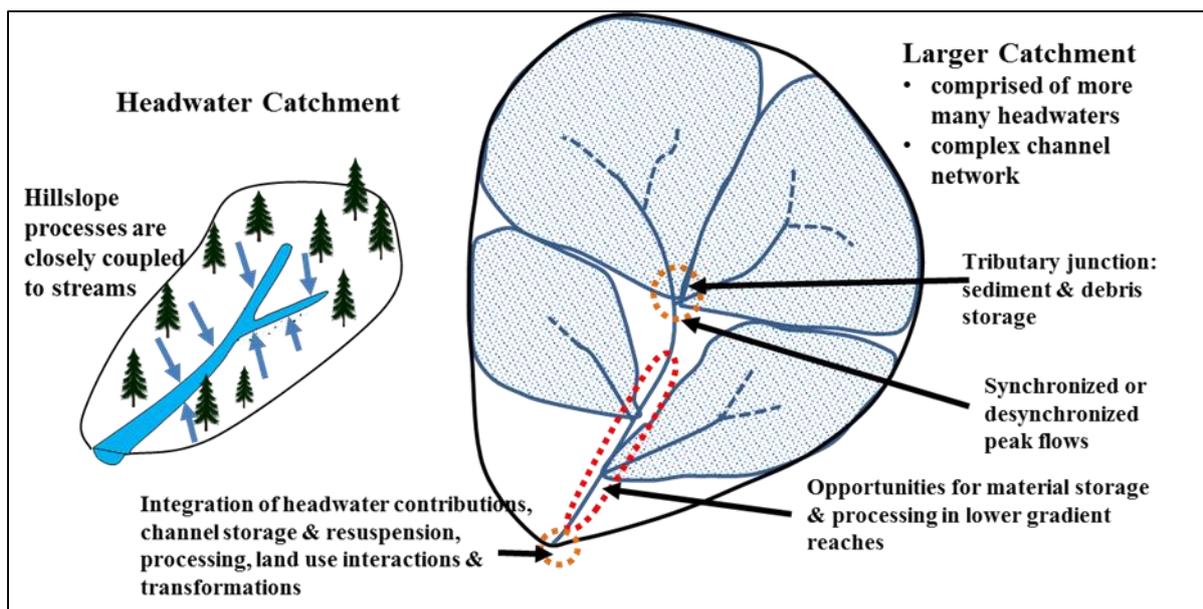


Figure 15. Comparison of processes affecting the movement of water, sediment, nutrients, and contaminants from upstream to downstream reaches, as influenced by the channel network characteristics. Based on the concept introduced by Gomi et al. (2002).

Spatially, individual headwater catchments are relatively small in temperate forests (usually <math>< 1 \text{ km}^2</math>), but collectively they may comprise 70% to 80% of the area of larger catchments depending on their drainage density. An attribute that defines the downstream limit of headwater systems in steep terrain is the transition from in-channel processes dominated by mass movement to those dominated by stream flow (fluvial processes). In steep temperate catchments where mass movement processes are active, this transition often occurs at the scale of <math>< 1 \text{ km}^2</math>. Where terrain is dissected with narrow, steep valleys, landslides originating on adjacent hillslopes can be readily transported to headwater channels, often initiating a potentially damaging debris flow (Figure 16b). Given that headwater streams have a greater interaction with riparian vegetation than larger channels, headwaters experience relatively greater recruitment of woody debris per unit channel area, coarser debris accumulations, and greater riparian canopy insolation from solar radiation (Gomi et al. 2002) (Figure 16a).



Figure 16. Frame A: a forest headwater stream in southeast Alaska where accumulations of woody debris create channel roughness and habitat niches; Frame B: a headwater channel emanating from an old landslide in the southern Japanese Alps with active mass wasting from hillslopes closely coupled to the channel; channel experiences periodic debris flows.

These factors all affect stream biology as do the steep and rough channels that create refugia for benthic invertebrates and certain amphibians. Storm runoff generally responds rapidly to precipitation inputs in headwaters because of the limited water storage capacity of catchments and short flow paths in hillslopes and channels (Figure 15). On the other hand, groundwater emanating from bedrock may provide stable baseflow and habitat conditions for biota.

Larger drainage basins have a complex structure and route water and materials from individual headwaters through a network of channel systems before being delivered downstream (Figure 15). For storm runoff, different land uses in headwaters may synchronize or desynchronize downstream peak flows depending on their juxtaposition and anthropogenic effects. Channel complexities like roughness, tributary junctions, and gradient changes can buffer peak flows (Figure 16a). The cascade of sediment from hillslopes in headwaters to downstream reaches involves a complex change of dominant processes from mass wasting in steep upper reaches of headwaters to bedload transport in the transition zone from headwaters to lower reaches, and finally to suspended sediment dominated transport downstream (Gomi et al. 2002) (Figure 16b). In this continuum, various opportunities for temporary sediment storage (e.g., tributary

junctions, channel roughness elements), resuspension, long-term storage (downstream riparian corridors and channel bars), and processing and breakdown exist (Benda and Dunne 1997) (Figure 15). Transport of nutrients and contaminants from sources to downstream reaches can be even more complex as transformations will likely occur along this migration pathway. These fluxes and transformations can be affected by changes in temperature, pH, oxygen, and dissolved organic matter, among other water quality characteristics. Thus, land use activities and channel attributes and structure downstream may exert cumulative effects on nutrients or pollutants that were introduced further upstream from spatially distributed sources in headwaters.

Headwaters exhibit unique and complex hydrologic responses at various scales which contribute to stormflow generation (Sidle et al. 2000). Understanding flow paths is a key to accurately predicting storm runoff, and more importantly, assessing the effects of spatially explicit land management practices on stormflow. The importance of particular flow paths can change over different scales and with different antecedent moisture conditions. In headwaters of temperate forests, infiltration-excess (Hortonian) overland flow is generally not a dominant mechanism for stormflow generation because temperate forest soils typically have high infiltration capacities. However, in degraded forests with sparse organic matter on the land surface, Hortonian overland flow can occur during high intensity storms. The propagation of runoff downslope determines the significance of this pathway as a contributor to stormflow (Gomi et al. 2008). Studies in degraded cypress forests in Mie, Japan showed that substantial Hortonian overland flow occurred from small plots (1 m in length), but at hillslope scales, Hortonian overland flow became 2 to 10 times lower than at small plot scales due to the patchy nature of surface conditions – i.e., hydrophobicity and surface crusting that induce Hortonian overland flow and areas of high infiltration capacity with vertical preferential flow paths that promote re-infiltration. These differences in runoff between plots and hillslopes were greater during major storms (Sidle et al. 2007). The connectivity of overland flow paths can be enhanced by bursts of high intensity rainfall on relatively dry sites where localized flow can be connected. As such, the spatial patterns of both lower and higher infiltration areas on the landscape play an important role in determining the connectivity and abundance of surface flow that contributes to storm runoff and alters water quality (Gomi et al. 2008). Much of this ‘overland flow’ in temperate forest hillslopes may actually occur as a type of slope-parallel preferential flow in the upper root-permeated soil horizons even under poor cover conditions (i.e., ‘biomat’ flow) (Sidle et al. 2007).

Quantifying the extent and pathways of subsurface flow in forested catchments is difficult because of measurement challenges. Nevertheless, it is generally believed that subsurface flow is the dominant stormflow mechanism in steep headwaters with narrow or no riparian corridors (Sidle et al. 2000). Subsurface stormflow through the finer pores of the soil matrix is a relatively slower pathway and largely contributes during the falling limb of stormflow hydrographs. Lateral flow conducted by macropores within sloping soils occurs when the soil reaches specific threshold levels of saturation. Thus, it may also be delayed as well, contributing mostly to the peak and falling limb of storm hydrographs. Studies in Japan have noted that self-organization processes may augment the connectivity of short macropores across hillslopes (Sidle et al. 2000). This preferential flow connectivity is facilitated by increasing soil wetness with the flow initiation threshold occurring when a critical level of soil moisture is reached.

Saturation overland flow is an important, but spatially limited, stormflow generation process in deeply incised headwaters. Runoff occurs during storms due to a perched water table at the soil surface that blocks the infiltration of rainfall. As such, saturation overland flow occurs mainly in riparian corridors and also at slope breaks where the soil becomes shallower and the underlying bedrock (or confining layer) forces subsurface flow to the surface (also called return flow) (Dunne and Black 1970). Wider riparian zones promote more saturation overland flow during storms. In steep headwaters with very narrow riparian corridors, saturation overland flow rarely occurs because adjacent hillslopes efficiently drain subsurface water via preferential flow pathways and the soil matrix. Saturation overland flow in incised valleys is only important during dry conditions when few other flow paths are active (Sidle et al. 2000). This process may also occur near the base of slopes near the end of large storms when a perched water table develops or in areas with poorly drained soils that promote a perched water table. In contrast, lower, gently sloping reaches of larger catchments typically have wide riparian corridors with water tables near the ground surface. Thus, saturation overland flow may be the dominant stormflow generation mechanism in these reaches (Figure 14).

Different paradigms have emerged to explain stormflow generation in steep, forested headwater catchments. In the mid-1960's, the variable source area concept of streamflow generation was developed and widely accepted as the working paradigm for forest catchments (Hewlett and Hibbert 1967). This concept invokes a dynamic riparian source area that shrinks and expands in response to rainfall and fluctuating water tables, linking subsurface flow from hillslopes to channels. However, the model does not specify flow mechanisms or pathways functioning at different spatial and temporal scales within the catchment. Studies in gently sloping catchments with wide riparian corridors have shown that saturation overland flow is the major contributor

to storm runoff (Dunne and Black 1970). Findings from more recent studies in Japan contributed to the development of a linked hydrogeomorphic model that explains stormflow response in headwaters (Sidle et al. 2000). This conceptual model recognizes the close coupling of hillslope and channel hydrological processes and the unique contributions of four major geomorphic features in the catchment (Figure 17): (1) more-or-less planar hillslope segments; (2) zero-order basins (geomorphic hollows); (3) riparian zones; and (4) stream channels. During the driest conditions, catchment water yield is very low and runoff occurs as saturated overland flow from the small riparian zone and via direct channel interception.

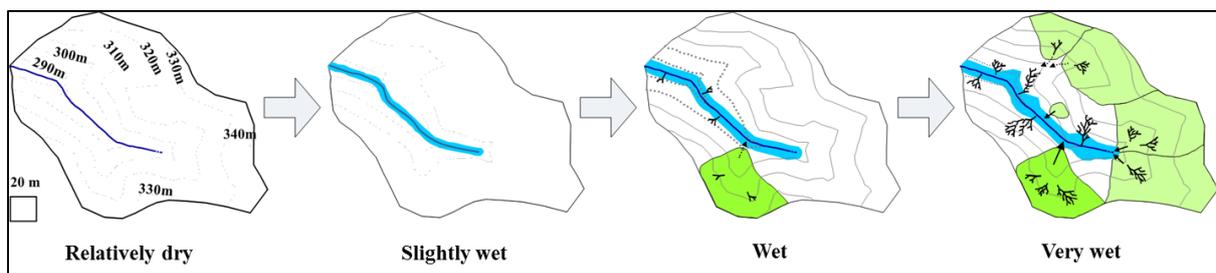


Figure 17. Illustration of the hydrogeomorphic concept of stormflow generation in headwater catchments, showing hydrologically active areas during a range of antecedent wetness conditions. Stormflow contributions are denoted as: (1) dark blue lines represent channel interception of rainfall; (2) light blue areas are contributions of subsurface flow in the soil matrix; (3) dark green areas are zero-order basins (hollows) with shallow soils; (4) light green areas are zero-order basins with deeper soils; and (5) ‘branched’ structures are preferential flow pathways. Based on paradigm introduced by Sidle et al. (2000).

For slightly wetter conditions, subsurface flow from the soil matrix augments stormflow. As wetness increases, two significant non-linear hydrologic responses occur: (1) threshold response in zero-order basins where runoff initiates after an accumulation of shallow groundwater; and (2) self-organization and expansion of preferential flow pathways, which facilitate hillslope subsurface drainage. Increases in stormflow that occur during periods of increasing antecedent wetness depend upon temporal and spatial linkages and the unique hydrologic behavior of the geomorphic components. These linkages form the basis of the hydrogeomorphic concept of stormflow generation for headwater catchments (Sidle et al. 2000; Figure 17). The spatially and temporally variable hydrological responses have strong implications for catchment management that are discussed later.

3.3.3. Effects of Forest Management Impacts on Hydrology and Other Functions of Headwaters

Because of the close coupling of hillslope processes with headwater channels (Figure 15), it can be strongly argued that management activities in headwaters more directly affect stream

systems compared to land uses that are located downstream and away from channels. Nevertheless, many forest management policies ignore headwater streams and only focus on downstream indicators. This conundrum poses significant issues for sustainable forest management, given the large areas that headwaters occupy and the difficulties in linking downstream indicators to headwater processes and perturbations.

Although numerous studies in temperate mountain forests have shown the effects of clearcutting on hydrologic regimes, many misperceptions persist. When trees are removed, interception of rainwater and evaporation from tree canopies declines, soil water storage increases, stream baseflow usually increases, and small peak flows generally increase (Thomas and Megahan 1998). In areas dominated by winter snowpacks, clearcutting increases snow accumulation and depending on aspect and radiation inputs during the spring melt season, snowmelt peak flows may increase (Ellis et al. 2013). Much controversy still persists around the effects of forest removal on large floods; however, the evidence for increases in major peak flows due only to forest removal is difficult to justify based on physical evidence. Complicating factors that may augment peak flows include the effects of road and trail systems in managed forests and areas of soil disturbances, including compaction due to logging.

Roads and skid trails in managed forests augment and may short-circuit storm runoff to streams, producing more rapid and higher peak flows. Much of these effects depend not only on the density of the road/trail network, but more importantly on the hydrologic connectivity of these disturbed and compacted corridors to stream channels. Roads or trails cut into steep hillslopes are most problematic because they not only produce Hortonian overland runoff from compacted and disturbed areas, but also intercept subsurface flow along cutslopes, especially if cutslopes intersect bedrock or other confining layers (Sidle et al. 2006). Within a headwater catchment, an unimproved road or trail segment may shunt overland flow into the channel during storms, but this effect may mostly augment stormflow during drier conditions when other portions of the catchment are not contributing to runoff. However, the timing of this road-runoff from headwater with respect to the timing of enhanced runoff from other headwaters in the same system, together with the interconnections of road and trail systems, will ultimately determine the effects of these disturbances on downstream flooding. Downstream flooding effects will also be influenced by forest removal (particularly in snowmelt dominated ecosystems), logging practices (e.g., ground-based harvesting versus full-suspension skyline logging) and near-channel land uses in the lower catchment reaches.

Effects of forest harvesting and roads on peak flows and sediment production and transport may differ depending on timing and intensity of the rainy season with respect to timing of forest

operations. Temperate forests that experience an Asian monsoon climate tend to have more frequent and sometimes more intense rainfall compared to North America and Europe, which have more distinct rainy and dry seasons. Thus, avoiding certain logging practices during wet periods when impacts are the greatest is often more problematic in East Asia compared to North America or Europe. Forest operations in the wet tropics, where the hydrologically contributing areas of catchments are relatively large year-round, require special precautions to avoid adverse effects. Thus, it is important to consider the biogeoclimatic setting relative to impacts of forestry operations.

It is well known that forest harvesting and roads and trails in steep headwaters contribute to enhanced landslide initiation and surface erosion. Surface erosion is particularly a concern on unpaved forest roads and skid trails, which are highly interconnected to stream channels (Sidle et al. 2006). Clearcutting commonly increases the probability of landslide initiation in steep unstable terrain by a factor of 2- to 10-fold compared to natural forests, whereas roads may accelerate landslide erosion by more than 100-fold per unit area affected. As such, changes in peak flows in headwater channels have the potential to significantly alter the downstream transport of sediment from these headwater sources. Channel roughness caused by woody debris and boulders can temporarily store sediment and alter the transit time downstream; roughness can also buffer the movement of peak flow signatures to downstream reaches.

A poorly understood issue related to downstream propagation of peak flows and sediments involves the temporal releases from headwaters (Ellis et al. 2013). For example, if one of two neighboring catchments within a snow accumulation zone is clearcut, the clearcut catchment will likely accumulate more snow and produce more peak snowmelt runoff compared to the undisturbed catchment. However, snowmelt from the clearcut catchment will generally occur earlier from the clearcut compared to the undisturbed catchment. As such the peak runoff from the two catchments will be de-synchronized and the maximum peak flow will be less (Figure 18a) than in the case with both catchments are either clearcut (Figure 18b) or undisturbed (Figure 18c). The scenario that would produce the highest and greatest volume of peak flow would be with both headwater catchments clear-cut – i.e., snowmelt is greatest and synchronized (Figure 18b).

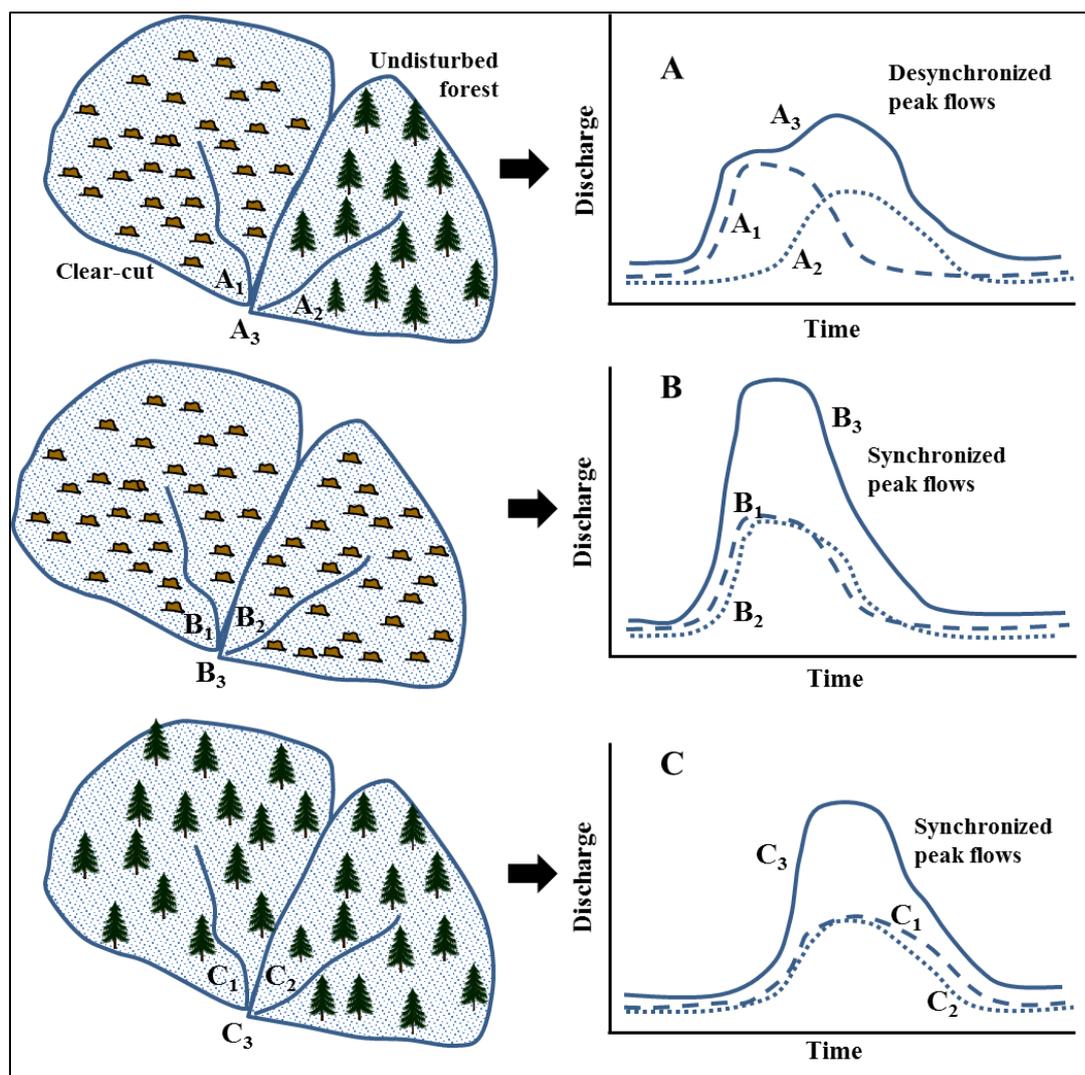


Figure 18. Examples of three scenarios of forest management that can desynchronize or synchronize peak snowmelt runoff from two headwater catchments: (A) desynchronized lower peak runoff when one headwater is clearcut and the other remains unharvested; (B) synchronized and high peak runoff when both headwaters are clearcut (maximum snow accumulation and largest release of melt water from the snowpack); and (C) synchronized and moderately high peak runoff when both headwaters remain unharvested.

The downstream propagation of sediments depends on the extent and nature of sediment sources, the intervening topography and vegetation between sources and the stream, and the channel characteristic and flow regime. Fine sediments (largely associated with surface erosion) move rapidly through the channel system, while coarser sediments travel much more slowly and their temporary deposition is strongly influenced by breaks in channel gradient, roughness elements (e.g., woody debris, boulders), and riparian vegetation. In steep headwaters where much of the sediment is supplied to channels by landslides, the migration of coarse sediments downstream is also affected by the synchronization of sources (Gomi et al. 2002). The further these sediments travel downstream, the more difficult it is to identify sources.

3.3.4. Policy implications

Forest management policies need to recognize the unique processes in headwaters and their linkages to the downstream movement of water, sediments, nutrients, and contaminants. Closely coupled hillslopes with headwater channels facilitate more direct linkages between management effects and streams compared to downstream reaches where materials follow less connected pathways to streams and may sometimes not reach channels. Additionally, stormflow from headwaters is very strongly affected by antecedent soil moisture conditions, with increasing wetness rapidly expanding hydrologically active areas. Such dynamic response has strong implications for management policies. During relatively dry conditions, forest management activities may have considerably less impact on water, sediment, and nutrient movement compared to wet conditions when much of the catchment is hydrologically active (Figure 14). Downstream peak flows can be moderated by effectively desynchronizing releases of snowmelt runoff from managed headwaters (Figure 15).

The cumulative effects of various land management practices in headwaters on downstream water flow regime, water quality, and aquatic biology need to be considered within the context of both headwaters and larger catchments. Such effects may be difficult to unravel due to various synergisms and non-additive attributes of sources or stressors. A systems-based approach that focuses on interactive processes may be the best way to approach cumulative effects analysis, rather than highly empirical approaches that apply indices of land-use intensity. Cumulative effects analysis needs to consider both spatial and temporal distributions of land use as well as consideration of natural disturbance processes in catchments, all of which affect water and material transport. Inherent in this analysis is the influence of headwater processes on downstream systems. One approach is to use a risk-based modeling approach based on conceptual models that include the relevant ecosystem processes. To be successful, such an approach needs to involve the full range of stakeholders. Issues like mixed land ownership, inappropriate regulatory standards, insufficient monitoring, lack of funding, and excessive reliance on problem solving and mitigation may be impediments to effective cumulative effects assessments. A key point is linking important ecosystem processes in such a risk-based decision model to quantitative attributes or indicators that forest managers value (e.g., harvesting volume, age distribution of the stand). To be successful, cumulative effects assessments may need to be conducted through an independent government authority with appropriate engagement of stakeholders.

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3.4 Managing water for environmental services under increased climatic extremes in mountain watersheds

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3.4.1. Introduction

Nature provides a wide range of essential environmental services that have been under-appreciated and the value for such services has for a long time eluded satisfactory economic evaluations (de Groot et al. 2002, Pahl-Wostle et al. 2013). In many mountain watersheds, the use of water has been a human priority and as long as there was sufficient water available, little attention was given to the water needs to maintain all the environmental functions provided by nature. Many of the human allocation rights were initiated during relatively stable climatic conditions but there is now sufficient evidence to show that climatic variability is increasing. Relying on historic streamflow records is no longer entirely valid because not only has the climate shifted but land use intensification and human water use have significantly increased, altering the hydrological regime (Postel and Richter 2003, Arthington et al. 2006). How do we partition and re-allocate and protect in-stream and off-stream water use in an equitable manner to meet the essential human and environmental needs under these changed climatic and land use conditions?

Mountain watersheds are generally more dynamic and more fragile than lowland systems. They contain the majority of the water supplies that are used by the urban population at lower elevation. The stream processes in the headwaters are very different from those in the lowland portion of the watersheds. There are more direct pathways for soil erosion to reach the streams from land use activities, while the sediment processes in the lowlands are dominated by transport, resuspension processes and bank erosion. Climatic changes also have a magnifying impact on stream hydrology, which usually results in more extensive flooding events in the lowland and this can augment or decrease streamflow during drought periods. Similarly, water

that originated in the headwaters is usually of high quality and changes in the downstream direction as land use activities increase.

Climate models and field observations have shown that due to higher temperatures and more variable precipitation, the stream hydrology is changing in different ways depending on whether the watershed is rain dominated, snow dominated, has a glacial source, or a combination of all three. Those watersheds at intermediate elevation ranges have already seen a major decrease in the accumulation of snow and this has resulted in seasonal advances in stream peak flow by 1-3 weeks. Earlier peak runoff often results in a decline in summer flow due to reduced soil water storage from lack of snow and increased demand for water by human activities. Using the projections of all the global models there is good agreement on the upwards direction of temperatures in the mountain regions in the northern hemisphere. However, projections of precipitation are highly uncertain with some models projecting a 25% increase and others a 20% decreases in the same watershed in the Canadian mountains (Hamlet 2011). It is becoming increasingly clear that the uncertainty and variability of precipitation are increasing due to the many microclimatic effects in mountain environments, and downscaling of model results is unlikely able to improve the predictive capability. This simply means that we will have to adapt to these greater uncertainties and change the way we manage and protect mountain watersheds.

3.4.2. The role of forests in mountain watershed

As shown in Figure 19 forests moderate the hydrological cycle by evapotranspiring precipitation by 20-30%, allowing the intercepted rain to enter soil and groundwater, and depending on site conditions only 5-10% of the rainfall is converted into surface runoff that enters streams in forested watershed. These functions not only allow the water to be retained but trees within the riparian buffer zone shade the headwater streams and moderate water temperatures during the summer. They also provide large woody debris that improves the pool and riffle systems in the stream and enhances the habitat for the aquatic biota. It improves aeration which enhances the decomposition; increases water purification processes, nutrient cycling and the wetlands within the riparian zone store carbon, act as filters and moderate streamflow. There is general agreement that forests in headwaters are the most effective way to provide and enhance the wide range of environmental services that nature provides. In different parts of the world these functions are disturbed by increased global warming and pressures on the forest resources for economic exploitation. The conditions in the European Alps are

somewhat different from those in other mountain areas in the world because societies in the Alpine region have learned from the effects of widespread historic land use conversions from forest to agriculture. These forest conversion and conservation efforts have now resulted in significant increases in forest cover in many headwater areas. As a result, the risk to these protected forested area is now not from land use changes but primarily from increased climatic variability, while in the North American context the combined effect of forest exploitation and climate change are of major concern.

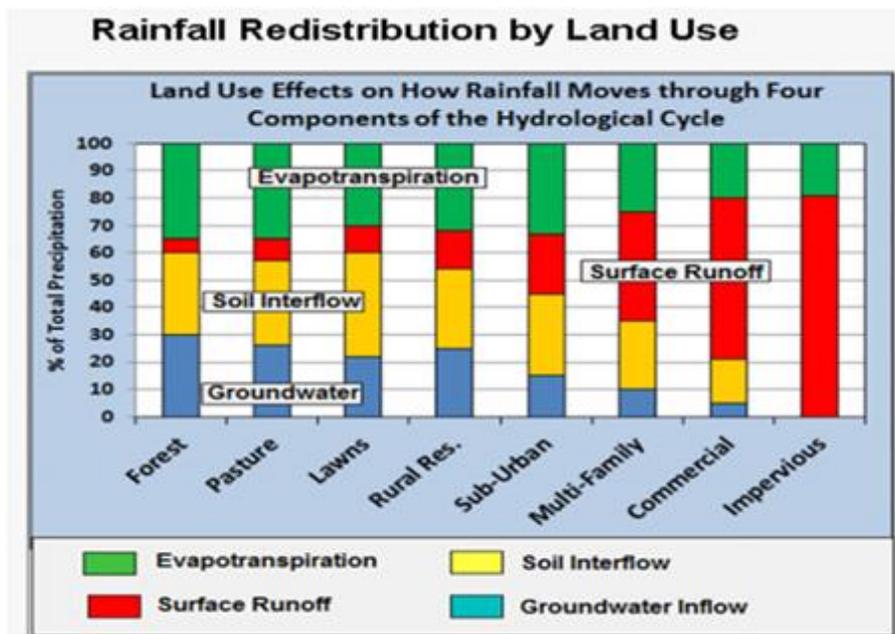


Figure 19. Rainfall redistribution by land use.

3.4.3. Evidence of increased climatic variability in mountain watersheds

In the mountains of the Columbia Basin in Western Canada there is now enough evidence to show that not only are the temperatures increasing, but the snowpack is becoming more sporadic. The snow water equivalent (SWE) in late winter has been declining rapidly and rainfall variability has increased dramatically. As an example, the mountain community of Kaslo, which relies on a mixed rain and snow regime has experienced three major rainfall events in June in 2005, 2012 and 2013 that are between 30-70% higher than the highest 100-year rainfall events that occurred in 1963 (Schreier et al. 2016). This led to widespread flood events that destroyed much of the water supply infrastructure. In contrast the same region experienced some of the highest summer temperatures and an extended drought in 2015 that required widespread water conservation efforts. These extreme events over the past 10 years clearly

show that the climatic variability is increasing. The question that needs to be asked is: How are these new climatic conditions affecting the forest cover that protects and enhances the environmental services in the headwaters?

3.4.4. Climate change and its impact on the forest cover

There is new evidence that higher temperatures and extended droughts increase the stress on trees, encourage pest and disease outbreaks and negatively impact tree physiology leading to increased tree mortality (Allen et al. 2015). These new climatic conditions in British Columbia resulted in a massive outbreak of pine beetle infestation which affected the 65% of the conifer dominated forest in the Province. Pine beetle infestations have periodically occurred over historic time but usually lasted only short time periods because of rapid dieback of the beetles whenever the average January temperatures reached minus 30° C or lower levels. Since 1999, winter temperatures have increased dramatically and are now well above those experienced over historic times and this resulted in the greatest historic outbreak of pine beetle infestation that lasted from 1999 until 2014, consumed 18 million hectares of forests, and affected 800 million m³ of timber. It devastated 1/3 of the standing forest in British Columbia with Lodgepole pine being the most affected species. The problem could not be contained and the only reason for the decline was that the beetles have now exhausted the desired and available wood supply. This created a major dilemma. Leaving dead trees creates an enormous fire risk and if trees are harvested within 1-3 years after infestation the wood can still be used. Given the concern of potential devastating effects of wildfires on mountain communities, and the concern about excessive CO₂ emissions from large fires, the government opted for extensive logging, which occurred at the landscape scale. How this will affect the regional hydrology has yet to be investigated because most of the hydrological research involving logging impacts has been conducted at the plot and small watershed scale.

In spite of the extensive logging to reduce fire risk, the number of forest fires has not declined primarily because only a small portion of infested trees could be harvested and the increased temperatures and drought conditions have affected other healthy trees that are stressed and thus more susceptible to fire. Data from the forest service in the USA and in British Columbia has shown that the annual number of fires have not increased over the past 15 years but the average size of the area affected by individual fires has increased from less than 50 ha/fire between 2002-2008 to 201 ha/fire in 2001, 250 ha/fire in 2014 to 190 ha/fire in 2015 in British Columbia.

The effects of fire on mountain streams are of course significant and highly dependent on the size of the fire and the fire intensity. The dead trees no longer evapotranspire precipitation and the hydrophobicity created from fires in conifer forests reduces the water infiltration capacity. Soil carbon that helps retain water is reduced and the changes to the soil surface conditions lead to widespread erosion particularly if intensive rain events follow drought periods. The darker soil surfaces after the occurrence of fire absorb more heat, and increase stream temperatures once the sediment reaches the stream. The protective role of the riparian zone is reduced, and the input of sediment changes the water quality, modifies the channel morphology in the downstream direction and leads to a short-term nitrogen flux in the water which usually follows fire events.

3.4.5. Land conversion and forest management impacts on water

Historic land conversions in the European Alps from forests into agriculture had many devastating impacts on the stream hydrology and stream health in the past. Over time the mountain communities have learned to restore the forests in the most sensitive sites. This protects communities and ecosystems and restores the processes that provide the key environmental services. Depopulation from mountain agricultural areas has resulted in abandonment of many fields which have now reverted back into forests. In contrast, the key relatively recent land use changes that have occurred in the alpine region have been for summer and winter tourism. This has resulted in increases in urbanization, enhancement of the transportation infrastructure and the creation of extensive networks of trails and ski runs. Soil compaction during construction and the creation of more impervious surfaces are responsible for a larger portion of the rain to be converted into surface runoff (Figure 19), resulting in more flashy stream regimes. In addition, many of the intermediate and low elevation ski areas are now engaged in snow making, which requires large quantities of water at the time in late fall when streamflow is in the declining phase.

The land use changes in the Canadian mountains watersheds have been very different. Relatively few watersheds have been impacted by winter tourism and the main activity is commercial harvesting of trees. Over the past 50 + years some 450000 km of logging roads have been constructed in British Columbia in order to access and harvest timber. Under Western Canadian climatic conditions, it takes up to 100 years for trees to mature and much of the harvests have taken place on old stands of trees. As a result, the access roads were built for

forest extraction and replanting and since it takes a long time for the next generation of trees to mature, access roads are not well maintained over time. The roads not only modified the hydrological regime but are the main source of sediments in the mountain catchments. Efforts are under way to decommission some of these roads in the most sensitive environments but as a result of the pine beetle infestation more emphasis has been placed on building new access roads for harvesting the diseased trees and to reduce the fire hazards. The main challenge now is to decide what trees to replant in the harvested and pine beetle affected areas in view of climate change, length of time to mature trees and economic considerations.

3.4.6. Climate change adaptation strategies to maintain and enhance environmental services in forested mountain watersheds

Forests moderate the partitioning of water in the hydrological cycle and enhance most of the functions that are responsible for maintaining healthy ecosystems. It is therefore imperative to conserve and enhance headwater forests. Depending on the site conditions the precautionary principle is to address the combined effect of climate and land use change. There is evidence of forest expansion into higher elevations due to climate warming and the question needs to be proposed: should we assist and speed up this enhancement process by planting efforts, and what type of trees should we select for such planting, or should we leave it up to nature to decide how the forest is expanding? Even if we protect the forest, management is required to reduce the risks imposed by climate warming which results in higher tree mortality, enhances the spreading of diseases and pests, and contributes to fire impacts the water cycle. There are a wide range of adaptation measures that need to be considered (Gillian and Brown 1997).

Advantages of tree-biodiversity

With all the uncertainties associated with temperature and precipitation changes and the relatively long time for trees to reach maturity, it is prudent to encourage the planting of a wide range of tree species. This is often in conflict with the trend towards plantation forests of those species that have the greatest economic value. Much more emphasis should be given to the assessment of water requirements for different tree species. In areas where drier conditions are predicted trees that are water efficient should be promoted and in those areas where wetter conditions are forecasted, trees that increase water cycling should be given preferences. Having a diversity of plants will also reduce the rapid expansion of diseases and fires.

Enhancing snow accumulation at appropriate elevations

Snow accumulation is critical in mountains because it retains water longer at the surface and in soils in the spring and delays more rapid runoff when there is a shift from snow to rain. Snow accumulation is usually less efficient in forests and recent studies have found that creating forest patches and openings rather than thinning allows more snow to accumulate and be retained longer in the spring (Dickerson-Lange et al. 2015a, b). This might be an effective short term strategy in watersheds at elevations which are experiencing the transition from snow to rain as a result of climate warming. It is a practice that might be even more effective at higher elevations.

Maintaining large riparian buffer zones

Channelizing streams is a poor way of enhancing environmental services and, if we hope to provide enhanced habitat for aquatic organisms, wide buffer zones ranging up to 60-80 m should be promoted. This will not only allow the development of wetlands within the buffer zone but can retain sediments, remove nutrients, allow energy in the stream to dissipate and allow aquifers in the riparian zone to be recharged. These buffer zones should have a combination of grass, shrub and tree communities that can tolerate rapidly changing conditions.

Designation of temporary water storage areas

Since we are expecting more extreme flood events building protective dykes and structures is no longer sufficient. Provisions should be made to select a wide range of appropriate topographic settings to be designated to store and retaining water during extreme storm events on a temporary basis. These can be natural areas, agricultural fields or constructed wetlands specifically designed for delaying the runoff.

Water use restrictions during dry periods

The majority of mountain communities get their drinking water from headwater streams, and in view of increased climatic variability we need better provisions in place on how to reduce water demands during extended dry periods and to make sure enough water remains in headwater streams to maintain environmental services. Water extraction permits were provided during periods when supplies were plentiful and under these new climatic conditions reallocation and conservation will be required. In Canada where water is cheap and where little consideration is given to efficient water use, the most cost effective measures are to focus on widespread water conservation initiatives (Schreier et al. 2016). This not only applies to

domestic water use but equally to irrigation in agriculture. Water use reductions of 30 or more percent are readily possible using the most efficient technologies and by changing human behaviour. Similarly, most communities now are required to develop a source water protection strategy for their domestic water sources in order to reduce the cost of water treatment. This will also help to maintain healthy water ecosystems.

Changing land use management practices

We have plenty evidence of how much water is used and what the contaminant impacts on water are from different land uses activities. Using beneficial management practices (BMP's) is now heavily promoted. BMP's in forestry focus on ways to reduce the fire risk by reducing the fuel load, providing fire breaks and modifying the tree composition and stand age. Some of these measures will also assist in snow retention. Logging activities that minimize forest floor disturbance and measures to increase soil organic matter are also heavily promoted. The past practice of draining wetlands and removing above ground biomass has now also been reduced somewhat by building constructed wetland particularly in mountain communities. These buffer the runoff and reduce the contaminants contained in the urban stormwater runoff. What is equally important is to manage protected forests by selectively removing diseased trees, to pay attention to fuel load changes, and to monitor mortality changes due to increased temperatures.

Develop better methods to assess the value of environmental services

One of the major challenges dealing with environmental services is how to put a value on the services nature provides. Most of the economic methods that have been developed to put an economic value on these services are problematic. Neither the Market Value methods (replacement or restorative value, preventative expenditures), the Shared Preference methods (non-market valuation, contingent valuation-willingness to pay, conjunct choice comparison) nor the Revealed Preference methods (hedonic pricing, benefit transfer) have proven to be acceptable and partially effective by decision makers (de Groot et al. 2002). Determining the replacement or restorative cost methods are more realistic but hinge on how successful the replacement and restoration projects are to provide all the ecosystems services that occur in undisturbed environments. The additional challenges are how to determine how resilient the undisturbed environments are to emerging climatic changes and how they will adapt naturally to these changes.

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3.5 Protection forests and their management: an overview

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3.5.1. Introduction

One of the most important functions provided by the forest is its protective role. All forest stands accomplish this role, protecting the soil from surface erosion and affecting directly and indirectly the water cycle, regardless their location. However, not all of them are protection forests. Only when they are protecting actively or passively against a specific natural hazard we are referring to them as protection forests.

A protection forest is a forest whose main function lies in the protection of people, buildings and infrastructures against the impact of natural hazards. They might fulfil also other functions, but their protective role is predominant.

A further classification of protection forests is based on the presence of a specific object to be protected. This classification is important for forest planning, especially for the prioritization of intervention and definition of management targets (Berger and Rey 2004). Stands are then usually classified into direct and indirect protection forests (Brang et al. 2006). A direct protective function is due to the location of a particular forest in relation to the presence of an asset to be protected, e.g., a forest located above a group of houses or a road, which it protects against snow avalanches. The area under direct protection is usually limited in size and located below and close to the protection forest.

Forests may offer also indirect protection, by their presence at broader scale (e.g., the landscape level), independently by their exact location. This could be the case of stands in mountain catchments where they could potentially reduce soil erosion and flooding.

We can affirm that almost any forest can offer a certain level of indirect protection, since it can have an effect against soil erosion, intercept precipitation or affect the local climate, while direct protection is limited only to some forests concerned by gravitational hazards.

Increasing importance is attributed to protection forests, given our expectations to access and build settlements in remote mountain areas all over the year, mostly for tourism (Wehrli and Dorren 2013).

How forests can exert their protective effect? It is essentially the presence of trees (with certain characteristics) that builds up the protective ability of the forest. Different parts of a tree can provide protection against a natural hazard. Tree crowns can intercept snow and reduce the risk of avalanche formation; tree stems can stop, slow down or deviate falling rocks on a slope; roots can prevent shallow landslides. Even after death, trees still play an important role. Deadwood can be useful for instance in increasing soil roughness and providing obstacles against rockfalls. The canopy as a whole can mitigate different climate impacts, e.g., reducing wind speed, buffering temperature variation.

The protection role of a forest can be of two different kinds. In some cases, a forest stand plays a role in the prevention of a natural hazard (active protection), in other situations in the mitigation of its effects (passive protection). This depends on the characteristics of the considered process. For instance, forests play an important protective role against snow avalanches in the starting zone, preventing the departure of an avalanche. Considering rocks falling down a slope, forests can reduce the speed and number of rocks reaching the bottom of the slope.

Protection forests are particularly effective against snow avalanches, rockfalls, debris flows, shallow landslides, surface erosion and floods. Their protective role is often fundamental in mountain areas, whose steep slopes increase the risk of gravity-driven natural hazards. Lowland protection forests are instead more active against wind erosion and within coastal areas against wave erosion.

The degree of protection offered by a forest, and thus the effectiveness of its protective function, is strictly related to the natural hazards involved, their characteristics (namely intensity and frequency of occurrence), and the main features of the stand, together with its conditions when a damaging event occurs (Brang et al. 2008).

Ideally protection forests should provide their function constantly through time. Anyway, we must consider that, as any other forest, they are subject to stand dynamics, which may modify or limit their protection effectiveness. Most of these dynamics are driven by the occurrence of natural disturbances, which often coincide with the hazards they are in charge to prevent or mitigate.

Both small- and large-scale disturbances can affect protection forests, the latter (including for instance wildfires, storms, snow load, bark beetles) being particularly troubling for the

maintenance of the protective function. After the disturbance event, protection forests undergo a process of recovery, strongly influenced by the extent and severity of the disturbance itself. At this stage, the quality and quantity of biological legacies (e.g., logs, root plates) can affect both the recovery process, favouring for instance the establishment of natural regeneration (Marzano et al. 2013), and the residual protection function offered by the disturbed stand (Fuhr et al. 2015).

When a protection forest is temporarily or permanently unable to fulfil its function, artificial constructions (e.g., fences, barriers, terraces, dams and galleries) might be adopted to replace its function or enhance its effectiveness. Moreover, even if the presence of protection forests is sufficient to provide effective protection against natural hazards, they cannot offer complete and constant protection against any type of damage. In this situation, we can again make use of artificial constructions. It should be however underlined that adopting this solution is usually not alternative to a properly managed protection forest, since the costs to build and maintain them will generally be much more expensive than those created by proper silvicultural management, without obtaining the multifunctionality of a forest stand.

3.5.2. Managing for protection

A stand with a direct protective function should be permanently effective. This means that the forest stand should be characterized by high resistance to natural hazards and high persistency. In order to maintain a stand in this efficiency window, forest management has to be actively conducted. Proper management of protection forests should find a balance between forest structures highly resistant and resilient to disturbances and at the same time effective in providing protection against natural hazards possibly affecting people and structures. This is particularly true for forests with a direct protection function (Brang et al. 2006).

Structure and composition of protection forests should thus be designed based on the disturbance regime, the required protection function and the possibility to guarantee stand renewal. To reach these management goals, obtaining the desired stand structures is a long-term process requiring decades or even centuries.

Minimal tending

In 1996, the guide *Minimale Pflegemassnahmen für Wälder mit Schutzfunktion* (Minimal tending for forests with a protective function) was published in Switzerland.

In 2005, an updated edition (NaiS - *Nachhaltigkeit und Erfolgskontrolle im Schutzwald*) was published in the three main official languages of the Confederation (German, Italian, and French) reporting guidelines concerning silvicultural interventions in forests with protective function (Frehner et al. 2005), and subsequently partially translated in English in 2007 (Frehner et al. 2007). Likewise, in 2006 France and Italy produced their own handbook based on the Swiss guidelines, with explicit reference to their specific forest types and case studies (Gaquelin and Courbaud 2006; Regione Autonoma Valle d'Aosta – Regione Piemonte 2006). Recently, due to new findings on the protective function of forests against rockfall, a further update has been released and included for this specific hazard.

The NaiS guidelines provided a list of seven principles to observe when planning a silvicultural intervention in a protection forest in order to ensure a cost-effective management. According to this list, silvicultural interventions have to be (Frehner et al. 2005, Frehner et al. 2007, Wehrli and Dorren 2013):

1. With a focus on the protective target
2. In the right place
3. At the right time
4. Consistent with natural life processes
5. Tailored to each stand, transparent, replicable and controllable
6. Effective
7. With reasonable effort

Although the majority of the aforementioned principles should generally be adopted for any marking treatment in mountain stands, they are particularly important in protection forests where the costs of silvicultural intervention are higher and the consequences of forest management are potentially affecting human beings (Motta and Haudemand 2000).

Current management of protection forests adopts the term target profile to describe the characteristics of the stand that we want to obtain through silvicultural interventions, according to the natural hazards involved and local site conditions (Brang et al. 2006). A target profile thus describes the state of the forest that is expected to have an effective protective action against natural hazards and that can be permanently maintained with minimum effort. In the following basic information about the protective role of forests against the prevalent natural hazards affecting mountain forests is provided. Stand parameters to be considered in shaping forest structure to reach the management goal of maximizing the protective function are also reported (based on Frehner et al. 2005, Frehner et al. 2007 and updated). Details on specific target profiles referring to different forest categories can be found in the national guidelines.

Protection against rockfall

If there is a slope larger than 30° , a rock can start moving. The size and shape of the rocks are influenced mainly by the type of bedrock and its stratification. This area is called zone of origin or release zone, where forest usually plays a limited role, which could have both positive and negative implications. Trees could have a positive influence in preventing the start of the rocks by holding them with their roots, but at the same time roots themselves can speed up the process of weathering (organic acid from roots and coniferous litter can corrode the rocks) and cracking (increasing frost wedging). Furthermore, when a tree that was anchoring rocks to the ground is swaying (tall tree) rocks can be released due to wind, tree collapse, or windthrow and snowbreak. The potential contribution of the forest is instead prominent in the **transit zone**, where rocks are moving down the slope sliding, rolling (between 30° and 35°), and bouncing (over 35°). In this zone, protection forests can provide a significant mitigating effect against rock fall, up to a size of blocks of 5 m^3 , since trees are acting as energy-dissipating mechanisms. Hitting trees, lying deadwood logs and root plates, results in falling rocks losing energy, deviating trajectories and eventually stopping. The efficiency of energy reduction by a tree is strongly related to the size of the stem and to the size of the rock. Larger trees are more effective in dissipating the energy or stopping rocks, but a dense forest made up by big trees is not ecologically feasible and would, in any case, lead to a short-lived protection effect due to senescence dynamics (big trees are usually older and more prone to collapse). A higher tree density increases the probability for a stem to be hit by a falling rock, but due to the self-thinning rule when we have a large number of stems in a forest stand, the average size is smaller and vice versa (few large trees). In order to guarantee the protective function, a certain structure (i.e., combination of tree density and average size) has thus to be achieved and maintained (Table 8). The desired target profile can be obtained by means of silvicultural management, focusing on prominent stand parameters such as the basal area with the mean diameter at breast height (1.3 m – DBH) or the stem density. Concerning species composition, broadleaves (hardwood species) are generally preferred since more resistant than conifers. It is very important not to create gaps between stems bigger than 40 m along the maximum slope, since rocks can regain high speed in this short distance, depleting all the protective role of the upslope forest. When the slope diminishes to less than 30° , rocks decrease their speed and stop quickly if the slope reaches less than 25° . In this run-out and deposition zone forest plays an important role in reducing the length of rock path, slowing the rocks in the same manner as in the transit

zone, even in a more effective way. Since rock energy (i.e., speed) is reducing because of the slope, even small trees can stop big rocks.

To be effective against rockfall, a protection forest should have a minimal length of 250 m along the slope.

Table 8. Rock size, assumed effective minimum diameter (DBH – diameter at breast height) and minimum requirement for the target profile (tree density, average DBH, and basal area (G); modified after Frehner et al. (2007) using the online tool RockforNET -<http://www.ecorisq.org/rockfor-net-en>).

Rock volume	Rock diameter	Assumed effective minimum diameter	Minimum requirements for target profile
up to 0.05 m ³	up to about 40 cm	up to 20 cm dbh	400 trees ha ⁻¹ dbh > 12 cm G = 20 m ² ha ⁻¹
0.05 m ³ up to 0.20 m ³	about 40 to 60 cm	20–35 cm dbh	300 trees ha ⁻¹ dbh > 24 cm G = 28 m ² ha ⁻¹
0.20 m ³ up to 5.00 m ³	over about 60 cm	over 35 cm dbh	150 trees ha ⁻¹ dbh > 36 cm

Protection against avalanches

An avalanche is a rapid down slope movement of a large mass of snow. It is a gravity-driven natural hazard, in which a mass flow of snow, air and debris is moving downslope from a starting or release zone to the runout zone along an avalanche track. Altogether those zones define the avalanche path. The protective importance of the forest in this case is in preventing the start of an avalanche. A protection forest will be effective in the starting zone, and only very marginally at the edge of the avalanche track and deposition zone, diminishing its reach and spreading into the surrounding forest. Forests are effective in preventing avalanche formation since they affect snowpack quantity, pattern and structure. Crowns intercept snow precipitation, delaying and reducing the quantity of snow reaching the ground (sublimation and wind erosion losses). The formation of a homogeneous continuous layering of snowpack is thus avoided also by the presence of stems and stumps. Furthermore, in the forest the surface roughness is higher than in the open. Trees also act as wind brakes avoiding the deposition of wind – transported snow, a critical triggering factor for avalanche formation. Inside a stand there is a specific forest climate where temperature ranges are reduced and snow temperature is higher than in the open, leading to an equilibrium metamorphism that stabilizes the snowpack (less formation of surface

or depth hoar). The target profile is thus focused on reaching a sufficient canopy cover (>50%; Figure 20), avoiding the presence of openings with length along the fall line greater than 30-60 m (e.g., for slopes greater than 45° maximum opening length should be 30 m, while a 30° slope will allow openings up to 60°) (Frehner et al. 2005). Concerning species composition, evergreen coniferous species are usually preferred for their persistent canopy cover in winter.

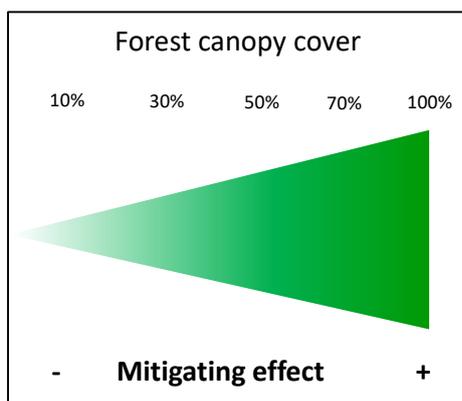


Figure 20. Gradient of the mitigating effect on avalanche release provided by a forest based on its canopy cover.

Protection against landslides

The potential contribution of a forest in preventing landslide occurrence is strictly related to the depth of the gliding surface; however, this contribution could not lead to the complete elimination of this hazard, even in the presence of an ideal stand. Considering shallow landslides, when the gliding surface is up to 2 m depth, forests can exert their role in two different ways: by stabilizing the soil with the tree root system and by regulating the water balance of the soil. The latter is supported through the crown interception of precipitation, transpiration and the enhancement of soil permeability; moreover, this effect, though with limited impact, is generated even for intermediate and large depth landslides. If the incline exceeds about 40°, the effectiveness of protection forests is greatly reduced. The target profile should be an uneven-aged stand, with the highest possible canopy cover and a species composition including tree species with a deep-reaching root system (e.g., silver fir, scots pine, ash, oak) (Frehner et al. 2007).

3.5.3. Final remarks

The importance of protection forests calls for increasing efforts in the comprehension of forest dynamics in mountain ecosystems and the development of efficient science-based decision

making. Current knowledge resulted in several handbooks or guidelines for the management of protection forests of many Alpine countries, which provided great support for forest managers and practitioners. The target profiles defined for different forest categories and local site conditions are based on decades of experience in proactively managing protection forests. However, many questions still have to be resolved. There is still a need to define a clear common methodology to assess protection forests, and to provide harmonized maps and quantitative data (i.e., amount and characteristics of protection forests) to policy makers at the European level (Wehrli and Dorren 2013). Further research, taking advantage of new technologies and approaches, should be focused on the combination of different factors and processes acting within a protection forest, on developing accurate methodologies to map protection forests, and defining mitigation strategies under current and future scenarios of climate and land use changes.

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4. FOREST-WATER INTERACTIONS IN EUROPEAN HEAD-WATERSHEDS

4.1 Austria Forest Dialogue: Participative development of the Austrian Forest Strategy 2020+

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4.1.1. Introduction

Due to the alpine nature of Austria's landscape, forests are particularly important in the protection of human environments against various types of natural hazards like debris flows, avalanches, rockfall and erosion (Lexer et al. 2001). Moreover, with respect to flood prevention forest stands also provide runoff reduction (lower flood peaks), a higher water retention capacity of the soil and stronger prevention of soil erosion. 20% of the Austrian forests are protection forests. About one third of the protection forests are located on hardly accessible or inaccessible sites and constitute stands, which, by nature, show an extremely low yield.

A high share of forest cover, multifunctional and productive forest management, recreational forests, increasing biological diversity, comprehensive programmes to ensure the protective effect of forests against natural hazards are key factors for sustainable management of Austria's forests. However, to ensure the economic, ecological, protective and social services of Austrian forests under changing framework conditions, the *Austrian Federal Ministry for Agriculture, Forestry, Environment and Water Management* (BMLFUW) initiated a broad policy formulation and implementation process – the Austrian Forest Dialogue.

The Austrian Forest Dialogue was initiated in 2002. It is a participative process of policy development in which more than 90 institutions and stakeholders are continuously involved. This Dialogue is a nationally and internationally renowned example of a national forest programme and good governance. In 2005, the first Austrian Forest Programme was adopted

in this framework and implemented in a work programme. Based on the results of an intensive evaluation of the process and its products, it was decided to develop an Austrian Forest Strategy 2020+, which was officially adopted in May 2016.

4.1.2. Protective effects of forests

Alpine natural hazards constitute a security risk in many regions in Austria. Floods, mudflows, avalanches, slope movements and rockfall are threatening people, their living environments, their settlements and economic areas, transport routes, supply lines, and infrastructure. They constitute thus an important threat to the fundament of livelihood. The increasing settlement pressure, further extension of transport routes in the Alps, as well as strong growth rates in tourism have resulted in a considerable spatial extension of endangered areas and damage potential. This accumulates to an increased demand for protection vis-à-vis stable protection forests.

Forests are indispensable for the protection of living areas in Austria and their protective function is of enormously increasing economic significance. About 70% of the total Austrian territory area is part of a torrent and/or avalanche catchment. Thousands of settlements and infrastructure facilities in Austria are protected against natural hazards (like debris flows, sediment disasters, snow avalanches, erosion, landslide events, rockfall, etc.) by forests, which causes the necessity of major strategic planning on a national and regional level in order to manage these forests effectively and to maintain their protective functionality. The reasons why forests have a significant role in reducing natural risks can be summarized as follows:

- Forests have a sustainable and resilient role in the protection against natural risks, if they are managed in a site-adapted manner.
- Forests represent an ideal vegetation to reduce runoff- and erosion processes, for rockfall protection and protection against avalanches.
- Forests provide a plethora of additional positive effects, such as object protection and provision of drinking water both in quality and quantity.

4.1.3. The Austrian Forest Dialogue

The Austrian Forest Dialogue is a voluntary process based on international policy commitments regarding sustainable development in general and sustainable forest management in particular.

It serves the purpose of strengthening sustainable management, tending and protection of forests as per Section 1 of the Austrian Forest Act and resolution H1 (General Guidelines for the Sustainable Management of Forests in Europe) of the Ministerial Conference for the Protection of Forests in Europe (MCPFE 2003). The Austrian Forest Dialogue thus addresses the economic, ecological and societal aspects of forests as three equal pillars of sustainable forest management.

In addition, the Forest Dialogue serves as a basis for the forest-related development as a tool for a holistic policy approach according to international requirements. It tackles respective agreements of the Ministerial Conference on the Protection of Forests in Europe (FOREST EUROPE), of the United Nations Forum on Forests (UNFF) and of other forest related processes, e.g., Convention on Biological Diversity, European Forest Strategy or Sustainable Development Goals (SDGs).

The Forest Dialogue strives for concrete targets that are defined in an operational way by means of criteria and indicators. The results serve all political decision-makers as guidelines for orientation. The results are elaborated consensually and represent the basis for a sectoral or forest-related contribution to the Austrian Strategy for Sustainable Development.

4.1.4. Structure and Procedure of the Austrian Forest Dialogue

The Austrian Forest Dialogue follows internationally recognised principles in a structured, participatory and transparent way (see Figure 21). The guiding principles are as follows:

- Active participation of all interested groups
- Openness
- Transparency
- Commitment
- Holistic, inter-sectoral and interdisciplinary approach
- Long-term and iterative process
- Consistency with international agreements and contracts

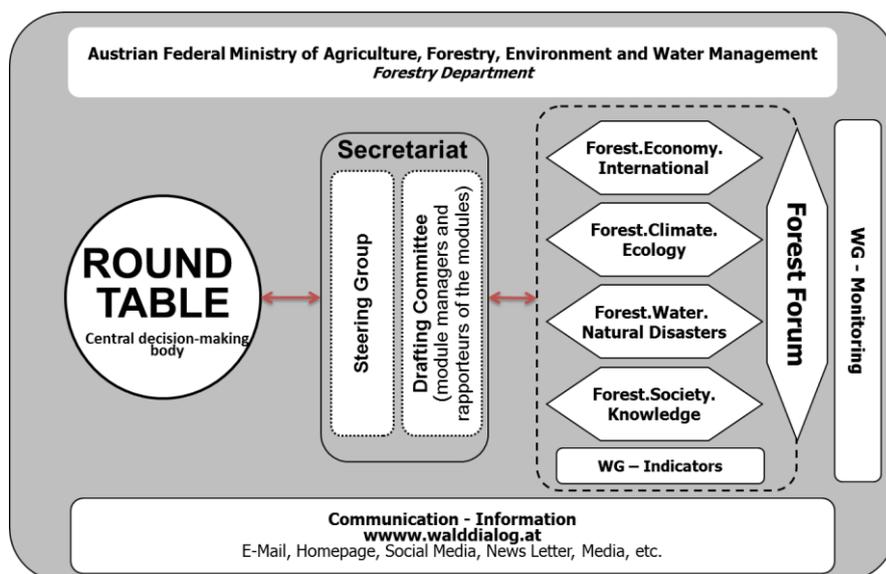


Figure 21. Structure of the Austrian Forest Dialogue.

4.1.5. Levels of public participation and methods used

In order to reconcile the different interests in the utilisation of forests, all interest groups relevant to forest matters have been invited to the Austrian Forest Dialogue. The main target groups for active cooperation are environmental and forestry NGOs, the chambers ("Austrian social partnership", e.g., the worker's chamber or the chamber of commerce), administrative bodies at federal and at provincial level dealing with forest matters, the Ministries and the political parties represented in Parliament. More than 90 stakeholders represent the interests of environment and nature protection, recreation, forestry, agriculture, the wood-based and paper industries, occupation, health, safety and consumer protection, hunting, the church, development cooperation, youth, science, education, energy management and public administration. The rules of cooperation and the principles of process structure and procedure were jointly elaborated and adopted in the initial phase of the Dialogue. These rules and principles form an important basis for the success of the process and the result-oriented work in the Forest Dialogue. The rules of cooperation are not static and adopted accordingly as the process enters different phases and cycles.

In the Austrian Forest Dialogue, all the three levels of public participation, namely information, consultation and cooperation (active participation), are combined for different target groups. *Political decision makers* are involved at so called "Round Tables". The Round Table is the political decision-making body of the Forest Dialogue. It establishes the principles (rules), the procedure and the content orientation of the Forest Dialogue and adopts the individual results

of the Forest Dialogue by consensus. The Round Table is chaired by the Federal Minister for Agriculture, Forestry, Environment and Water Management. For practical reasons only representatives of groups of stakeholders can participate actively at the Round Table. So far, 59 organisations have accepted the invitation of the Minister; one organisation (Greenpeace) has withdrawn from the Round Table in the course of the process. Technical experts and representatives from *administration* and from *interest groups* dealing with forest matters are involved at Forest Forums and Workshops. At this technical level, content-related work and the balancing of interests with regard to the individual topics takes place. The task of the Forest Forum is to continue the reconciliation of interests in forest-related matters according to the requirements provided by the Round Table. The Forest Forum is also responsible for the ongoing implementation of the Forest Strategy 2020+ with the help of a continuous work programme, for evaluating the measures taken, and for addressing new issues of importance. In addition to the meetings of the Forest Forum, thematic workshops support the implementation of the Forest Programme and to update the work programme.

Via the platform www.walddialog.at and written comments, the general public can participate in the dialogue process. They can access information on the outcomes of the Round Table and Module meetings. The public is comprehensively informed also by means of a Forest Dialogue Newsletter which reports regularly on the current state and the progress of the Forest Dialogue.

4.1.6. The Austrian Forest Strategy 2020+: Primary objective

The primary objective of the Forest Strategy 2020+ is to ensure and optimise all dimensions of sustainable forest management⁴ in a well-balanced way, paying special attention to the added value and the potential of the Austrian forestry and timber sectors for Austria. With this in mind, the Forest Strategy 2020+ is to help ensure the multifunctional services that forests render for present and future generations.

4.1.7. Content of the Austrian Forest Strategy 2020+

The Austrian Forest Strategy 2020+ is structured in 7 Action Areas, which relate to the 6 “Pan-European Criteria for Sustainable Forest Management” identified by the Ministerial Conference

⁴ Sustainable forest management means the tending and use of forests in a way and at a rate that maintains their biodiversity, productivity, regeneration capacity, and vitality as well as their potential to fulfil, now and in the future, relevant ecological, economic and social functions on local, national, and global level, and that does not cause damage to other ecosystems.

on the Protection of Forests in Europe. The seventh Action Area on “Austria’s international responsibility for sustainable forest management” has been added additionally on request of the participants of the Forest Dialogue.

1. Contribution of Austrian forests to climate protection
2. Health and vitality of Austrian forests
3. Productivity and economic aspects of Austrian forests
4. Biological diversity in Austrian forests
5. Protective functions of Austrian forests
6. Social and economic aspects of Austrian forests
7. Austria’s international responsibility for sustainable forest management

For each Action Area a vision, seven strategic goals, strategic key challenges and specific strategic priorities have been identified with the attempt to cover all interests expressed by the individual participants to the best possible extent. In a further step concrete individual measures will be elaborated. A set of indicators (including target values) to monitor the implementation complement the individual measures precipitating in a concrete work program.

4.1.8. Protective functions of Austrian forests

The protective functions of Austrian forests are an integral key issue of the Austrian Forest Strategy 2020+. A specific vision and 7 strategic goals reflect the enormous importance of the protective functions of Austrian forests.

4.1.9. The Vision 2030

The Vision 2030 regarding “Forests and Protection” is as follows: *“Forest as “green infrastructure” provides sustainable protection against natural hazards and consequent risks. It creates, sustains and promotes resilience to climatic and societal change. The “green infrastructure” forest is an essential regulator of the natural water cycle, thus creating an important basis for our drinking water, food and energy security.*

4.1.10. The Strategic Goals

To achieve this vision, the following seven strategic goals have been identified in the Forest Strategy 2020+:

1. Maintenance and development of resilient forest ecosystems with functional natural buffering, storage and filter capacities.
2. Creating a framework that allows sufficient natural forest recreation with woody species of the potential natural forest societies.
3. Strengthening the forests in order to maximise their ability as “site-protecting forests” as well as “object-protecting forests” within and outside of forest areas.⁵
4. Creation of conditions for sustainable assurance of sufficient qualitative and quantitative water supply of the forests.
5. Provision, development and application of efficient, inclusive and participatory planning and management instruments for the protection against natural hazards.
6. Increased awareness raising of the society on the importance of the management of forests, natural hazards and water balance.
7. Strengthening risk governance approaches and their implementation with regards to forests, natural hazards and water balance.

In the course of the Forest Dialogue, the BMLFUW has set up a Federal Protection Forest Platform. Protection Forest Platforms are already in place in the Federal Provinces of Upper Austria, Salzburg, Styria, Tyrol and Vorarlberg; they exist at civil service level in Carinthia, and they are in an initial stage in Lower Austria and Burgenland. An essential objective of the Austrian Protection Forest Strategy is a closer collaboration between agriculture and forestry, hunting, tourism, nature conservation and other users of landscape in order to jointly provide efficient solutions for a sustainable provision of protective functions. It is also necessary to use synergies because the allocation of public funds for the restoration of protection forest becomes increasingly difficult.

⁵ Since the amendment to the Austrian Forest Act in 2002 protection forests are no longer divided into the categories of site-protection forests and protective forests but also into the new category of object-protection forests. Whereas site protection forests protect their site, or rather themselves, object-protection forests protect people, their settlements, constructions and cultivated land against elementary hazards and harmful environmental influences.

4.1.11. Conclusions

The preservation and improvement of the protective function of forests has been a central responsibility of Austrian forest policy for decades and the by far most inexpensive contribution to the inhabitability and development of Austria's mountain regions. Protective forests - but also alluvial forests - play a special role in this context. The wide range of watershed effects of the forest – such as object protection, retention area, protection against soil loss and erosion, water pollution control or also as water reservoir and air filter haven't achieved the recognition in terms of public awareness that appears needed from the vantage point of protective forest strategy. Therefore, the Forest Dialogue, and similar cooperation projects or initiatives contribute significantly to information and the balance of interests, notably with regard to target audiences inside and outside of the forest management sector.

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4.2 Forest management in head-watersheds: French approach for encompassing multiple ecosystem services

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4.2.1. Introduction

In mountain areas, forest management planning is not only faced with the strong heterogeneity of the natural environment, but also needs to encompass the multiplicity of forest ecosystem functions, which must be evaluated and quantified prior to any silvicultural action. In addition to his technical skills, the forest planner will need high-performance assessment and planning tools tailored for addressing this diversity and complexity.

Of the 16.2 million hectares of French mainland forest, 4.4 million ha (27%) are defined as “mountain forest” (more than 600 m a.s.l.). If we focus on high mountain forest only (higher than 1200 m a.s.l.), 1 million ha (6.5%) are relevant (IFN 2011). Mountain forests can be divided into the following categories:

- **Public forests** governed by public forest regulations and managed by the Office National des Forêts (ONF):
 - “state-owned RTM forests”, acquired and reforested by the French State from the beginning of the nineteenth century within the framework of a restoration of mountainous terrain (RTM) policy (257 000 ha);
 - “state-owned forests” (outside RTM) and forests owned by local authorities, which represent about 1 230 000 ha;
- **Private forests**: about 2 900 000 ha.

This paper presents the French approach for the multifunctional management of **public forests** which are required to be covered by an official 20-year forest management planning document. It will then focus on the specifics of public forest management in head-watersheds in order to encompass ecosystem services.

4.2.2. A regulatory framework intended to encompass ecosystem services

Even though the long-term preservation of forest resources has been guiding the management of French public forests for the past few centuries, regulations, and especially management tools, have gone through substantial changes during the past decades in order to integrate new challenges such as biodiversity preservation and public access to forests.

From a regulatory point of view:

- Article L.1 of the forest code endorses the **multifunctional character** of forest management.
- The National Guidelines for Management and Management Planning (ONAG) of public forests⁶ enhance the role of protection forests by introducing an obligation to assess relevant stakes.
- The law for the modernisation of agriculture and fisheries of July 27th 2010 particularly emphasises forests protective role.

From an operational point of view, the **forest management plan** (“*Aménagement forestier*” in French) is the main document of forest planning and strategy, which guarantees the consideration of goods and services provided by forests. Methodological management handbooks have been elaborated for mountain forests to improve the consideration of these forests specifics, notably their role as protection forests against natural hazards.

4.2.3. Forest management planning to guarantee the multifunctional role of forests

In every management unit, following a detailed assessment of context and issues, the forest management planner defines the **decisive function**, which will drive the principal actions of forest management (timber production, landscape enhancement, protection against natural hazards, biodiversity conservation, public access to the forest, ...) while taking into consideration all the other functions of the forest.

In order to reach this goal, it provides a precise methodological framework, which is outlined in the Forest management planning manual. Figure 22 shows an example of a simplified and non-exhaustive methodological itinerary applied.

⁶ ONAG approved by the Minister of food, agriculture and fisheries, order of April 7th 2010

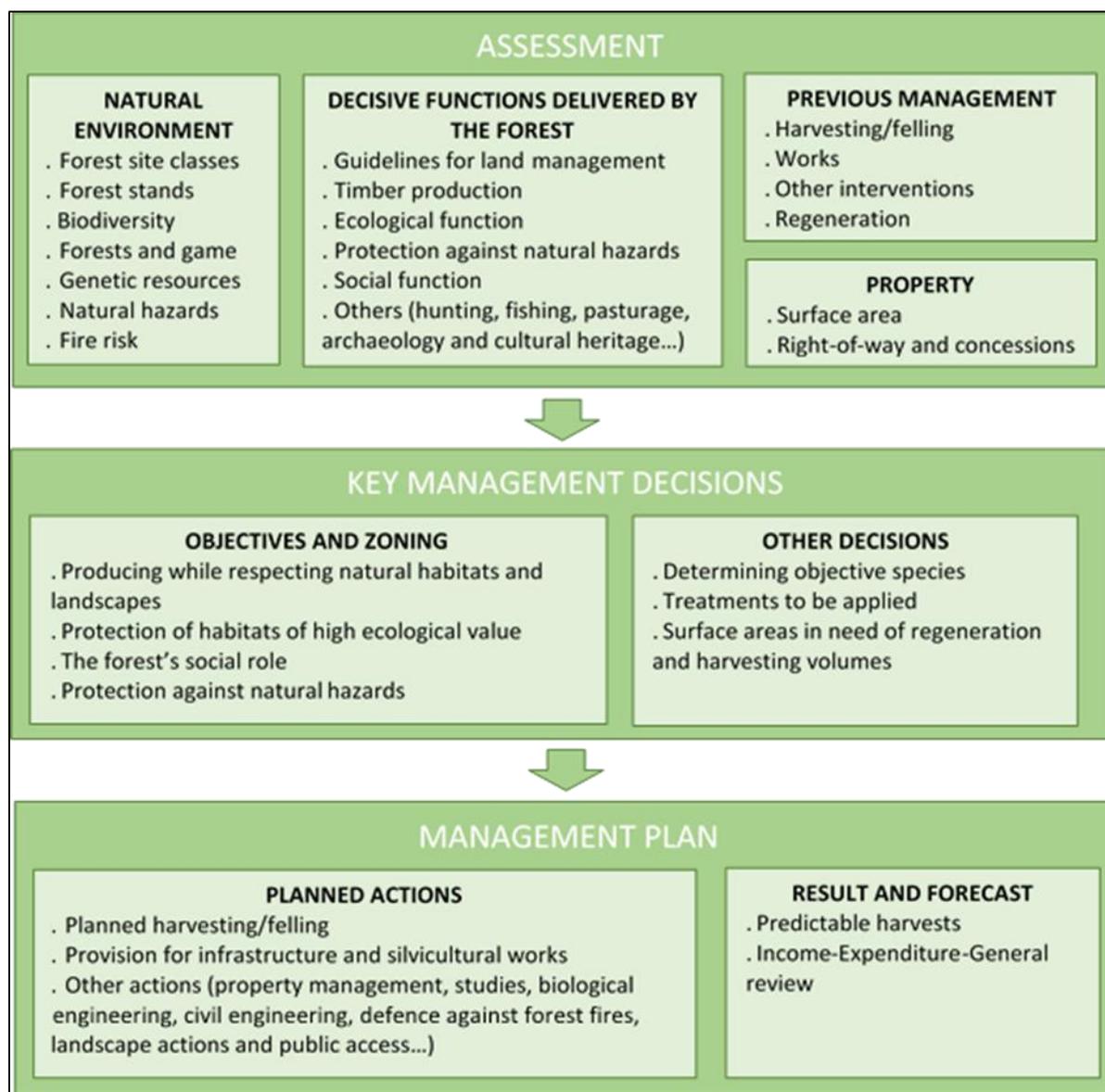


Figure 22. Methodological itinerary applied for management planning⁷.

The main function of the forest management unit is determined by the nature of the stakes (null/weak/medium/strong) on each site. The principal criteria taken into consideration for the evaluation of these stakes are presented in the Figure 23.

⁷ Translated in English from the original figure in Orientations Nationales d'Aménagement et de Gestion pour les forêts des collectivités (ONF 2010)

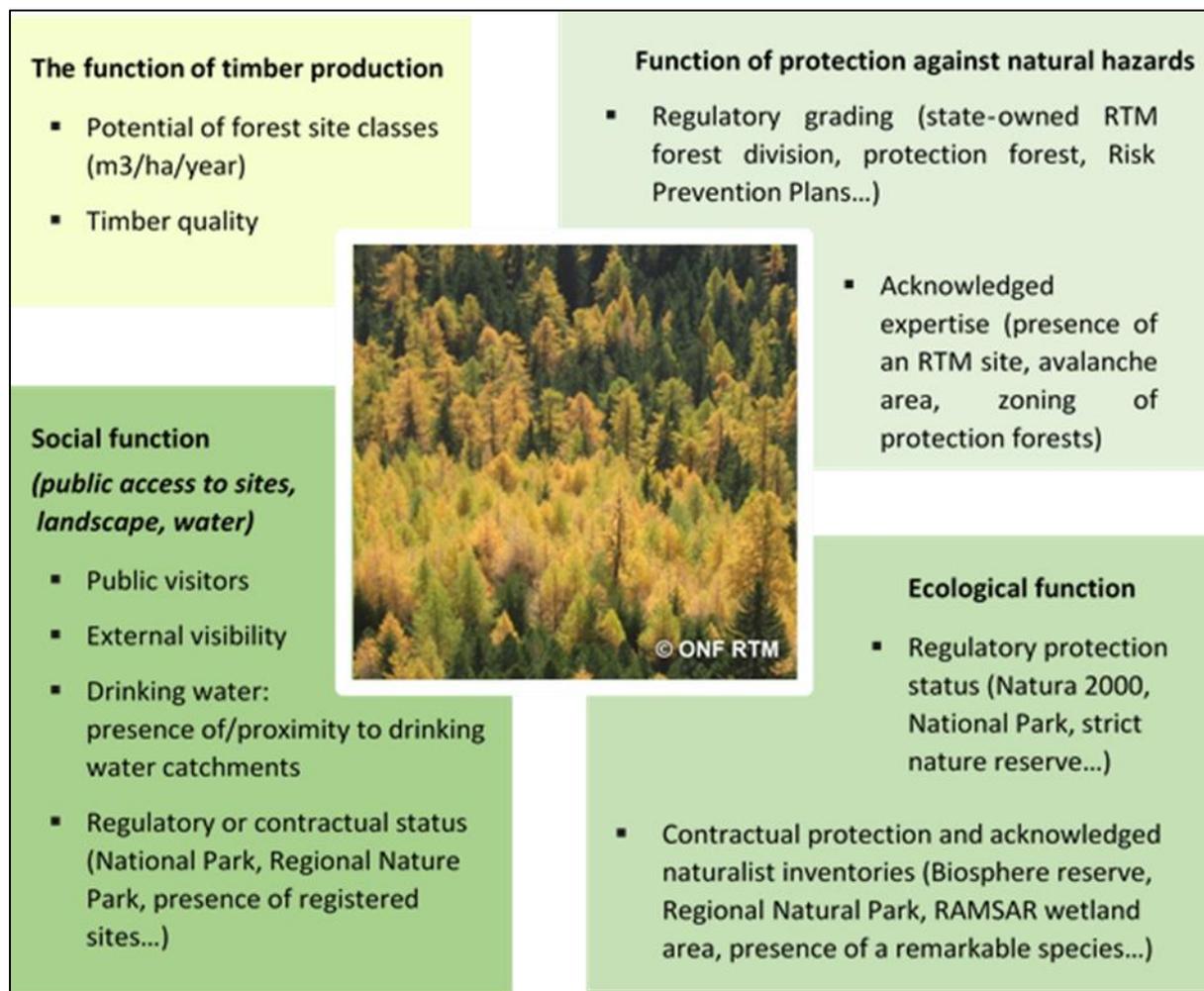


Figure 23. Example of criteria for stakes assessment in public forest.

4.2.4. The specificity of head-watershed forests for the consideration of ecosystem services⁸

Even though all forest areas provide multiple ecosystem services, forests in head-watersheds are considered to be of high ecological importance. Slopes and altitude are factors which considerably alter the physical and biological behaviour of ecosystems, making them particularly fragile and sensitive to human interference. In order to maintain the balance in these areas, it is recommended to specify each forest management action.

Forest management in mountainous areas gives as a rule priority to:

- a structure that will optimise the hazard control whenever a protection potential is identified
- natural forest stand dynamics while limiting silvicultural operations

⁸ This part is largely inspired by the Silvicultural Guidelines for Mountain Forests (SEE REFERENCES)

- mixing species: better ecological balance, better forest stand resilience and diversification of harvested products
- multi-storied structures: fast regeneration of forest stands in case of forest disruption and limited financial losses
- respecting landscapes and biodiversity

Below are detailed assessment criteria for main ecosystem services to be taken into account by forest management actions:

The function of protection against natural hazards. Concerning the function of protection against natural hazards, forest management planning is based on the **Hazard Control Index** (*Indice de Maîtrise d'Aléa – IMA* – in French) which quantify protective role on a scale from 0 to 6 (see Figure 24). In this way, it can be assessed the capacity of a forest stand to reduce the risk of socio-economic challenges threatened by one or several hazards. Moreover, the suitable silvicultural operations to maintain or strengthen its protective function can be determined. Calculations are based on a rating grid fixed by ONF, building on works carried out by the Irstea⁹, in which the indicators (% of plant cover summer/winter, density, diameters) reflect hazards under consideration (rock fall, avalanches, surface erosion, torrential floods, landslides). This index is particularly, but not exclusively applied to mountainous areas where many forests have a protective role (as decisive function).

ROCKFALLS (blocks of less than 1 m ³)			Stem diameter predominantly below 17.5 cm		Stem diameter predominantly above 17.5 cm	
			Stem density (N/ha) diameters of 7.5 to 17.5 cm		Stem density (N/ha) diameter of 17.5 cm and +	
			N < 2 000	N > 2 000	N < 350	N > 350
AREAS OF TRANSIT AND DEPOSIT	Wooded strip > 200 m (planimetric)	G < 25 m ² /ha	1	3	1	3
		G > 25 m ² /ha			4	5
	Wooded strip < 200 m (planimetric)	G < 25 m ² /ha	0	2	0	1
		G > 25 m ² /ha			2	3

Figure 24. Example of a grid used for the definition of the Hazard Control Index in relation to rockfalls; Nb: G: tree stand basal area (m²/ha).¹⁰

⁹ National Research Institute of Science and Technology for Environment and Agriculture

¹⁰ Translated in English from the original figure in *Fiche du Manuel d'Aménagement 9200-12-GUI-EAM-018-VERSION A (ONF 2012)*

In view of aging RTM protective stands, most of them are over 100 years, the task of renewing forest stands and maintaining their protective role is substantial. In order to determine the Hazard Control Index (HCI), the first step to be taken is therefore to prioritise forests with an important protective role. This is the objective of the “Renewal of Protection Forest Stands Programme” ordered by the Ministry of Agriculture and Forestry in 2007.

The first phase of the programme was achieved in 2011 and concerned hazard zone mapping of 555600 ha of state-owned forest. Results from the programme showed that 7% of RTM forests could be defined as high protection potential. These forests will be prioritised in terms of HCI determination and silvicultural procedures to renew protective forest stands.

The second phase, currently under preparation, will outline the implementation of protection forest renewal procedures according to the grading based on the determination of the HCI within forest stands of high protective value. Costs related to operations in RTM forests in these sectors are estimated at 3 to 4 million euros per year.

Timber production. Mountain forests are characterised by a substantial accumulation of standing timber. The average volume per hectare exceeds the national average by 20% (IFN 2011) which clearly demonstrates the under-exploitation of mountain forests.

Timber production is high in the Vosges, the Jura and to a lesser extent the Massif Central. In the other mountain massifs (Alps, Pyrenees), harvesting is affected by higher altitudes and steep slopes, which create unfavourable conditions for the timber industry. The Corsican mountain massif and the Southern Alps are under the permanent threat of fire, adding a risk factor to forest activities.

For production mountain forests, the forest planner has to determine the forest’s harvesting potential in regard of economic and technical criteria before defining silvicultural actions while taking into account landscape and environmental elements (i.e., interrupted logging during the reproduction period of a remarkable species).

Landscape and recreation. The relief in mountain areas provides for multiple viewpoints, making silvicultural operations extensively more visible than in the lowlands. Forest planners take landscape factors into account by implementing a grid to measure landscape sensitivity as well as potential impacts of future silvicultural operations. Forest operations will be adapted according to evaluated risks involving, if needed, consultations with local stakeholders (elected officials, players in the tourism industry, ...).

Some examples of silvicultural solutions to maintain or improve landscape quality are:
adapting the shape and the surface area of forest intervention areas

Uneven-aged silviculture for forest edges

Keeping afforestation in retreat from roads

creating viewpoints and paying particular attention to public reception area design

Biodiversity conservation. French mountain massifs represent 28% of the national mainland territory and are one of richest areas of France in terms of natural heritage (Amoudry 2002): 45% of protected plant species and 87% of protected mammals in mainland France are found in mountain areas;

Some 30% of the total area of all mountain massifs are protected (as compared to 12% at the national level), and 89% of national territory under high protection is located in mountain areas (National Parks, Nature Reserves and Strict Nature Reserves); 5 out of 7 National Parks, a quarter of all Nature Reserves and half of all Regional Nature Parks in mainland France are located in mountain areas.

The rules for forest management which are applied in these protected areas vary according to the level of protection and the location of the specific forest area, from policies of non-interference to silvicultural operations in consultation with the administrative entity of these areas.

Outside of regulated protection areas, public forest authorities aim at biodiversity conservation by implementing rules of good practice during timber marking, logging and silvicultural operations.

Silvicultural mountain guides (northern and southern Alps) identified 24 remarkable forest habitats and actions to be implemented in order to preserve these areas (no silvicultural operations, favouring certain rare species, opening up of the landscape and others actions).

Mountain forests and water. French mountain massifs act as the country's water reservoirs. The objectives of water quality maintenance and improvement, including the role of forests, have received particular attention in the past few years.

Besides the aspects of *natural hazards* (superficial erosion, torrential floods) and water-related *habitats*, already addressed in the previous sections, the forest planner has to focus on three main interactions between forest management and water for selecting silvicultural actions: riparian management, impacts due to felling, and water resources and catchment protection.

Give a large development zone for riparian vegetation by choosing native broadleaf species with deep-growing roots to avoid the risk of destabilising the riverbank and acidifying the natural environment. It is also important to maintain the riparian zone by favouring species diversity and different strata, by removing instable trees and by limiting the number of large-diameter trees.

Regarding logging impacts in proximity to streams, the forest planner has to follow good forest practices which should be defined in logging contracts. A few examples: removing coarse woody debris and cut timber from zones close to streams, using biodegradable oil in logging equipment, minimising stream crossings with logging machinery.

As concerns forest stands within a water resource and catchment perimeter, the forest planner will often go beyond the in-force regulations by applying good forest practices. The focus should be on species diversity and uneven-aged silviculture to ensure forest stand permanence, to favour water infiltration and to limit acidification. Logging operations shall be performed with particular attention to any risk of disruption to the natural environment.

4.2.5. Conclusions

In accordance with the Alpine Convention's mountain forest agreement, the multiple functions of forests have been an acknowledged concept for a long time. However, in order to fully appreciate the mountainous forest ecosystem services, a number of specific tools have been developed and implemented more recently, which quantify such services and guide silvicultural interventions.

These interventions to maintain or enhance ecosystem services can be very costly, as for protective function against natural hazards. Budgetary constraints oblige to make choices and give priority to certain actions or certain areas according to the stakes involved.

One of today's great challenges in head-watershed management is to balance ecosystem services provided by forests. A key element for meeting this challenge is to involve local stakeholders and different users of forest resources through consultation and dialogue.

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4.3 Protection Forests in Switzerland: from Delimitation to Management¹¹

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4.3.1. Introduction

On the basis of the assumption that forests protect against natural hazards, forest use was limited in certain forests in Switzerland already in the 14th century (Schuler 2015). In 1876, the Swiss Forest Inspectorate Act came into force. This act was a reaction to various natural disasters in the 19th century, placed mountain Swiss forests under strict protection and laid down the principles of sustainable management (Federal Office for the Environment 2013). The act included also a definition of protection forests and the Cantons were obligated to delimitate forests with a protective function within two years. Since then, experts, researchers and practitioners have dealt extensively with protection forests, and the knowledge in protection forests management 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 (e.g., Lange et al. 2013, Dorren et al. 2007). This article gives an overall view of the Swiss experiences in the field of protection forest delimitation and management.

4.3.2. When is a forest a protection forest?

The Article 77 of the Swiss Federal Constitution mandates the Confederation to ensure that the forests are able to fulfil their protective function. A uniform national definition of a protection forest is therefore of great importance for a successful protection forest policy.

In 2003, the Federal Government and the Cantons decided to initiate a harmonized protection forest delimitation that is based on objective criteria. In a first step, a common ground was set

¹¹ Some parts of this text originate from the following publication: Fehner, M., Wasser, B. and Schwitter, R. 2007. Sustainability and success monitoring in protection forests. Guidelines for managing forests with protective functions. Partial translation by Brang, P. and Matter, C. Environmental Studies no. 27/07 Federal Office for the Environment (FOEN), Bern, Switzerland. 29 p. + 26 p. Appendix.

by establishing a generally accepted definition: “A protection forest is a forest, which protects an acknowledged damage potential against a natural hazard or reduces the potential risks”.

In a second step, the Federal Office for the Environment put simulated hazard processes in relation to damage potential and to forested area over the whole of Switzerland as a basis for the harmonized protection forest delineation of the Cantons. For this reason, the project SilvaProtect-CH was launched (Losey and Wehrli 2013). This project comprises four main steps.

1. **Modelling hazard perimeter:** Relevant hazard processes (avalanches, rockfalls, landslides and torrent related processes) 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 (e.g., buildings, roads, railroad lines etc.) 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.

Based on these damage-relevant process areas in forests, the Cantons delimited their harmonized protection forest. This procedure ensures consistent and comparable protection forest delimitations of the Cantons. The cantonal protection forest delimitations show that nearly 50 % of the forested area in Switzerland has a protective function. Taking into account that approximately 1/3 of Switzerland is forested, about 1/6 of the land surface is covered by protection forests.

4.3.3. Protection Forest Management

The Swiss Law on Forest obliges the Cantons to ensure that forests with a protective function are managed accordingly. Protection forest management is based on the assumption that there is a direct link between the protecting effectiveness and the state of a forest. As an example, a rockfall protection forest needs a certain number of stems with an appropriate diameter in the transit and deposit area to fulfil its protective function. The aim of protection forest management is therefore to ensure that a forest is as effective as possible in reducing the intensity and/or the frequency of natural hazards.

Prescribed silvicultural interventions which are subsidized must comply with the following seven principles. They must be

1. **with a focus on the protective target.** Silvicultural interventions in protection forests serve exclusively to reduce natural hazards.
2. **in the right place.** Silvicultural interventions are carried out in areas where the forest can prevent or reduce the effects of natural hazards on people and infrastructures.
3. **at the right time.** Silvicultural interventions are carried out at that point in time when an optimal effect can be attained with minimal effort.
4. **consistent with natural life processes.** Silvicultural interventions are tailored to site conditions to make use of the forces of natural forest dynamics.
5. **tailored to each stand, transparent, replicable and controllable.** Silvicultural interventions are determined by experts on the spot. This makes it possible to adapt them to small-scaled variations in site factors. A standard decision-making procedure is followed and documented. This makes it transparent, replicable and controllable.
6. **effective.** Silvicultural interventions must with reasonable certainty reach the targets.
7. **with reasonable effort.** Silvicultural interventions have a reasonable cost-benefit ratio.

4.3.4. The guideline “Sustainability and Success Monitoring in Protection Forests”

In 2005, the guideline “Sustainability and success monitoring in protection forests” (German abbreviation: NaiS) was published (Frehner et al. 2005). This guideline is a legally binding instrument for subsidized silvicultural interventions in protection forests. NaiS describes requirements and suitable instruments for protection forest management and helps to put the above-mentioned principles into practice.

The guideline defines so-called target profiles that describe stand conditions (tree species composition, stand structure, stability carriers 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 stem density improves the protective effect against rockfall. 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).

Target profiles

Site-related targets. The most stable, and therefore sustainable, states of a forest are assumed to be represented by the range in variation of developments of a natural forest. If the state does not comply with the range of a natural forest (e.g., a pure Norway spruce stand on a site where the natural forest community is dominated by beech), the forest will be less resistant to disturbances (wind, insects, etc.). This does not imply that all conditions, which can be found in a natural forest, are advantageous concerning the protective effect. In particular, extensive pioneer phases may offer poor protection.

The site-related target includes all important tree species of the climax stand. The stand structure should be diverse, with single trees or clusters able to resist disturbance, and regeneration should be continuous. The self-regulating process of the natural forest should be utilized to an optimum so that disturbances to the ecosystem can be avoided or kept to a minimum and the silvicultural interventions can be as small as possible in the long term.

Hazard-related targets. The knowledge of the effects of specific stand properties on hazard processes is a prerequisite for defining hazard-related targets. It is assumed that there is currently sufficient knowledge to determine the significance of forest characteristics on avalanches, erosion, shallow landslides, torrent related processes (driftwood, debris flow) and rockfall (Wasser and Perren 2014).

For each of these processes, the targets for the stand and the single tree to avoid or reduce the effect of the hazard are specific. The requirements concerning the hazard mainly concern the stem number, the size of gaps in the stand and the canopy density. Table 9 shows some simplified hazard-specific target profiles for protection forests according to the guideline NaiS.

Table 9. Simplified target profiles¹ according to the guideline “Sustainability and success monitoring in protection forests”.

	Avalanches ²	Landslides, Erosion and debris flow	Rockfall	Torrent related processes										
Locality	Zone of origin (coniferous forests)	Zone of origin	Transit, runout and deposition zone ⁴	Forested channel slopes										
Potential contribution of the forest	Large in: <ul style="list-style-type: none"> larch forests if incline $\geq 30^\circ$, in evergreen coniferous forests if incline $\geq 35^\circ$ 	Large in the case of shallow landslides and surface erosion	Large for smaller rocks	Small to large, depending on the channel characteristics										
Target profile: minimum requirements	<table border="1"> <thead> <tr> <th>Incline</th> <th>Opening length³ in fall line</th> </tr> </thead> <tbody> <tr> <td>$\geq 30^\circ$</td> <td>< 60 m</td> </tr> <tr> <td>$\geq 35^\circ$</td> <td>< 50 m</td> </tr> <tr> <td>$\geq 40^\circ$</td> <td>< 40 m</td> </tr> <tr> <td>$\geq 45^\circ$</td> <td>< 30 m</td> </tr> </tbody> </table> <p>Minimum requirements of site-related target profile accomplished</p>	Incline	Opening length ³ in fall line	$\geq 30^\circ$	< 60 m	$\geq 35^\circ$	< 50 m	$\geq 40^\circ$	< 40 m	$\geq 45^\circ$	< 30 m	<p>Horizontal Structure:</p> <ul style="list-style-type: none"> Maximum gap³ size: 0.06 ha, if secured regeneration exists 0.12 ha Canopy cover permanently $\geq 40\%$ <p>Minimum requirements of site-related target profile accomplished</p>	<p>Target basal area and the associated number of stems per diameter class according to the Online-Tool http://www.ecorisq.org/rockfor-net-en</p> <p>Gaps⁵:</p> <p>Stem distance in the fall line < 40 m</p> <p>For gaps > 20 m in the fall line: lying logs every 10 m and high stumps (ca. 1.3 m)</p> <p>Minimum requirements of site-related target profile accomplished</p>	No unstable trees or stems prone to slide
Incline	Opening length ³ in fall line													
$\geq 30^\circ$	< 60 m													
$\geq 35^\circ$	< 50 m													
$\geq 40^\circ$	< 40 m													
$\geq 45^\circ$	< 30 m													
Target profile: ideal requirements	<table border="1"> <thead> <tr> <th>Incline</th> <th>Opening length³ in fall line</th> </tr> </thead> <tbody> <tr> <td>$\geq 30^\circ$</td> <td>< 50 m</td> </tr> <tr> <td>$\geq 35^\circ$</td> <td>< 40 m</td> </tr> <tr> <td>$\geq 40^\circ$</td> <td>< 30 m</td> </tr> <tr> <td>$\geq 45^\circ$</td> <td>< 20 m</td> </tr> </tbody> </table> <p>Ideal requirements of site-related target profile accomplished</p>	Incline	Opening length ³ in fall line	$\geq 30^\circ$	< 50 m	$\geq 35^\circ$	< 40 m	$\geq 40^\circ$	< 30 m	$\geq 45^\circ$	< 20 m	<p>Horizontal Structure:</p> <ul style="list-style-type: none"> Maximum gap³ size: 0.04 ha, if secured regeneration exists 0.08 ha Canopy cover permanently and at a small scale $\geq 60\%$ <p>Ideal requirements of site-related target profile accomplished</p>	<p>Hazard related target according to the minimum requirements.</p> <p>Ideal requirements of site-related target profile accomplished</p>	<p>No unstable trees or stems prone to slide</p> <p>Ideal requirements of site-related target profile accomplished</p> <p>Pioneer vegetation on temporarily or permanently unstocked areas</p>
Incline	Opening length ³ in fall line													
$\geq 30^\circ$	< 50 m													
$\geq 35^\circ$	< 40 m													
$\geq 40^\circ$	< 30 m													
$\geq 45^\circ$	< 20 m													

¹: The table gives a simplified picture of the target profiles for the most important natural hazards in Switzerland. For detailed information, see the guideline “Sustainability and success monitoring in protection forests”.

²: For avalanches, there is also a target profile defined for broadleaved and mixed forests of the upper and lower montane zones

³: Opening length measured from crown edge to crown edge in pole and older timber stands

⁴: There exist also a target profile for the zone of origin

⁵: Gap size is measured from stem to stem

Normally, the long-term silvicultural target corresponds to the ideal profile (greatest protective effect in the long-term). Should there be other important interests (e.g., providing a habitat for capercaillie), the long-term targets can lie between the ideal and minimum target. The leeway between the ideal profile and the minimum profile can also be used to minimize the long-term silvicultural intervention costs.

Indicator plot. The target profiles established on the basis of natural hazards and site types not only apply to individual stands but also to large areas with similar conditions. All areas to which the same target profile applies are considered to belong to the same *target type*. Within one target type, stands in very different states needing rather different interventions can occur. Areas within a target type, requiring the same type of intervention to a similar extent, are called *treatment types*. The treatment types provide the basis for planning and implementation measures. For the assessment of the need for action, a so-called *indicator plot*, is selected which is as representative as possible of every target type or treatment type.

Determining the need for action. Determining what is the need for action on any given indicator plot is the most important procedure in the planning of sustainable protection forest management. This assessment bases 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 stand without interventions, which accounts for the natural forest dynamics. This comparison is made for all important 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 (see Figure 25). As a first step, the site type and the relevant natural hazard are determined. Then, the minimum target profile for both the natural hazard (see Table 9) 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) on the stand. Since a forest continually changes even without interventions, predictions are made for all the characteristics for the next 10 and 50 years. The expected development is marked with arrows. 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 is compared with the minimum profile. If the conditions are predicted to be worse than the minimum profile, effective interventions should be considered to improve the development. Provided the recommended interventions can be assessed as reasonable, there is a need for action. To determine the urgency of an intervention, the current state of the forest is considered

as well as the speed and the direction in which the stand could develop without interventions. According to Principle 3 (see above), silvicultural interventions should be made at the point in time when maximum effects can be achieved with a minimum input.

Municipality: Example		Locality: Example		Date: 10.01.2016	Author	
1. Site type(s): <i>Luzulo-Abieti-Fagetum typicum</i>						
2. Natural hazard and effectiveness: shallow landslides, zone of origin, high protective effectiveness of forest						
3. State of the forest, trend analyses and interventions						
Stand and tree characteristics	Minimum target profile (including natural hazard)	Current state of the forest	Current state, trend in 10 & 50 years	Effective intervention	Appropriate	6. Stage targets To be checked in 10 years
Species mixture (type and degree)	Beech: 30 - 80 % Fir: 10 - 60 % Spruce: 0 - 30% Sycamore maple: seed trees	Beech: 15 % Fir: 5 % Spruce: 80 % Sycamore maple: 0 %		Improve species mixture by initiating regeneration: create gaps, remove spruce, preserve beech and fir	X	Increase the percentage of beech by 20 % at the expense of spruce
Vertical structure (dbh variation)	Sufficient number of trees with development potential in at least 2 different dbh classes per ha	Only one dbh class present (20 - 40 cm)				At least 2 dbh classes present
Horizontal structure (% cover, gap length, stem density)	Individual trees, possibly clusters, openings < 0.06 ha, if secured regeneration exists 0.12 ha, canopy cover permanently at least 40 %	Mostly individual trees, no openings > 0.06 ha, canopy cover 95 %				No openings > 0.06 ha, canopy cover > 40 %
Stability carriers (crown development, slenderness, target dbh)	Crown length of silver fir at least 2/3, of Norway spruce at least 1/2. Coefficient of slenderness < 80, upright stems, well anchored, few trees leaning at extreme angles	Some deformed crowns, about 50 % of spruce instable, some leaning trees		Remove strongly leaning and unstable spruce, preserve stable clusters	X	No large trees leaning at extreme angles
Regeneration: seedbed	Area with strongly competing ground vegetation < 1/3	Little competition from vegetation				
Regeneration : small saplings (0.1 - 0.4 m tall)	At canopy closure < 0.6 at least 10 beech/fir per 0.01 ha (on average one sapling every 3 m), in openings maple present	Few saplings		Initiate regeneration by creating gaps	X	Small saplings under canopy on half of the area, species mixture according to the target profile
Regeneration: large saplings (0.4 m tall to 0.12 m dbh)	On each ha, a least 1 group (0.02 - 0.05 ha, on average 1 group every 100 m) or canopy cover at least 4 %, mixture in line with target profile	Few suppressed broad-leaf sapplings		Create gaps to bring light to the ground	X	Large saplings (> 1 m) in openings, species mixture according to the target profile
			very bad minimum ideal			
4. Need for Action yes X no						
5. Urgency small medium X high						

Figure 25. Example of a completed form to determine the need for action in a protection forest against shallow landslides.

Figure 25 shows an example of such a form. The natural forest community is a *Festuca-Abieti-Fagetum* but planted Norway spruce dominates the current forest. The potential protective effect of the stand on the relevant natural hazard (shallow landslide) is high. Comparing the minimum target profile with the current state of the forests indicates the following divergences to the minimum target profile: (1) the species mixture is dominated by spruce due to the plantation. Thus, the current stand is not that of the natural forest community. Without intervention, the species mixture will presumably slightly improve in the next 50 years since beech is more competitive than spruce at this location. (2) The vertical structure is uniform which is also a consequence of the afforestation. Both insufficient vertical structure and species mixture result in dense and uniform stands with short crowns, coefficients of slenderness > 80 and therefore low stability (3). Moreover, some trees are leaning. Due to the missing light on the floor, regeneration is rare (4). In contrast, the hazard-related targets are currently reached (no openings, high canopy cover). In consequence of the instable stand, the canopy cover will

presumably decrease in the future due to disturbances, which may also lead to gaps. Even if the protective effect is currently good, it is of high probability that it will decrease because of the instable stand and the lacking regeneration. Thus, the protective effect is most likely not sustainable and there is the need for action. Since the protective effect is good now and will presumably not significantly diminish within the next 5 to 10 years, the urgency for an intervention is medium.

Stage target. To define quantitative stage targets enables to verify the success of an intervention. Stage targets define intermediate objectives as steps towards realizing the long-term silvicultural targets and are to be reached within a time span of 5 to 10 years. There is some leeway when defining the stage targets. In principle, a stage target should not be below the minimum profile. Usually, it is a step in the direction of the ideal profile. If the initial condition is bad, this requirement cannot always be complied with. In the example shown in Figure 25, it is hardly possible to reduce the percentage of Norway spruce by 50 % with a single intervention. Such strong woodcutting would disproportionally reduce the stability of the stand and result most likely in gaps that decrease the protective effect. Thus, the stage target is below the minimum profile.

Success monitoring. To monitor the success of measures for protection forest management is of high importance to improve the effectiveness of the interventions and to achieve a high protective effect as efficient as possible. Moreover, appropriate monitoring should ensure that new findings and experiences are promptly fed into practical implementation. NaiS defines therefore four stages of success monitoring that cover the review of the target profiles, the effectivity analysis of the taken measures, the implementation assessment and silvicultural monitoring.

Target review - Protection forest management is based on the assumption that there is a direct link between risk reduction and the state of the forest. This link has partially been demonstrated by research, but should be subject to further studies. Quantitative investigations into the influence of forests on natural hazards and therefore on risks to people and material assets are still needed. If there is some new knowledge relevant for the hazard-related target profiles, the target profiles should be revised accordingly. In the last years, the target profile for rockfall was substantially edited and a new profile for protection forests along channels is in preparation. But also, the requirements based on site types must be periodically reviewed in the target analyses. We still have a great deal to learn about the natural dynamics of forests and it is often not known how much need there is for action, for example in chestnut forests in the south of the Alps.

Effectivity analyses - As it is often uncertain which interventions are correct or which level of intervention intensity or deliberate omission is the most effective, practitioners need an instrument to analyse the effectivity of their silvicultural interventions. The effectivity analyses aim at showing whether the interventions realized have the wished-for effect on the state of the forest and is therefore the core element in the silvicultural monitoring in protection forests. It promotes the professional competence of the manager and enables protection forest management to be highly effective and tuned to local conditions based on up-to-date knowledge.

Implementation assessment - In the framework of this assessment it is checked whether the planned interventions have been carried out at the correct location and with due professional care. The implementation assessment is needed to enable the canton and federal forest authorities to inform third parties reliably about whether the forest management has been implemented at the correct location, according to the planned framework and professionally. It should be possible to do on the spot checks that require little documentation. An implementation plan, and a basic intervention description for every intervention unit, will, however, be needed.

Silvicultural monitoring - Silvicultural monitoring involves checking to what extent the status of the forest corresponds to the target profile. It serves as an important link to higher planning and monitoring levels. The level of protection provided can be monitored by comparing the actual state of the forest with the target profile.

4.3.5. Conclusions

The experiences in Switzerland show that sustainable and effective protection forest management is a joint task between forest owners, practitioners with local knowledge, communities, the cantons and the confederation. It is of high importance that all these partners have a common vision of what a protection forest is and how it should be managed. The definition of protection forest and the determination of relevant hazard process areas in forests in the framework of the project “SilvaProtect-CH” in close cooperation with relevant stakeholders was therefore an important step towards a nationwide protection forest strategy. The system of the guideline “Sustainability and success monitoring in protection forests” conveys current scientific knowledge about protective effects of forests in a form suitable for practical use. However, even with this proven concept, the success of the guidelines is only guaranteed if accepted and implemented on site by trained individuals with local knowledge.

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4.4 Effects of fog precipitation on environmental services in mountain catchments of Central Europe

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4.4.1. Introduction

Mountain watersheds in central Europe are mostly forested; therefore, the forestry practices are among the most important factors of their broad environmental benefits. FAO (2006) used the term ‘water towers’, expressing namely the important role of mountains in the freshwater supply. With rising civilisation pressures (including changes of the global climate, and declining environmental health), the call for stakeholder dialogues in mountain regions is increasing. Agnew and Goodess (2016) emphasize science-based dialogues as the basis for the environmentally sound management of mountain watersheds. Collaborative watershed management should be based on the detailed environmental studies, their validation, and social and environmental impact assessment (Reed 2008). Several examples of that approach were reported by FAO (2006), showing a progress in the participatory watershed management.

According to Millennium Ecosystem Assessment (2005), environmental benefits of mountain watersheds include water resources recharge (quantity and quality), recreation, timber, habitat, and beautiful scenery. In contrast to former sustainable timber production, the concept of multifunctional forestry (seeking the simultaneous production of several interdependent substances and services) is addressing forests as biophysical systems (Agnew and Goodess 2016).

The aim of this paper is to discuss the role of fog precipitation (not collected by the standard rain gauge monitoring networks) in environmental services of forested mountain catchments, with priority of the drinking water supply.

4.4.2. Environmental services in the Jizera Mountains (Czech Republic)

The Jizera Mountains region (350 square kilometres, altitude of 50°40' - 50°52', longitude of 15°08' - 15°24', humid temperate zone, Northern Bohemia, Figure 26) is a part of the “Black Triangle”, epicentre of the acid atmospheric deposition in Europe. The mean annual precipitation ranges there from 800 to 1,600 millimetres, and the mean annual air temperature from 4 to 8 degree Celsius (Tolasz et al. 2007). The snow cover usually lasts from the beginning of November to the end of April with an average maximum of 120 centimetres. The bedrock (granite) and shallow podsollic soils are extremely sensitive to acidification. The surface runoff is dominant, groundwater bodies occur only in shallow subsurface layers.

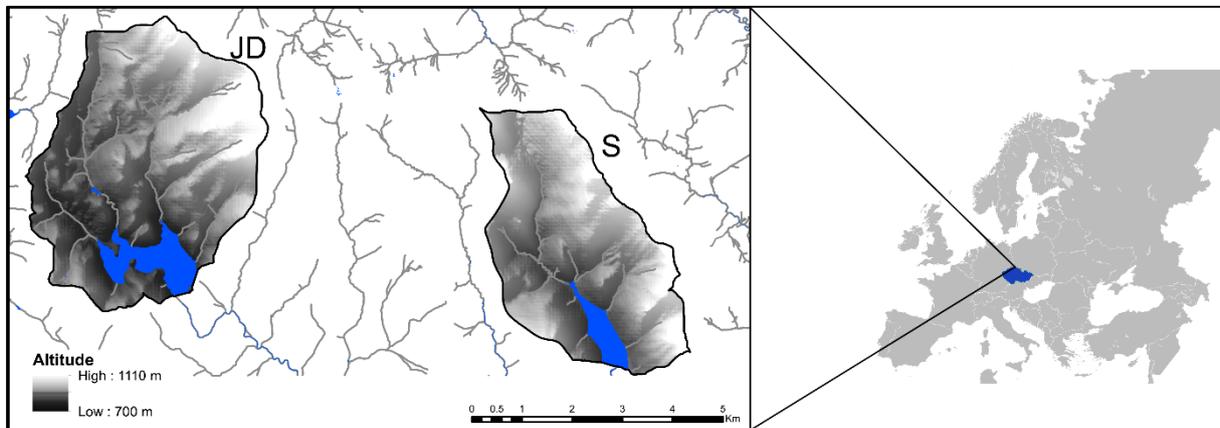


Figure 26. Drinking water supply catchments Josefův Důl (JD) and Souš (S) in the Jizera Mountains.

The area of about 200 square kilometres consists of the upper plain above the elevation of 800 metres, almost completely forested. In the past, native tree species in this region were beech (*Fagus sylvatica*), Norway spruce (*Picea abies*) and silver fir (*Abies alba*). However, significant timber harvest had occurred during the 19th century, and spruce plantations are dominant nowadays, covering 90% of mountain forests. Over time, priorities in land-use services have changed there with the development of the society; from early control of the state boarder, support of the game, sustainable timber harvest, downhill flood protection, to a recent accent on drinking water supply. In 1902-1909 (after the catastrophic flood of 1897), five retention reservoirs were constructed in the Jizera Mountains to protect the lowland cities and villages, and the still existing system of drinking water supply was introduced after the World War II.

To support the recharge of water resources (quantity and quality) by forestry practices in headwater catchments, *the Protected Headwater Area of the Jizera Mountains* was declared by the Czech government in 1978 (Křeček and Hořická 2006). However, an environmentally sound

forestry (including limits in clear-cut extends, and harvest technologies) was hampered by air pollution and acid atmospheric deposition. In the 1980s, spruce plantations were severely impacted, and significant forest dieback occurred mainly in the upper plain of the mountains. Consequently, intensive timber harvest with large clear-cut areas and heavy mechanisation occurred. Consequently, the run-off genesis and water quality in water courses and reservoirs declined; intensive soil erosion and sedimentation were consequences of rising network of skid-roads, and length of periodical stream channels. The restoration of catchment and lakes in the Jizera Mountains followed the *Sulphur Protocol in Europe* (Křeček and Hořická 2010): in the 1990s, the atmospheric deposition of sulphate decreased to approx. 40 %, compared with the year 1987. That time, the issue of environmentally oriented forestry became an option for a wider discussion (Chalupa and Křeček 1995).

4.4.3. Role of fog precipitation in water resource recharge

The effective fog water trapping by vegetation has been reported mainly in mountain cloud forests, where the fog drip can significantly increase water yield (Agnew and Goodess 2016). Hence, the conservation of high elevation forests is considered as an important tool in water supply supporting growing populations in the surrounding lowlands. This statement is opposing findings of many watershed studies indicating that water yield increases when forests are harvested (FAO 2006). This contradiction relates to the negative interception loss of high elevation cloud forests (Křeček and Palán 2015).

On the other hand, in regions affected by significant air pollution (emissions of sulphur and nitrogen), and acid atmospheric deposition, processes of trapping the fog water from the atmosphere could contribute to the decline of water quality (namely water quality degradation, chemistry and biota; Křeček and Hořická 2006). The range of pH values is one of the most important operational parameters of water quality; and, national guidelines for drinking water quality often suggest the optimum pH in the range between 6.5 and 8.5. However, the rising atmospheric deposition of sulphur and nitrogen registered in dense mature spruce stands of higher elevations result in a decreased pH of water, reducing contents of calcium and magnesium (water hardness), mobilisation of toxic aluminium in the water environment, and stressing/reducing the water biota (Křeček and Hořická 2006). In headwater catchments of the Jizera Mountains, in the late 1980s, water pH dropped to 4 – 5, and concentrations of aluminium increased to 1 - 2 mg per litre (the limit of aluminium in drinking water is 0.1 mg per litre).

Thus, the rising acidity of raw water has caused several additional investments in the water treatment plants (Křeček and Palán 2015).

4.4.4. Drinking water reservoirs of the Jizera Mountains affected by fog precipitation

In catchments of the drinking water reservoirs Josefův Důl (JD) and Souš (S) (see Figure 26), the long-term study on relationships between volumes of fog drip, elevation, and forest canopy density was integrated in the international field project of the Earthwatch Institute (Křeček and Hall 2008), which focused on the recovery of mountain watersheds and lakes from acidification (1991 – 2012). The observed fog precipitation in catchments JD and S was found significant namely in zones above 900 m a.s.l. (increasing the annual water yield by 88 – 106 mm, i.e., from 10 to 12%; Figure 27). Generally, the collected fog drip there varies from 7 to 8% of the gross precipitation, monitored by the standard rain gauge network.

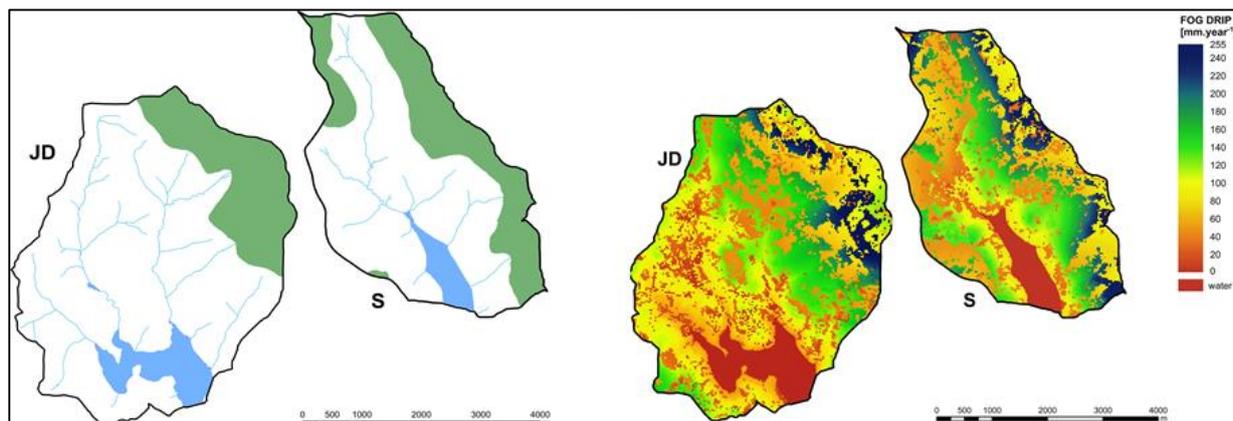


Figure 27. Zones of significant fog precipitation (left) and support of water yield (right) in drinking water supply catchments of JD and S.

On the other hand, fog precipitation contributed to higher amounts of acid atmospheric deposition in studied watersheds JD and S. recently (2010-2012), the mean annual load of sulphate and nitrate found in the fog drip was 1,975 and 1,080 kg per square kilometre, respectively. These amounts represent 55% of total sulphur and 48% of total nitrogen, registered in the bulk by standard methods. Annual pH values of fog precipitation, and the load of nitrogen, in focused catchments are shown in Figure 28. The atmospheric loads by rainfall and fog drip, in the elevation of 975 m a.s.l., are compared in Table 10.

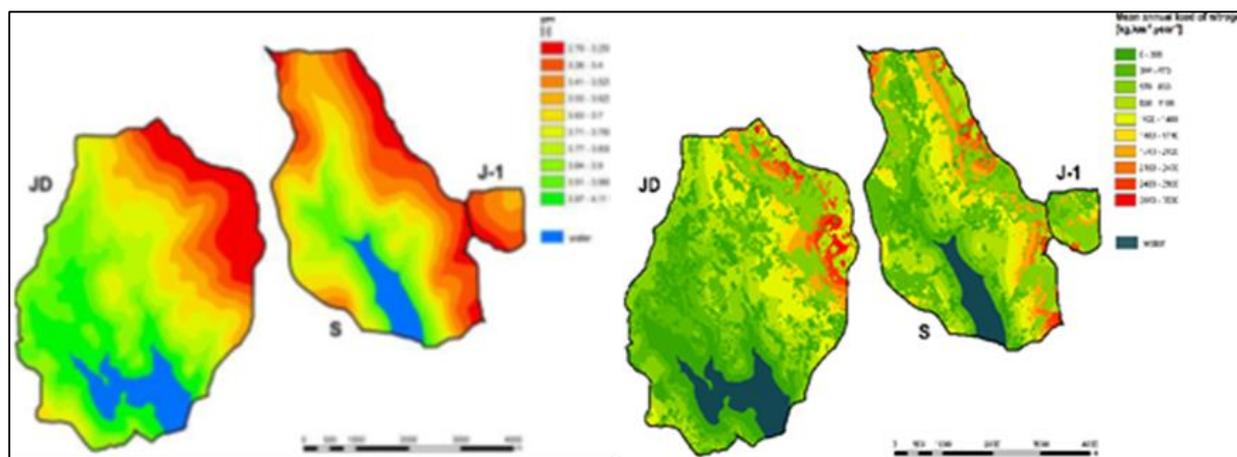


Figure 28. Annual pH values of fog water (left), and nitrogen load (right) by fog drip in drinking water supply catchments of JD and S, 2010-2012.

Table 10. Rainfall and fog drip contamination at the elevation of 975 m a.s.l..

Precipitation	Amount (mm)	pH (-)	S-SO ₄ (mg/l)	N-NO ₃ (mg/l)
Rainfall	683	4.8	5.8	2.6
Fog drip	120	3.8	20.3	7.5

The acidification of the water environment has increased operational costs of water treatment practices because of required additional investments in modification of water pH, contents of aluminium and heavy metals, and more frequent replacement of sand filters. Also, the last reconstruction of the Bedřichov water treatment plant (4.5 million EUR) relates to acid problems (Křeček and Palán 2015).

4.4.5. Environmental services in catchments of the drinking water supply

In 1995, the stakeholder dialogue on managing the catchments of drinking water reservoirs in the Jizera Mountains has started with the support of the EFC/FAO Working Party on the Management of Mountain Watersheds (Chalupa and Křeček 1995). The dialogue included core participants (project management team, local communities, and upper managers in water, forestry and landscape sectors), customers (business companies in drinking water supply, timber harvest, and tourism), controllers (regional environmental agencies), partners (academia, research and education, NGO's), and the public. The special target was to create multi-stakeholder partnerships with a perspective to inform policy and business practices.

Concerning environmental services in watersheds of drinking water reservoirs Josefův Důl and Souš (Figure 26), there is the priority to secure the required drinking water supply. Further specific partial targets are: sustainable water resource recharge, guarding the water quality (chemistry and biota), and control of runoff timing (extreme hydrological events, particularly). The hierarchy of these targets has been changing with the acid atmospheric deposition, and changes of the global climate. The threshold of the “acid rain” could be characterized by pH value of precipitation below 5.6 (Křeček and Hořická 2006). In conditions of acidified environment, the following order of environmental services has been recognized in i. reducing the acid atmospheric load (including minimization of the canopy fog drip), ii. control of runoff genesis and flood events (supporting infiltration and deeper circulation of water within catchments) and iii. water resource recharge.

However, with possible climate change impacts (expected in 2071-2100, Christensen and Christensen 2007) this order could alter to the absolute priority of water resource recharge (by supporting the additional fog drip, and control of evapotranspiration).

At the current situation (2010-2012), it is possible to decrease the deposition of sulphur and nitrogen in the zones with significant fog precipitation (Figure 27) up to 33% by reducing the canopy area of mature spruce plantations, or to 18% by their shift to the grass canopy.

4.4.6. Conclusions

The environmental monitoring in headwater catchments of the Jizera Mountains, identified fog precipitation as an important factor of the water budget in elevations above 900 m a.s.l.. In basins of the drinking water reservoirs Josefův Důl and Souš, the mean annual fog drip under the canopy was between 88 and 106 mm (i.e., from 7 to 8% of the gross precipitation, monitored by the standard rain gauge network). On the other hand, the mean annual load of sulphur and nitrogen by fog water presented 55 and 48% of the ‘open field’ deposition (collected in the bulk). Thus, the canopy fog drip can increase water yield, but, at the same time, reinforce the acid atmospheric deposition.

In municipal watersheds with the priority of drinking water supply, forestry practices should respect the level of acidification. In the environment of a significant acidification (pH of precipitation below 5.6), the priority is to reduce the additional acid load by the canopy fog drip. Therefore, the forest ecosystem services in the zone above 900 m a.s.l. should lead up to the reduction of the canopy area (particularly, in winter seasons of a relatively higher

atmospheric pollution). Generally, forestry practices there might support deciduous or mixed forest stands with lower canopy area.

Acknowledgements

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4.5 The environmental aspects of water management in mountain forests - Polish experiences

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4.5.1. Introduction

Mountain forests in Poland occur in the northern part of the Carpathians and the Sudeten, extending about 700 km along the southern border of the country. They occupy about 0,96 out of 9 million hectares of total forest area in Poland. The timber line reaches about 1650 m. a.s.l. and the mountains are diversified by climate, soil, vegetation and anthropogenic impacts. Mountain forests bear great natural assets and play an important role in shaping water resources. Compared to an average annual rainfall in Poland (600 mm), precipitation in the mountains reach 1500 mm (Pierzgalski et al. 2011).

Mountains forests are significant elements of the landscape. Because of the scenic landscape, natural wealth and other important features, the mountain areas have been subjected to different forms of protection over the time. It should also be noted that in Poland almost all of the mountains forests have the status of soil and water protective areas. The unique form of nature protection is Forest Promotion Complexes (LKP), designed to promote eco-friendly forest policy. The main objectives of LKP include the protection of biological diversity, use of the forest respectively to the natural, economic and social conditions, and dissemination of biological and ecological methods of forest protection. The legal basis for defining the principles of ecological forest management is included in several acts, *inter alia*: Nature Protection Act, Forests Act, National Forest Policy and the documents underlying the establishment of Natura 2000 areas.

Mountain forests are natural formations highly susceptible to disturbances that sometimes lead to the forest dieback on large areas (Lenart et al. 2003). Hydrological conditions are among the factors that initiate forest decline. Since the 1980s, the water conditions in the Polish forests

have been affected by an increase in air temperature and frequency of extreme hydrological phenomena (e.g., droughts and floods). Numerous projects aimed at improving the water circulation in mountain watersheds are undertaken in order to reduce these harmful effects. For example, a project entitled "Counteracting the effects of rainwater runoff in mountainous areas. Increasing retention and maintaining streams and associated infrastructure in good condition" was implemented in Poland during the 2006-2015 period. The general objectives of this project included: (i) increase of water retention capacity in watersheds, (ii) reduction of sheet, rill, gully and torrent erosion, and (iii) maintenance of torrents and connected infrastructure. The project was implemented by the State Forest and was coordinated by the Coordination Center for Environmental Projects (2010), which is the administrative unit of the State Forests. Within the project, about 3500 different measures and hydraulic devices were built including *inter alia* 130 reconstructed and new water reservoirs, liquidation of 53 km of skidding paths, and restoration of 173 km torrents. The total area of mountain forests covered by the program amounted to about 0.7 million hectares with over 8500 km of total length of the torrents. Because of its large range and undertaken solutions, the project was unique also in the international scale. In this and others projects the great attention has been paid to environmentally friendly solutions. The project "Restoration of the patency of the ecological corridor of the river valley of Biała Tarnowska" implemented in the years 2010-2014 is an example of such activity. The article presents the methods used to increase water retention capacity, reduce soil erosion as well as restoration of patency of the ecological corridor in the rivers.

4.5.2. Increasing the water retention capacity

Current and forecasted climate change indicate the need to take action to increase water resources in the forest habitats. Natural and technical methods can be used for this purpose. The application of the natural methods should be the priority. Effective natural treatments include:

- increasing forest cover, especially by afforestation in upper parts of the watershed,
- reconstruction of stands by the selection of tree species with lower water needs and higher interception,
- increasing the water retention capacity of litter and soils.

Deciduous trees mostly have higher water needs compared to the coniferous ones. An important feature of the forest, which can be shaped by the species selection, is interception. Interception of spruce can reach up to 30% of precipitation depending on the parameters of trees and

dynamics of the precipitation. In general, the interception of coniferous is greater than of deciduous trees (Osuch 1998). Improving the retention capacity of forest soils can be achieved by their respective preparation for afforestation, as well as avoiding the compaction. Increase in the water retention capability improves the forest ecosystem and reduces the risk of erosion. Increasing of water resources through technical methods is achieved by slowing the outflow of water in streams, and increasing the surface and ground water resources. Water reservoirs serve to increase the surface water resources. Such objective might be achieved by the restoration of the old reservoirs or by the construction of the new ones by installation of a dam in river bed (with or without fish paths). The criteria for the location of new ponds are rather simple: the existence of a water source, suitable terrain as well as low cost of construction and operation. It is necessary to recognize the natural surface conditions, in which the reservoir is designed, and to determine its impact on the surrounding forest ecosystem. Hydrological calculations showing the possibility of filling the pond should be the basis for determining the parameters of such reservoir. Depending on the size and terrain conditions, reservoirs can perform one or more tasks. The priorities of design and operation must be clearly defined. Larger reservoirs are built mainly for energy production, water supply and mitigating the flood waves. Smaller, mid-forest, ponds serve primarily the environmental function to improve water conditions in the forest ecosystem. They should have easy access to water for animals, intake water for fire protection, irrigation in the nursery, etc. It is also important to shape the pond similarly to nature and appropriately incorporate it into the environment. Most reservoirs in the mountains are sources of public water supply. This requires additional terms and conditions of protection, ensuring the water quality. From the ecological point of view, a large number of small ponds is a better solution than a small number of large reservoirs.

One of the important measures is restoration of mid-forest wetlands. It aims to increase the biodiversity and to mitigate the periodic excess or shortage of water around wetlands or even in the whole watershed, if the wetland is large enough. Precipitation on wetlands is captured almost entirely thanks to the flat shape and large surface roughness. Wetlands are also a system of water purification. The main factor of wetlands re-naturalization is water conditions. It is extremely important to initiate the desired succession of plants by determination of groundwater level ensuring adequate moistening of the topsoil. In a typical peat-muck, the water level should range from 20 to 55 cm below the ground surface. The most commonly used method of re-naturalisation of wetlands is to block draining ditches or to supply water in the case of deep groundwater level.

4.5.3. Mitigation of water erosion

Major problems in mountain areas are the sheet, rill and gully erosion as well as bed and bank erosion in torrents. Mountain forests play an important role in protection against erosion by reducing:

- the energy of rain falling on the soil surface;
- the amount of water flowing over the surface area (the interception of plants and water retention of litter);
- the speed of runoff (high surface roughness).

An important function of forests is also increasing the soil resistance to leaching due root systems. The most common methods of protection against erosion in mountain forests include:

- increase the water retention capacity in watershed;
- afforestation;
- anti-erosion measures on slopes;
- reduce the speed of water flow in streams.

The best results can be achieved through a comprehensive approach, which means that the anti-erosion projects should be one of the elements of the integrated water management in watershed that includes the application of natural and technical methods (Figure 29).



Figure 29. Device used to disperse the surface runoff in order to reduce erosion of the slopes.

Erosion processes in mountain forests are initiated mainly by anthropogenic activities. It is very important to minimize the forest management damages. It is necessary to afforest all sites with slope inclination over 15%, paying attention to appropriate selection of species. The skidding trails should be eliminated just at the end of their use.

Efficient drainage of water from the catchment area requires a proper state of mountain streams. Maintenance of the mountain streams is closely related to their hydrodynamic parameters and discharge magnitude. Maintenance of the ones exposed to flood waves needs a prediction of changes in the bottom of stream, which may occur after the passage of the wave. The aim of the projects undertaken in the streams is to achieve sustainability of their state, which means:

- stream remains in a state of dynamic equilibrium in which it is discharged down its course the same amount of sediment, which is supplied, and the bottom part is maintained in the long term at the same height;
- balance between of draining flood waves and their retention in floodplains;
- good ecological status of the stream and its role as the biological corridor.

Available local materials shall be used to stabilize the bank and bottom of the streams primarily. More common is the use of gabions. It is also important, as with the natural regulation of the rivers, to reduce to the possible minimum interference in the environment and to extend to the possible maximum the use of biological material. The purpose of dams is to retain debris during periods of thaw or heavy rains. It is now accepted that it is necessary to retain only the part of the debris that causes the greatest destruction of streams, roads and technical infrastructure. Since the solid concrete dams are relatively expensive, so in recent years, attempts are made to use cheaper solutions, for example mesh dams. They protect against the runoff of larger parts of trees, rocks, etc. down the streams.

4.5.4. Restoration of patency of the ecological corridor in the rivers

In many mountain streams there are hydraulic structures, whose task is to reduce channel erosion. These structures have a negative influence on the biological life in watercourses limiting or preventing the migration of fish and other organisms (Shields et al. 2003). Recently, many of such devices are being modernized to create ecological corridors in streams. The project "Restoration of patency of the ecological corridor of the river valley Biała Tarnowska" is one from many examples of such activities. The project was implemented in years 2010-2014 and included the investments for the continuity of the biological corridor and improving the

living conditions of organisms in rivers and floodplains. This was done in terms of valuable and endangered natural habitats - gravel and riparian vegetation, water zone characteristic species - fish and mussels, as well as shore zone species - amphibians. Within the project, the barriers to migration of aquatic organisms in Biała Tarnowska river were removed, as well as reintroduction of salmon and restoration of amphibian and mussel populations were fostered. The restoration of forest and scrub vegetation in floodplain was carried out as well as actions were undertaken to increase the public awareness on the issues connected with the project. The cumulative effect of the realization of these investments included: (i) the re-creation of an ecological corridor with a length of 41 km for 21 species of fish in the lower part of the river and (ii) reconstruction of 10 km section barrier-free for 11 species of migratory fish in the upper part of river, where previously numerous hydraulic constructions occurred (Figure 30).



Figure 30. Wooden steps reducing the slope of the torrent but not blocking the movement of aquatic organisms.

In order to remove the barriers against mobility of aquatic organisms, a lot of attention is paid to hydraulic structures (Bojarski et al. 2005). Dams are obligatory equipped with fish passes, while the pipe culverts are converted in arched ones, bridges or fords (Figure 31).



Figure 31. Wooden bridge more user friendly to aquatic organisms replacing concrete culvert.

It is also recommended to create water reservoirs outside the river bed if geomorphological conditions for such solutions allows.

4.5.5. Conclusions

Activities aiming at the improvement of water conditions in mountain forests should take into account the following principles:

- complexity (deliberate, rational and holistic treatment of surface- and groundwater resources),
- cohesion (“the principle of common interests”, which means cooperation of water users in order to obtain maximum social, economic and environmental benefits),
- precautionary (the use of such methods of water management that will not cause harmful effects in conditions of uncertain changes of environmental and economic factors).

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4.6 Control of suspended solids and nutrient load in Lake Pyhäjärvi catchment area in Finland

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4.6.1. Introduction

Boreal lakes are facing both large and small scale environmental challenges due to the climate change and changes in land use practices. Extended periods of non-frozen season during winter are causing both excess runoff and nutrient flow towards recipient waters, resulting in darkening of the water colour and eutrophication of lakes and rivers. Although the load from point sources has been taken into control in recent decades, there is still a lot to be done in non-point sources of eutrophication regarding Finnish inland waters. Most commonly used natural water treatment structures in both forestry and agriculture in Finland are constructed wetlands, overland flow fields, sedimentation basins and subsurface dams. One possible way to construct such structures are publicly funded sustainability projects, as implemented by Vapo Oy Clean Waters in The Lake Pyhäjärvi Project.

4.6.2. Sustainability project in Lake Pyhäjärvi

The Finnish Forest Centre funded the Lake Pyhäjärvi project and it included both planning of natural water treatment methods and calculations of load estimates in project area. The project area consisted mostly Western and Southern catchment areas of Lake Pyhäjärvi, almost 20000 hectares. In total, there were 33 different structures planned in 22 outlets of the project area. The main planning guideline was to place multiple structures in key point along the outlet. In this way, a space requirement for single water treatment structure remained reasonable.

Planning included negotiations with landowners and engineering of suitable water treatment structures in those outlets. Lake Pyhäjärvi in Eastern Finland as an ultraoligotrophic clear-water border lake is unique among Finnish lakes and is therefore included in many national

monitoring programmes; e.g., long-term changes in water quality, biological monitoring, and ecological monitoring of border lakes and rivers in Finland.

The 22 outlets entering Lake Pyhäjärvi vary greatly in size and catchment area. Land use in these catchment areas is predominantly agriculture and forestry with varying shares. A large percentage of forestry in Lake Pyhäjärvi catchment area is in ditched peatlands. Water treatment in those areas are especially important because there are potentially much more suspended solids in the runoff water. Vapo Clean Waters presented a detailed plan with cost-effective structures and methods for the protection of Lake Pyhäjärvi water quality also in the future.

4.6.3. The present state of Lake Pyhäjärvi

Forestry and agriculture are the main land use practices around the Lake Pyhäjärvi. In addition to loading from scattered settlement, few point load sources (e.g., municipal waste water treatment facility) were also recognised surrounding the lake. For background information, long-term (30-40 years) data representing the possible changes in quality of the lake water were available provided by the Finnish Environment Institute.

When considering the changes and trends in lake water quality of a large lake, spatial and temporal variation in quality parameters must be taken into account. The concentration of dissolved oxygen (DO) is one of the most important parameters in water quality, describing effectively the physical, chemical and biological conditions within the lake. Dissolved phosphorus content (total phosphorus, total P) is most often the growth limiting factor in Finnish inland waters, determining the trophic state of the lake or river. These two parameters were selected to assess the current state of the Lake Pyhäjärvi water quality. According to the results, there was no clear deterioration in the lake water quality in two of the monitoring sites, the first situated in northern and the second in the southern part of the lake. Nevertheless, there was a slight decreasing trend in the oxygen concentration of the near-bottom water layers. In addition, the water quality in bays and other areas sheltered from wind can vary from the state observed in the centre of a large lake.

4.6.4. Lake Pyhäjärvi load estimations

We assessed the reduction of the nutrient and suspended solids load towards Lake Pyhäjärvi if the proposed water protection structures would be built with load reduction percentages

presented in recent literature. To estimate the load, we needed information on the discharge in the direct sub-catchment areas of the Lake Pyhäjärvi. Therefore, we monitored the discharge by continuous measurements in two small streams in the direct catchment area of the lake. In the Stream Koivikonoja we used the conventional discharge monitoring method based on the Thompson weir and pressure measurement logger provided by Nablabs Ltd. In the Stream Kuoreoja an ultrasound discharge meter provided by Luode Consulting Ltd was operated, due to the small amount of running water in the open channel and relatively small catchment area of the stream. Discharge estimations for the rest of the sites studied were based on comparing the discharge to area -relation in subcatchment areas similar in size and land use to the measured sub-catchment areas.

We also monitored the quality of water in these two discharge measurement sites and in a large stream, the River Harkonjoki by water samples taken monthly during the study year (Figure 32). The sampling and determination of suspended solids, total nitrogen and total phosphorus, nitrate, phosphate as well as dissolved organic carbon and water colour were performed by Nablabs Ltd. The measurements and subsequent calculations of suspended solid and nutrient load were performed in the sub-catchment areas of the direct catchment area of Lake Pyhäjärvi and the River Harkonjoki, and therefore cover the total load entering the lake only partially. Modelled estimations of the total load of the suspended solids and nutrients were provided by the Finnish Environmental Institute with the WSFS-VEMALA- hydrological and water quality model.

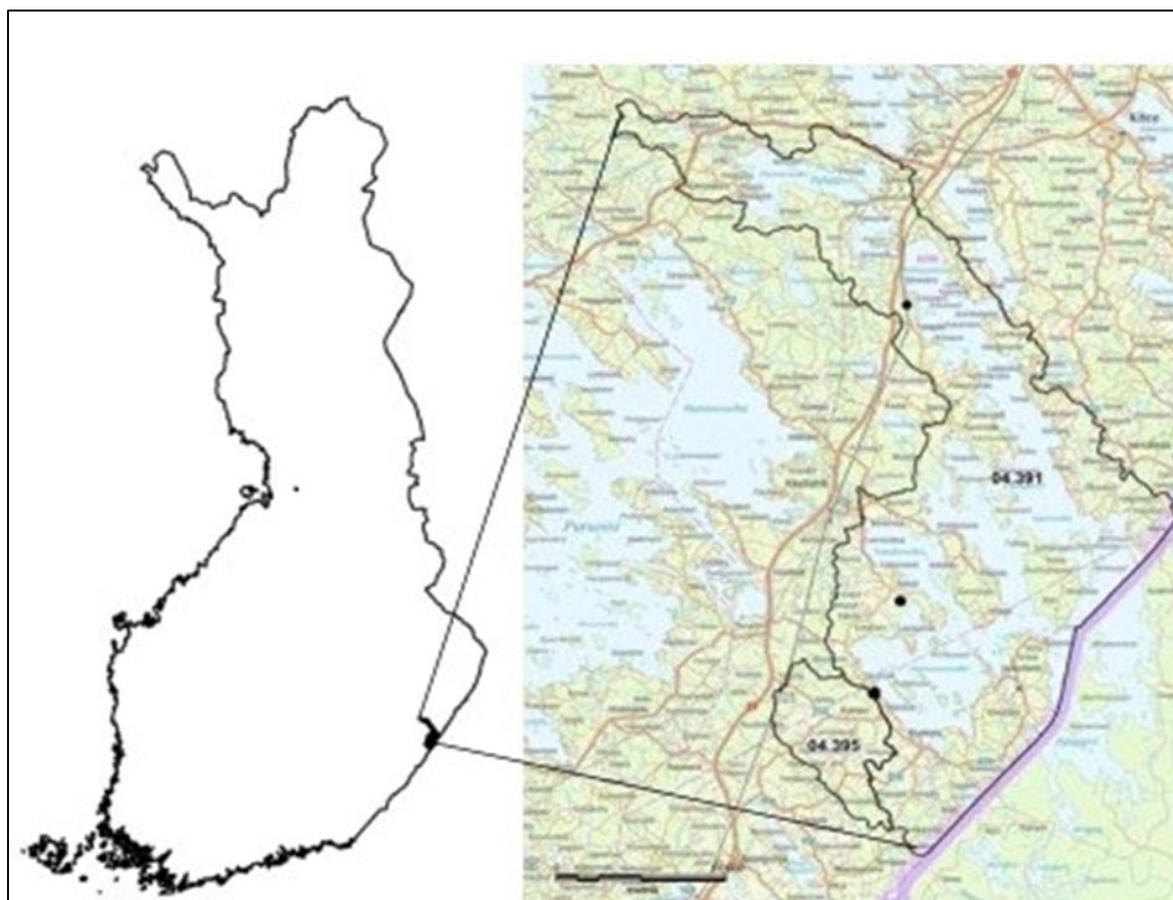


Figure 32. Map of Finland (left) and the monitoring locations (right) in the sub-catchment areas of Lake Pyhäjärvi (04.391, uppermost dot: the Stream Kuoreoja; middle dot: the Stream Koivikonoja) and in the catchment area of the River Harkonjoki (04.395, lowermost dot). Source: Environment 2010, ©Karttakeskus 2014.

According to WSFS-VEMALA model results (Finnish Environment Institute), the average annual load of suspended solids from the direct catchment area of Lake Pyhäjärvi was 140 t/a, total P-load 1.3 t/a and total N-load 56 t/a during the period 2000-2013. During the same period, the average annual load of suspended solids from the catchment area of the River Harkonjoki was 220 t/a while the total P-load was 1 t/a and total N-load was 14 t/a. The calculated average annual load of suspended solids from the sub-catchment area of Lake Pyhäjärvi in question in our study was 38 t/a, total P-load was 0.3 t/a and N-load 9.3 t/a (Table 11). In the sub-catchment of the River Harkonjoki, the average annual load of suspended solids, total P- and total N-load was 26.7, 0.2 and 5.9 t/a, respectively. In the River Harkonjoki case, we assumed that the water protection structures into the riverbeds entering the river are to be built successively. In such a way, we do not overestimate the load reductions achieved by the structures.

4.6.5. Estimated reductions in load

Natural water protection structures commonly applied in non-point sources of forestry and agricultural nutrient-rich runoff in Finland are different types of dams, settling ponds and constructed wetlands. Dams slow down the current velocity in order to allow particles to settle and control the flow during flood periods. Settling ponds operate in the same way on a larger scale. Constructed and natural wetlands also level out maximum flows and allow particles to settle during flood periods, but in addition also remove nutrients from the runoff by vegetation and microbial activity.

As the reduction of the load of suspended solids and N-load by dams or weirs was not reported in recent literature, we assumed it similar to the one achieved by settling ponds, 18 and 3%, respectively. Hjerppe (2013) reported the reduction in P-load with dam structures to be approximately 30% and with a wetland construct 20%. Puustinen et al. (2007) studied the agricultural load reductions achieved by settling ponds, and reported 18, 6, and 3% reduction to the suspended solids, total P and total N loads, respectively. They also reported the load reduction achieved by a wetland construct in the case of suspended solids to be approximately 37% and with total N to be 16%.

The estimated reductions of suspended solids, total P and total N are presented in Table 11. Total of 33 water protection structures or structures were proposed to be built in the direct catchment area of Lake Pyhäjärvi (Scenario 1). Detailed constructions were designed for 22 sites that located in estates or properties which the land owners allowed the structure to be built (Scenario 2).

Table 11. The estimated loads of suspended solids and nutrients entering Lake Pyhäjärvi from its direct catchment area and via the River Harkonjoki sub-catchment area included in the case study. SS, P and N are the annual average load of suspended solids, total P and total N, respectively. SS, P and N reduction (%) denotes the load reductions achieved if Scenario 1 (all the planned cost-effective structures were to be built) or Scenario 2 (structures with allowance from the land owners were to be built) would take place.

Location and scenario	SS (t/a)	P (t/a)	N (t/a)	SS reduction (%)	P reduction (%)	N reduction (%)
Lake Pyhäjärvi						
Present state	37.9	0.29	9.3			
Scenario 1	25.0	0.24	7.8	34	19	16
Scenario 2	29.1	0.26	8.3	23	14	10
River Harkonjoki						
Present state	26.7	0.22	5.9			
Scenario 1	2.3	0.07	3.7	91	97	38
Scenario 2	7.1	0.20	3.9	73	91	34

4.6.6. Conclusions

According to our study, marked reduction in both suspended solids and P load (> 90%) could be achieved especially in the River Harkonjoki subcatchment. With N load the reduction remained smaller (approximately 40%). In the direct catchment area of Lake Pyhäjärvi, the achievable reduction in suspended solids, P- and N-load was 34, 19 and 16%, respectively. Not all the structures were accepted by the land owners; therefore, according to the current situation the reductions remain slightly smaller.

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4.7 Balancing security demand of flood hazard in Alpine forest ecosystems: the current approach in Trentino, Italy

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4.7.1. Overview of the Trentino region and key ecosystem services

Trentino is an Alpine region in north-eastern Italy that extends over 6212 km² (Figure 33). Mountains are spread all over the region, creating a mosaic of valleys enclosed by mountain chains. Altitude varies greatly, ranging from 62 to 3769 m above the sea level (the highest peak is Cevedale), with about 30% of the territory under 1000 m a.s.l., about 50% between 1000 and 2000 m a.s.l. and about 20% over 2000 m a.s.l.. Areas over 2000 m a.s.l. are essentially covered by glaciers, bare rocks, natural grasslands and pastures. Forests cover about 56% of the Trentino total area, up to approximately 1800 m a.s.l.. The region is divided in 9 watersheds with area 20 ÷ 35 km², 68 watersheds with area 10 ÷ 20 km² and 17194 watersheds with areas < 10 km². The major tributaries follow east-west or west-east directions towards the major river, i.e., the Adige river. Total length of water courses is 5670 km (3338 water courses are identified). More than 300 lakes are found, including the northern part of Garda Lake, the largest lake of Italy. The total area of the water surfaces (lakes, glaciers and riparian lands) is 192 km². Agricultural areas cover 5.8% of the whole region, while artificial surfaces (i.e., urban settlements and roads) cover 3.1% of the region. Urban settlements are located mostly along the Adige river axis and host about 536,250 people (year 2013). For each valley, there is a major urban settlement but several small villages and scattered houses are found across the entire region.



Figure 33. Localization of Trentino Alpine region (Italy).

Such variety of territory ensures the provision of a relevant number of goods and services for the local population (i.e., ecosystem services). According to the knowledge and know-how of experts belonging to local administrative offices and research institutes located in the Trentino region, 24 ecosystem services are considered to be important for the local population nowadays (second column of

Table 12).

Table 12. 24 ecosystem services (ES type, 2nd column) are grouped in three themes (1st column) according to MA classification (MA 2005). 14 ecosystem services (out of 24) are found in forests ecosystems (brown cells) and 6 in water ecosystems (blue cells).

ES theme	ES type	Description of ES type
Provisioning	Agriculture production	It is the ability of any cultivated land to provide vegetable food for people and animals.
	Hunting production	It is the availability of animals for hunting in game reserves (agricultural and forest areas).
	Fishing production	It is the availability of fish in water network, both in rivers and lakes.
	Mushroom production	Forest ecosystems provide suitable conditions for the production of mushroom.
	Honey production	Forest and grass ecosystems provide suitable conditions for the production of nectar and honey.
	Timber production	It is a biomass product of forests for building or other uses. In Trentino, the most renowned timber is that of Valle di Fiemme (in the North-East of the region), whose wood is used to make violins.
	Fuel wood production	It is a biomass product of forests for energy production. In Trentino fuel wood is mostly supplied for domestic use.
	Water supply from surface water network	Water for drinking, irrigation and industrial uses is withdrawn by the surface water network. In Trentino water is withdrawn from 2803 points over rivers, lakes and reservoirs.
	Water supply from groundwater	Aquifers also provide water for drinking, irrigation and industrial uses. Water is withdrawn in 10617 points (springs or wells).
Regulating	Water quality regulation	It is the capacity of permeable riverbeds and riparian areas to regulate the chemical elements in water, by filtering and absorbing incoming pollutants from agricultural activities.

	Water flow regulation	It is the capacity to accumulate water and to regulate the hydrological flows for normal weather conditions. Water is accumulated mostly in lakes/reservoirs, in glaciers and in aquifers.
	Air quality regulation	It is the capacity to regulate the concentration in the air of the pollutants affecting human health and the quality of urban life. In Alpine regions, the presence of mountains and valleys influences local circulations, sensibly reducing the pollutants' transport range. Moreover, the presence of forests may help the deposition of such pollutants. At local scale, the presence of buildings, trees or other obstacles close to the roads may prevent the dispersion of pollutants emitted by the cars.
	Micro-Climature regulation	Forests actively contribute to mitigating microclimate conditions, in terms of temperature and humidity. The shadow and transpirations attitudes depend on the forests shape and the density of trees.
	Macro-Climature regulation	The extraction and the stock of the carbon dioxide from the atmosphere are essentially performed by forest and agriculture ecosystems.
	Hazards protection capacity	Forest vegetation covers an important role in the stabilization of the terrain during floods, debris flows, landslides and avalanches. Forests are also important for the protection of building and infrastructures from falling rocks, by mechanical action.
	Flood prevention capacity	It is the capacity of the territory to prevent negative consequences for human life and buildings coming from natural events like floods, debris flows, landslides and avalanches.
Cultural	Cultural heritage	Ecosystems may create the conditions for the visit of cultural heritage sites.
	Scenic beauty	Ecosystems may create landscapes of particular beauty, inspiring spiritual, aesthetic values and historic memory.
	Hunting	It represents the possibility of hunting animals in game reserves (agricultural and forest areas).
	Fishing	It represents the possibility of fishing in the water network, both in rivers and lakes.
	Mushroom collection	It represents the possibility of collecting mushrooms in forests.
	Honey collection	It represents the possibility of collecting honey in forests, pasture and scrublands.
	Outdoor recreation	Trentino environment offers several opportunities to practice outdoor activities, like walking, cycling, climbing, skiing, rafting, windsurfing and sailing.
	Leisure	Lakes provide opportunities to spend free time and to relax both in the valleys bottom and in the highest mountain peaks.

They are likely to represent typical ecosystem services of Alpine regions and semi-urbanized mountain areas with large forests. In fact, selected ecosystem services are partly recognizable in published lists (e.g., water quality regulation of water courses), while some of them have been specifically defined for the case study of Trentino (e.g., water storage capacity of local glaciers). Balancing the provisioning, regulating and cultural services (9, 7 and 8 ecosystem services, respectively) ensures the satisfaction of a wide range of human well-being needs: provisioning services are products obtained from ecosystems, regulating services are benefits obtained from the regulation of ecosystem processes and cultural services benefits obtained

from non-material activities (MEA 2005). Within forest ecosystems, 14 ecosystem services (out of 24) are considered to be important and those provided by forests in head watersheds range mainly from regulating and cultural services (Ferrari 2014).

According to Raudsepp-Hearne et al. (2010), the provision of regulating services is enhanced simultaneously like carbon sequestration and forest protection factor, but are in conflict with e.g., provisioning and cultural services. In fact, the provision of urbanized areas/fuel wood/ski slopes is enhanced at the cost of reducing the provision of carbon sequestration and of reducing the protection factor of forests.

Governments and administration are asked for balancing the different demands on services, where trade-offs might occur. In the case of Trentino, balancing these demands is the obligation of the local government (the Autonomous Province of Trento, PAT), which has the proper legislative, executive and financial competences. According to the provincial forest law (L.P. 11/2007), three offices are in charge of maintaining the balance: 1) the “*Servizio sviluppo sostenibile e aree protette*” that aims at ensuring habitat and forest species conservation, in order to guarantee the sustainability of natural ecosystems; 2) the “*Servizio foreste e fauna*”, that aims at improving the quality of natural ecosystems in order to improve opportunities for local population; 3) the “*Servizio bacini montani*”, which ensures watershed stability from floods and debris flows, in order to guarantee a safe and secure territory for inhabitants and their activities.

Considering that flood risk and related damages are very high in Alpine regions (Lugeri et al. 2013), guaranteeing a safe and secure territory is a priority for PAT. Actually, PAT has established a flood management strategy, able to balance security demand and other services provided by forests.

4.7.2. The flood management strategy

In its territory, PAT is responsible for planning and programming the flood management strategy. According to the European Flood Directive (60/2007/EC), the strategy is included in the Flood Risk Management Plan (FRMP) of PAT. The plan has been approved in December 2015 and it is part of the FRMP of the river basin district of the Eastern Alps. The strategy is based on the analysis of basin hazard and risk (see Figure 34) and addresses all aspects of flood risk management, focusing on prevention, protection and preparedness measures.

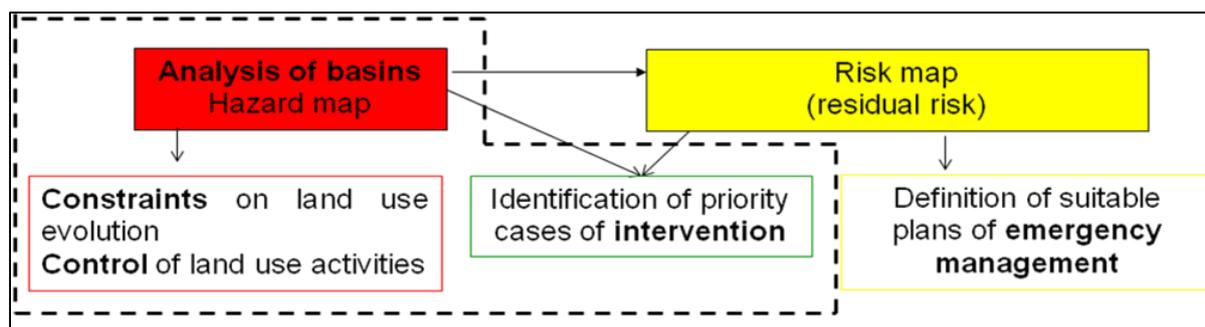


Figure 34. Flow chart of the flood adaptation strategy of PAT (boxes with red, green and orange borders represent respectively prevention, protection and preparedness activities of FRMP).

Prevention measures aim at minimizing/avoiding the presence of inhabitants and related activities in areas of risk/hazard. Prevention is carried out through a proper territorial planning: land use activities are controlled and constraints on land use evolution are defined, according to the level of hazard of transformable areas. In order to reduce the vulnerability of existing buildings in areas on risk, building codes are applied.

Protection measures aim at improving the security of the territory through a proper territorial territory management: priority cases of intervention are identified in natural and urbanized contexts, according to their level of hazard, and defence constructions (e.g. dams, flood levies and floodwalls) are built. Proper measures of forest management are set, in order to maintain the natural protection factor of forests. The Service for torrent control of PAT is in charge of the prevention and protection measures.

Preparation measures aim at increasing the awareness of people, in order to facilitate operations during rescue operations. According to the level of risk in urban areas, proper emergency management plans are set. The main activities endorse public awareness programmes, forecasting, warning and evacuation systems. The Civil Protection of PAT is in charge of Preparedness.

Three measures especially affect the balance with other ecosystem services provided by forests: territorial planning, forest management and defence constructions. Territorial planning is a non-structural measure, together with forest management. Defence constructions are structural measures of the territory.

4.7.3. Non-structural measures – Territorial planning

Territorial planning regulates land use changes for safeguarding the territory from flooding and saving resources (also monetary ones). Actually, changes in land cover can influence the

occurrence and frequency of floods by changing the responsiveness of river flows to rainfall. Jongman et al. (2014) suggested that changes in land cover for socio-economic growth (increasing built areas) can affect the costs of floods more than climate change.

PAT has been considering flood hazard in planning and managing its territory since 1987, when the first hazard map was published and included in the provincial territorial plan. It was a synthesis map of all hydrological hazard of the territory (i.e., floods, debris flows, avalanches and landslides), obtained by photographic interpretation. In 2003, first legal regulations were introduced in territorial planning (levels of hazard were used to limit land use planning) and a new hydrogeological hazard map was drawn. Since 2006, the hydrogeological risk map is used to define constraints on land use evolution and to control land use activities. The provincial water management plan has been established and is still into force. In 2008, new rules have been set up within the new territorial plan: hydrological hazard must be used to define constraints on land use evolution and to control land use activities (for a complete historical perspective see Figure 35).

1987: Territorial plan (PUP) - "Sintesi geologica" map First map of the synthesis of hydrogeological hazards	PASSED
2003: Territorial plan (PUP) - "Sintesi geologica" map The hydrogeological hazard affects the territorial planning by legal regulations 2006: Water management plan (PGUAP) – hazard and risk maps Use of the hydrogeological hazard map to create the risk map Definition of constraints on the land use evolution and control of land use activities Rules for new hazard mapping Analysis of floods, debris flows, avalanches, rock failure and landslides	CURRENTLY ENFORCED
2008: New territorial plan (PUP) – New hydrogeological hazard map Definition of constraints on land use evolution and control of land use activities 2011: Law on the civil protection activities Use of the new hydrogeological hazard map to create the risk map Planning structural measures Definition of civil protection and of emergencies management plans	WORK IN PROGRESS

Figure 35. Historical perspective of territorial planning.

At present, land use evolution planned according to the level of hazard, while different land use activities are controlled according to the level of risk. According to the EU Floods Directive (Directive 2007/60/EC), new maps of hazard are going to be drawn for most threatened areas of PAT (see Figure 36): they define 3 levels of hazard (high, medium and low) on the basis of the intensity and the likelihood of flood and debris flow events with a likely return period between 30 to 200 years, and a residual hazard for likely return periods up to 200 years.

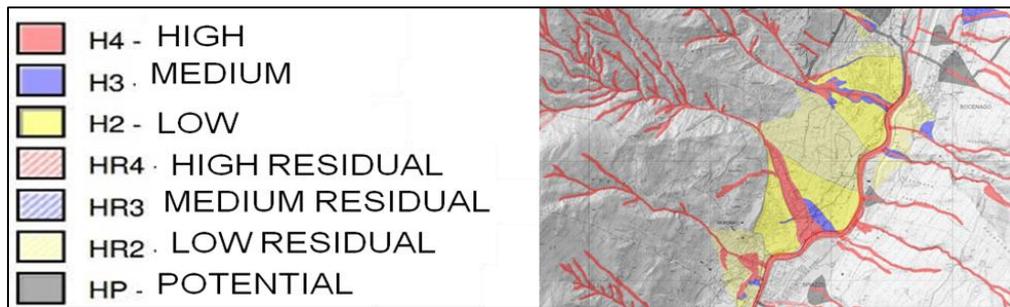


Figure 36. New map of hazard. On the basis of the intensity and the likelihood of flood and debris flow events, it is organized in: levels of hazard (H) with a likely return period between 30 to 200 years, levels of residual hazard (HR) for likely return periods up to 200 years and potential hazard (HP).

4.7.4. Non-structural measures – forest management

According to Solin et al. (2011), the forest management appears to be a stronger non-structural measure than territorial planning. Solin et al. (2011) demonstrated that the activities of forest management, such as road /ditch construction and other activities that may reduce rainfall infiltration, play a larger role in contributing to flood protection than whether the land is forested or deforested.

Trentino forests cover more than 56% of the total area and 75% of them are public. In order to guarantee the stabilization of the terrain during flooding (and debris flow, landslides and avalanches), the provision of forest material (essentially timber and fuel wood) through the years, and the maximum income of felling, PAT has defined management plans in each public property and also in some large private properties. Within plans, the growing stock and the increment of wood are monitored, in order to estimate the amount that can be cut per year while ensuring sustainability. Plans are revised every 10 years.

4.7.5. Structural measures – defence constructions

Across the region, hazard and risk maps are used to identify priority cases of intervention (typically alluvial fan) and to plan defence constructions. In Trentino, there are 2428 alluvial fans, which may be on hazard during debris flow events. 483 (out of 2428) are on risk, because they lie on urban areas (a fan is considered at risk if at least 100 km² of its area are urbanized). In the last 30 years, the Service for torrent control of PAT constructed 286 check-dams over 384 alluvial fans (out of 483). Anyway, carrying out structural measures is an endless work.

Actually, despite the presence of a huge number of defence constructions and extended forested areas in Trentino, 1609 floods and debris flows (together with 6527 landslides and 644 avalanches) occurred from 1965 to 2005. In order to minimize the occurrence of such events, every year new defence constructions are built by the Service for torrent control (for instance in 2014, the Service carried on 130 ordinary sites and 156 maintenance works). The Service has a wide technical autonomy on land use planning and managing: about 50 technicians are employed to plan and control the human activities that are close to water courses and 200 workers are employed to build defence constructions on threat territory (operatively, the territory is divided in four areas and about 50 workers are employed for each one; see Figure 37).

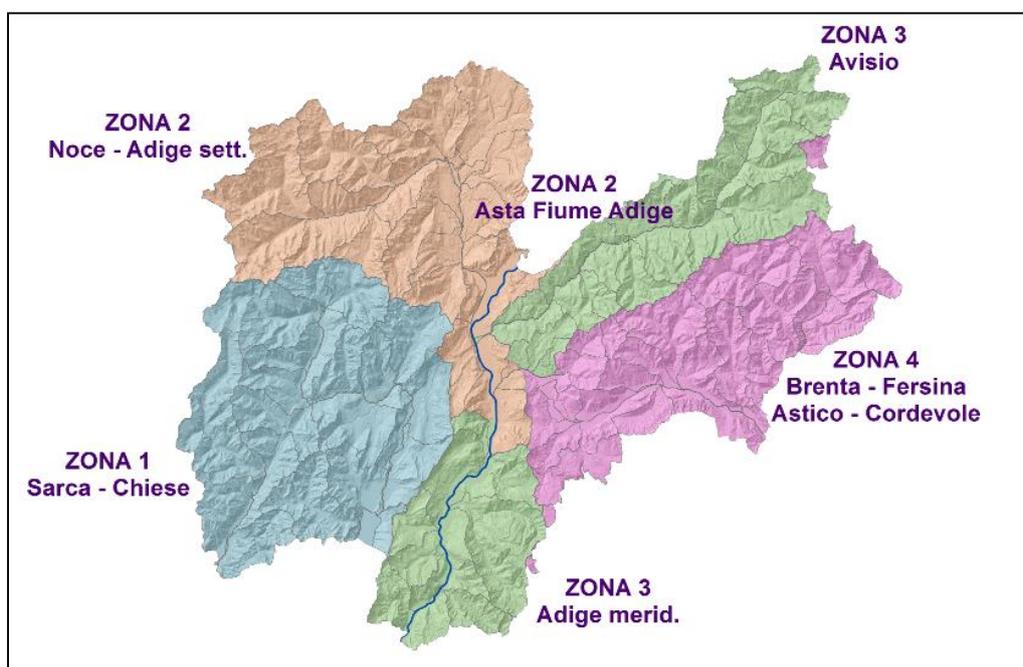


Figure 37. Areas of interventions of the Service of torrent control.

In accordance with the European Water Framework Directive (2000/60/EC), morphological restoration is carried out to substitute obsolete constructions (Figure 38) and bioengineering techniques are adopted to build new. The Directive calls for a low impact regulation of water courses, in order to ensure the capacity of riparian areas and bed rivers to regulate water quality. Restoration and bioengineering aim at improving the resilience of the river systems and providing sustainable and multifunctional use of the ecosystems (e.g., recreational and touristic activities).



Figure 38. Example of morphological restoration.

4.7.6. Main evidences

The flood management strategy of PAT allows planning, controlling and protecting activities to be carried on, while integrating other ecosystem services, like water quality regulation, recreation and tourism. In particular, the objectives of the Directive 2000/60/EC are matched with the Directive 2007/60/EC. The objectives are i. the protection of the water ecosystems and connected watersheds, ii. the achievement of a good status of water quality and mitigation of flood effects, iii. the maintenance of cultural heritage and iv. the promotion of the economic growth, while reducing risks from flooding.

Territorial planning is considered a key non-structural measure of PAT strategy, because of the positive synergies that may derive from including territorial planning and water management. Synergies are focusing on the long term, integrating projects with other sustainability measures and encouraging stakeholder participation (as suggested by Swart et al. 2014). According to Solin et al. (2011), the management of forests is also a key non-structural measure.

At present, the flood management strategy of PAT has allocated most of resources (both economic and human) for the realization of structural measures. PAT is aware that additional measures against flooding will be necessary in the next future. As recommended by the Flood directive, they will be non-structural measures, like communication about the present and residual risk of flooding (due to morphological conditions and functionality of defence constructions) and about the potential adverse consequences to human life, their activities and ecosystem services.

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4.8 Forest cover changes and moisture content in the upper basin of Jiu River, Romania

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4.8.1. Introduction

Forests play a crucial role in preserving moisture and act as a very important water reservoir for generating or, on the contrary, inhibiting specific hydrological processes. Although numerous studies have addressed the impact of forest cover on groundwater, precipitation, runoff, snow and humidity retention on the topographic surface (Tucker 1980, Biron 1994), not all aspects connecting the type, location and dynamics of forests with the issue of water availability in bare or vegetation-covered soil (but also other land cover categories) have been dealt with yet. Bibliographic and practical reports realized by Humbert and Najjar (1992) demonstrate the multiple implications of forest canopy in water cycle modeling and moisture content exchanges.

It is largely believed that forest cover type (transition shrubs, broad-leaved forests, mixed or coniferous forests etc.) and location (on the slopes, in the headwaters or in the alluvial plain) substantially influence moisture content availability and hydrological processes (Tucker 1980). However, simply mentioning its contribution to the water balance will not suffice if we do not quantify this relationship (Bargués Tobella et al. 2014). Spatial variation of moisture content in vegetation, known in the field of hydrological cycle theories as storage by interception, is obviously not constant in time (it varies seasonally) and space (it depends on the topographical and vegetation characteristics). These conceptual presumptions lead to crucial questions: Do forests dampen hydrological processes, such as runoff? What is the maximum amount of humidity each type of vegetation canopy can hold without turning it from storage to flux (subsurface, overland flow, or runoff)? Can we establish a unique relationship between the type of vegetation, particularly forest variety, and moisture content? In the attempts to answer all

these questions, consistent research has been made in order to clarify and determine the contribution of vegetation in the onset, slowing down and speeding up of hydrological processes (FAO 2013, Bargués Tobella et al. 2014).

Previous research on the interaction between forest canopy and water resources has indicated that the top layer of trees or its absence, is the first and perhaps most important interface between rain drops and further water-related processes (evaporation, transpiration, leaf absorption, different types of flow). According to Humbert and Najjar (1992), the incident rain that reaches the forest canopy may be involved in three distinct processes: interception, dripping rain and stemflow. The last two are further involved in the generation of throughfall, composed of subsurface and surface runoff. While conceptually compelling, the role of forests in shaping the water content above ground which can be trained in river discharge or by hydro-geomorphological processes requires more extensive investigations and is far from being fully revealed (Biron 1994). Although it is very problematic to quantify the direct link between forest dynamics or its composition and actual runoff, a good direction of research would be to stop in the middle of this path and study the moisture content of the forest (Gao 1996, Bargués Tobella et al. 2014). Further, there are various techniques for assessing the spatial link between forest and water resources, more precisely, the water content found in vegetation acting as an interface between rain and hydrological processes. In this context, we can mention forested watershed scale experiments, which are based on field measurements, although, but also on remote sensing approaches, due to their greater ability to integrate a wider area and reveal different phenomena and situations through numerous combinations of spectral bands (Mihai et al. 2014).

Hence, the present paper explores the relationship between land use and land cover categories (particularly the forested or previously forested areas) and their water contents in the upper basin of Jiu River. The study area is located in the south-western part of Romania, forming the upper sector of Jiu River, a first order tributary of Danube River. From an administrative point of view, the hydrographic study area occupies the northern part of Mehedinți and Gorj counties and the south-eastern part of Hunedoara county (Figure 39), while from a geological side, it forms what in Romania is known as “the mountain watershed of Jiu River”, with an altitudinal range from 500 to over 2.500 m a.s.l..

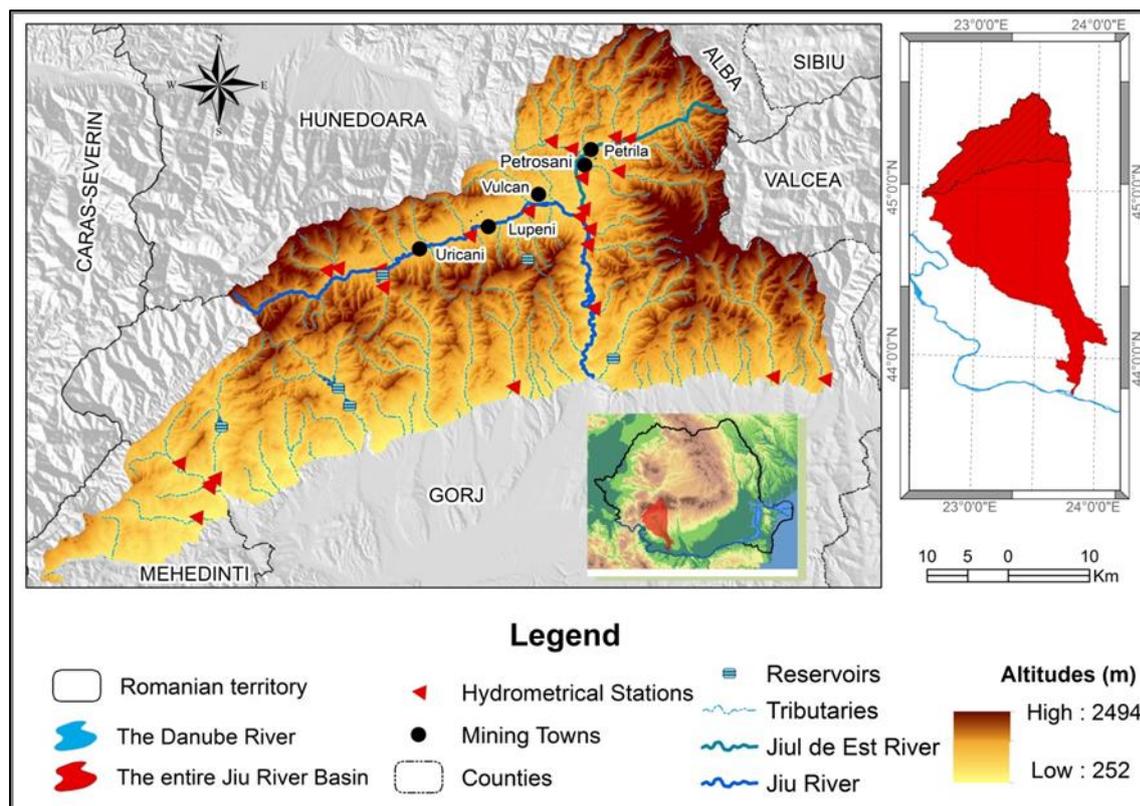


Figure 39. Location of the upper basin of Jiu River in the geographical Romanian context.

The first objective of the present paper is to review the changes in forest cover that have occurred between 1990 and 2012, by querying the Corine Land Cover database. Secondly, another more practical objective is to aggregate information from previous years with data obtained by processing some more recent satellite images from August 2015, in order to see if we can associate various types of forests with different thresholds for the volume of water they can store, using the NDWI index.

The idea of analysing this relationship appeared after a preliminary study on the changes in land use and land cover that had taken place between 1990 and 2012, by employing the Corine Land Cover database and consulting Romanian literature in the topic (Petrişor 2012, Popovici et al. 2013, Dumitraşcu et al. 2014). In this preliminary study, accompanied by a simple statistical analysis of the losses and gains suffered by the forested area, it was possible to observe the location where changes had occurred during the three periods and also the possible consequences of losses or gains experienced by each land use/cover category in terms of humidity and water content.

4.8.2. Data and methods

Built on the scientific matter set forth in the introduction, we envisage investigating the relationship between land use and land cover categories and the content of water stored. Therefore, our study commences from the idea that each type of land use and land cover has a specific interval of values that reflect the amount of water available and stored by vegetation or soil.

Regarding the technical steps for collecting and processing the data, our research comprises two main parts. The first one is dedicated to mapping and using descriptive statistics on the changes suffered by land use and land cover in the Jiu River's upper basin. The second part involves analysing the relationship between various vegetation types of land cover and their water content, through the use of the Normalized Difference Water Index (NDWI).

1. In the Preliminary Research, we used three sets of data from the Corine Land Cover database, a topographic map (with a scale of 1:25,000), aerial mappings from the QGIS plug-in and a series of vector data including geographic elements situated in the upper basin of the Jiu River (polygons of relief units, lines representing the hydrographic network).
 - a)* The first step involved the creation of the Corine Land Cover data base, which can be found on the Copernicus Program website.
 - b)* Vector data sets for the reference years 1990, 2000, 2006 and 2012 were cut according to the upper basin of the Jiu River, but not before a conversion into the standard Romanian projection, Stereo 70.
 - c)* The third step was to create maps of land use/land cover changes occurring over the three periods: 1990 – 2000, 2000 – 2006 and 2006 – 2012.

The Corine Land Cover database was corrected using mosaics made of satellite images from the Landsat archive for summer period of the years that make up our periods:

- Landsat 4-5 TM for 1989 and 1996 (for correcting CLC 1990 and CLC 2000)
- Landsat 7 ETM+ SLC Off for 2005 and 2008 (for correcting CLC 2006 and 2012)

Although we shall detail further on the methodology of classifying land use/land cover, we mention the fact that the scenes making up the upper basin of Jiu (contained in 4 images) did not correspond to the same day. Nevertheless, we tried to find images from similar and closely related moments during summer, in order to capture the state of vegetation.

- d) The last stage involved a series of cartographic and statistical analysis, depending on the type and location of land use/land cover changes identified during the three periods.

Thus, in order to have a global view of changes that took place between 1990 and 2012, the three resulting shapefiles (Change_1990-2000, Change_2000-2006 and Change_2006-2012) were merged in a single shapefile for the entire period (1990-2012) using the *Merge* instrument in ArcGIS.

2. In terms of getting the NDWI index for August 2015, the work steps consisted in:

- a) Creating the mosaic of four images Landsat 8 Oli TIRS covering the upper basin of the Jiu River. This was achieved in the ENVI program by using Mosaiking, Resampling and then Nearest Neighbour tools. The 4 satellite images were taken from the Earth Explorer database and correspond with the days of 14 and 29 August 2015.

- b) Classifying land use and land cover categories in the ENVI software, following the work flow of the verification and validation method:

- Creating regions of interest, where we used the images obtained for orientation, by trying various combinations of spectral bands (432 – natural colours, 543-vegetation, 652 – cultivated land or 564 – clear differentiation between land and water)
- Validation by using the post classification method (Disproportionate) – Generate Random sample and using Majority/Minority Analysis

- c) Index calculation by the formula:

$NDWI = \frac{NIR-G}{NIR+G}$, proposed by Mc Feeters (1996), where NDWI – normalized difference water index; NIR – near infrared spectral band and G – green spectral band (Mihai et al. 2014).

- d) Exporting NDWI product for further processing in QGIS and ArcGIS

- Re-projecting from UTM WGS84 to Stereo 70 Double Stereographic
- Extracting the region of interest (the watershed outline) by “Mask”
- Spatial statistics of the land cover categories and NDWI values: extract statistics by table, joined with the labels table and finally summarize the results by some descriptive statistical parameters.

Not least, the cartographic and statistical processing was carried out using the ArcGIS 10, SPSS 13, Quantum GIS 2.8.6. Wien, ENVI 4.7 and Microsoft Excel programs.

4.8.3. Results and discussion

One of the reasons that makes this research important is that, over the last years, Jiu's upper basin has been subjected to a number of human interventions (micro hydropower stations, hydraulic works, the conversion of forests into pastures and of areas covered by transitional shrubs into agricultural or urban land at the foot of slopes situated near towns and villages). Thus, the study of the dynamics of forested areas can also have a significant impact on the analysis of hydro morphological flows.

Furthermore, over the past 25 years, a series of hydrological and hydro-geomorphological risk events have been reported, particularly in the mining area along the Jiu Valley, in the Petroșani Depression or in the contact area between the Meridional Carpathians and the Getic Sub-Carpathians. These risk events are caused, to a large extent, by land use change, due to man's direct actions or because of indirect effects generated by changes in environmental factors and the connections between its elements (i.e., the disappearance of forested areas → increased slope instability → hydro-geomorphologic hazards).

A first reasoning involved the quantification of forested areas gained and lost (Figure 40) in the three periods, for each type of forest or transition category (scrub, broadleaf, coniferous or mixed).

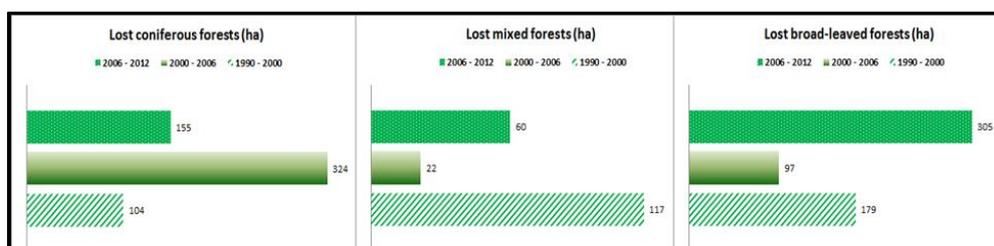


Figure 40. Statistics of the gains and losses of the areas covered with forests upper basin of the river Jiu (1990 – 2012).

Overall, between 1990 and 2012, the only changes in land use and cover belonged to scrub or forested areas. It is, therefore, possible to notice that the largest period that has undergone covers the first decade (lost broadleaf forests). In terms of coniferous forests, over the second period, we registered gains and in terms of area covered by mixed forests, we also discovered a reduction over the first period.

A second statistical analysis involved the total forested area that was gained or lost (Figure 41). Although at first glance this estimate does not seem to be important, it can give us a direction

of thinking the link between forest and water content, in terms of total area changes in one or another.

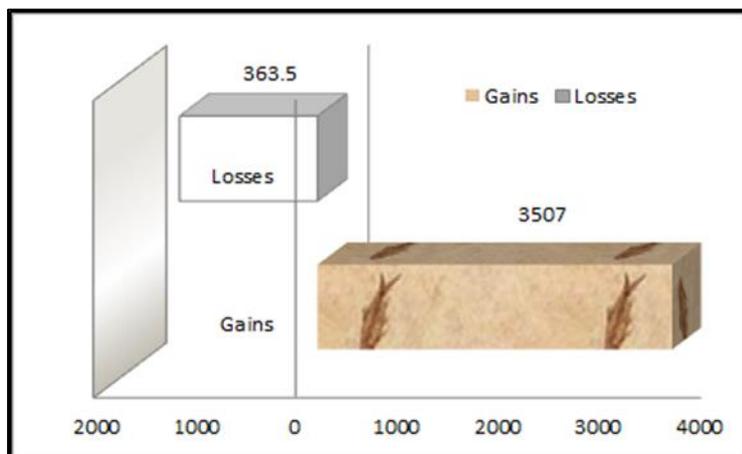


Figure 41. Gains and losses of forest stands in the period 1990-2012.

Even though the first analysis led us to the conclusion that losses exceeded gains in terms of forested areas, this final chart shows us that the surface gained between 1990 and 2000 through the transformation of transitional scrubs into mixed forests is overall larger than the area covered by forests that have changed into other land use categories.

A final yet important analysis, both from a spatial and a statistical point of view, was the correlation between altitude and the types of surfaces (interfluvial, slope, valley) on the one hand, and the type of change taking place on former or present forested areas (Figure 42).

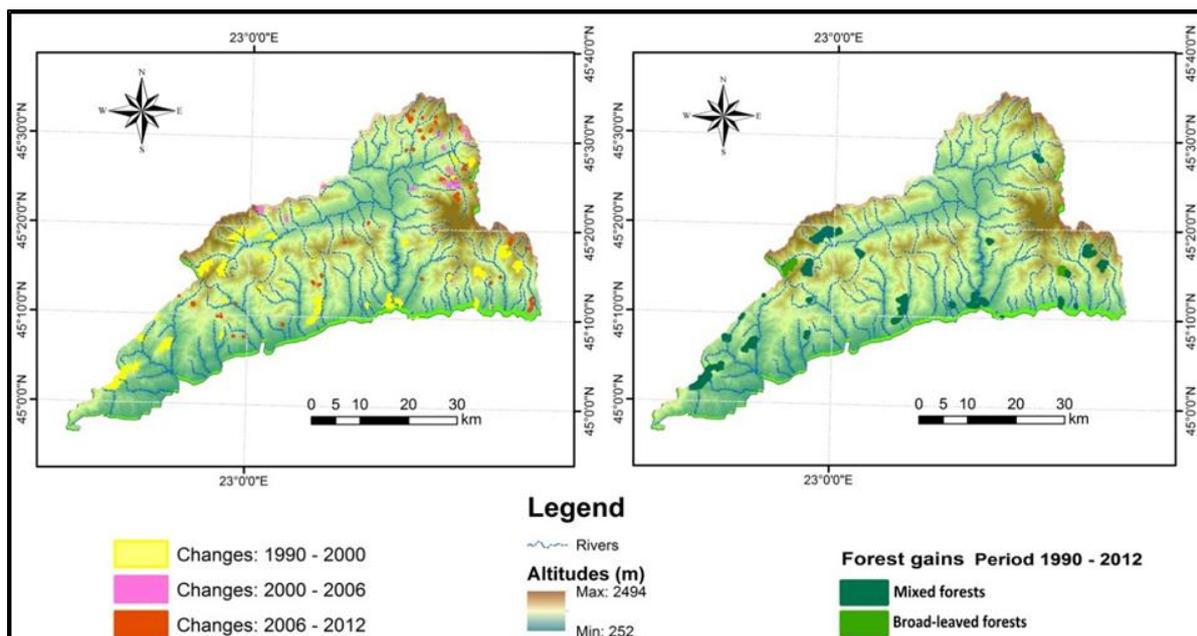


Figure 42. Representation of the changes in forest vegetation (1990-2012).

The areas where forests have undergone changes must, however, be analyzed in relation to local topography, the hydrographic network and the presence of various relief units. To such a degree, most of the changes occurred in the high-altitude area, towards the edges of Jiu's upper basin. In the map below (Figure 43), we have illustrated with different shades the changes that have taken place over each of the three periods, noticing that most of these changes are concentrated in the southern and western parts and have occurred during the first period.

After the year 2000, changes in the north-eastern part of the river basin start getting evident. With regards to the types of forests that appeared, we can notice the dominance of mixed forests, followed by broadleaf forests.

Thus, most forests disappeared from the areas along the river and from the lower basins, which can lead to major future hydro-morphological risks through the loss of protection offered by the forest in the face of water erosion phenomena, gravitational movements and alluvial transport (FAO 2013).

Last but not least, it was possible to establish the existence of a strong connection between the type of surface and the valley sector. More precisely, in most cases, forests were encountered in the downstream (lower) portion of Jiu's tributaries, accompanying the main valleys, whereas the disappearance of forests and their replacement by pastures and transitional shrubs is well correlated with higher altitude found in interfluves.

In the second part of the research, by observing in the preliminary analysis the close link between the location of current and former forested areas and the potential source zones for water erosion, we were able to use the correlation between the NDWI index and forest cover.

According to some authors (Tucker 1980, Gao 1996), the water differentiation index can be applied not only in studies strictly related to drought, dryness or, conversely, in case of soil moisture and gully erosion risk. It can also be adjusted in other kind of studies aiming to highlight the intensity of different fluxes or phenomena which describe the water balance. In our case, we were interested to find out if there is a statistical link between index values on the one hand and forest coverage and dynamics on the other.

As we shall see in Figure 43, the NDWI index varies between -0.3 and +0.6.

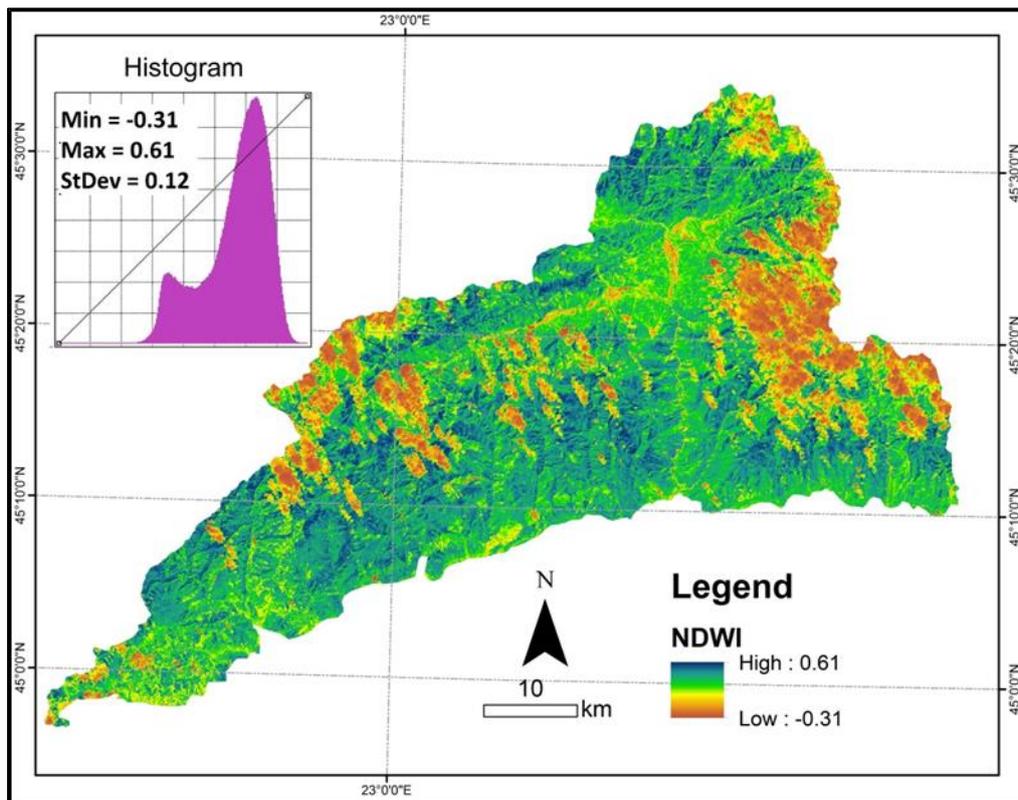


Figure 43. NDWI map in the upper basin of Jiu River for August 2015.

Note that the initial product is illustrated in shades of grey, with the lowest values appearing as dark grey or black, as they come close to the minimum limit of -1, and the highest values, which tend towards +1, are represented by light grey or white (Mihai et al. 2014). Negative values indicate that the areas are suffering from a water deficit, typical for surfaces such as exposed rocks, mountains soils, areas situated at high altitude or land affected by human intervention and made impermeable. Per contra, high values reflect well-irrigated agricultural land, forests or water bodies (Gao 1996).

Relative to the entire territory of the upper basin of the Jiu river, the average value of the index is 0.35, and the standard deviation is rather small (i.e., just 0.12), indicating a medium to high content of water and a small variation from the average value, which may be translated into an even distribution of water from rainfall.

Concerning the statistical analysis applied in the SPSS program, we used the Chi-square test for independence for studying the relationship between various types of land use/land cover and the average value of the NDWI index.

In order to transform our numerical values into nominal values, we allocated five specific codes to the vegetation types, as follows:

- code 1 belongs to classes that are known to contain a low amount of water (rocks and urban, impermeable surfaces);
- codes 2 and 3 describe intermediary categories (transitional woodland shrubs, natural grasslands and pastures);
- codes 4 and 5 were associated with different types of forests, where humidity is stored through the foliar cover (broad-leaved and mixed forests receiving the code 4 and coniferous forests the highest rank).

Next, we stated the null hypothesis (we cannot establish a connection) and research (alternative) hypothesis (there is a connection between land use and land cover categories and the values of the NDWI index). For the degree of freedom of 28, the value of chi-square test was higher (42.033) than the corresponding to minimum alpha level of 0.05, we decided to reject the research hypothesis and confirm the null hypothesis, according to which we cannot establish a correlation between the average value of NDWI and the land cover type. However, a good result was obtained between the amplitude of NDWI values and the land cover category (value of chi-square test being of 38.434, corresponding to a level of significance α higher than 0.05). This outcome shows that the higher we go from sparsely vegetated areas (0.34 NDWI amplitude) to coniferous forests (0.64 NDWI amplitude), or even to broad-leaved forests (0.91 NDWI amplitude), we expect a greater heterogeneity in terms of moisture content.

Nevertheless, it is possible to prove the existence of a correlation ($R_{\text{Pearson}} = 0.75$) between land use classes and the amount of water found on these surfaces. The highest values of the NDWI Index correspond to areas covered by broadleaf forests, and the lowest values were recorded on surfaces that have been affected by human intervention.

Although we took account of changes in vegetation between 2012 and 2015 (we assumed that in the reforested areas there is more humidity and where we lost forest stands the humidity is lower and therefore different from that of the same types of surfaces remaining in the same category since 1990), some updates of the analysis will be required in the future. For this reason, a future direction for our study will be the analysis of changes affecting the NDWI index in different time intervals, or the search for a new classification of land use or land cover categories that would better reflect the potential water value that these surfaces contain.

In any case, we must keep in mind the fact that data from CORINE has also several limitations. To begin with, using a unitary methodology allows the creation of such inventories only at large time intervals and, furthermore, available data describes a past situation. For example, we could

only access the data for 1990, 2000 (made available in 2004) and 2006 (made available in 2010). Even if CORINE data have the advantage to be free of charge, when used for studying a small area, they automatically lead to errors due to misclassification (Petrişor 2008). Thus, it is possible that we have faced a slower rhythm of change over time (1990 – 2012) because of the large scale used, inappropriate for detailed analysis. From the satellite images perspective, land cover classification for 2015 proved to be adequate for analysing changes occurring in the higher levels of nomenclature for territorial land cover hierarchy, but NDWI values based on images obtained from water bodies and rivers which have not previously been extracted can be deceiving and lower than normal reality.

4.8.4. Conclusions

Firstly, the upper basin of Jiu river proved to be a working space suitable for correlating the extraction of water information with the vegetation cover data. GIS-based assessment of the moisture content and the dynamics of the vegetation highlighted the spatial and temporal characteristics of the forest cover structure and the associated spectral signature of the leaves' water content. The highest NDWI values (0.6) occurred on some of the cultivation patterns, on the pastures and on the broad-leaved forests, while the lowest ones match the non-irrigated arable land and bare rocks. Maximum NDWI values (0.59) were equally registered over the mixed and coniferous forests, because in summer foliage is almost impartially developed in both types of forests. In terms of spatial distribution and altitude, moisture content increases with decreasing altitude and proximity to the slopes and river valleys, giving us a clue that hydro-morphodynamical areas are fairly well protected.

Changes in vegetation structure between 1990 (according to the database Corine Land Cover) and 2015 (according to the supervised classification of satellite images) were also distinctly captured through NDWI values. Summarizing the dynamics of vegetation in these 25 years, we see that the regeneration of coniferous and mixed forests on former surfaces covered with transitional woodland shrubs meant a higher intake of humidity (maximum NDWI of 0.57). Instead, deforestation from the past and replacement towards the end of the studied period of coniferous forests with shrubs led to the decreasing of the amount of water stored in the leaves (maximum NDWI of 0.49). Overall, however, the moisture content can be appreciated as increasing in the last years because a larger area of forest was rather regenerated than lost.

Although the analysis revealed a small connection between the vegetation cover structure and dynamics (particularly the forests) and the sensitivity of the vegetation canopy to water content, the method used should only be considered as a qualitative and complementary one. The uncertainties and limitations of this research, besides the statistical approach that can be improved, concern mainly the accuracy of the spatial scale. Thereupon, errors may consist in the lack of details capable of setting apart different hydrological phenomena and processes arising from the unevenness of land cover categories. In any other sense, if we overlook these potentially technical failures of supervised classification or visual interpretation of satellite images, the study could be considered a reliable starting point of a conjoint application of forest hydrology and remote sensing.

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