IntechOpen

Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR)

Edited by Michaela Teich, Cristian Accastello, Frank Perzl and Karl Kleemayr

Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR)

Edited by Michaela Teich, Cristian Accastello, Frank Perzl and Karl Kleemayr

Published in London, United Kingdom



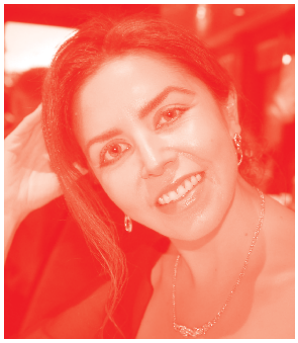




IntechOpen





Supporting open minds since 2005

Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR)
http://dx.doi.org/10.5772/intechopen.95014
Edited by Michaela Teich, Cristian Accastello, Frank Perzl and Karl Kleemayr

Contributors
Cristian Accastello, Silvia Cocuccioni, Michaela Teich, Frank Perzl, Alessia Bono, Matteo Garbarino, Renzo Motta, Gerhard Markart, Christian Scheidl, Bernhard Kohl, Emanuele Lingua, Niccolò Marchi, Francesco Bettella, Maximiliano Costa, Francesco Pirotti, Marco Piras, Donato Morresi, Raffaella Marzano, Christopher James Laplante D'Amboise, Anne Hormes, Stefan Steger, Frédéric Berger, Micha Heiser, Sebastian Kamper, Thomas Thaler, Werner Rammer, Rupert Seidl, Klaus Klebinder, Veronika Lechner, Fabian Nagl, Francesca Poratelli, Kathrin Renner, Christine Moos, Luuk Dorren, Peter Bebi, Alexander Bast, Kevin Helzel, Gregor Schmucki, Natalie Brozova, Yves Bühler, Ana Stritih, Matthias Plörer, Michael Kirchner, Fabio Carnelli, Lydia Pedoth, Gernot Koboltschnig, Paul Krenn, Anna Rudloff, Willigis Gallmetzer, Pierpaolo Macconi, Nicola Marangoni, Mirjana Stevanov, Max Krott

Cover graphic: Roberto Baldissera, Agentur für Grafik; Martina Eller, Austrian Research Centre for Forests (BFW)

© The Editor(s) and the Author(s) 2022
The rights of the editor(s) and the author(s) have been asserted in accordance with the Copyright, Designs and Patents Act 1988. All rights to the book as a whole are reserved by INTECHOPEN LIMITED. The book as a whole (compilation) cannot be reproduced, distributed or used for commercial or non-commercial purposes without INTECHOPEN LIMITED's written permission. Enquiries concerning the use of the book should be directed to INTECHOPEN LIMITED rights and permissions department (permissions@intechopen.com).
Violations are liable to prosecution under the governing Copyright Law.

Individual chapters of this publication are distributed under the terms of the Creative Commons Attribution - NonCommercial 4.0 International which permits use, distribution and reproduction of the individual chapters for non-commercial purposes, provided the original author(s) and source publication are appropriately acknowledged. More details and guidelines concerning content reuse and adaptation can be found at http://www.intechopen.com/copyright-policy.html.

Notice
Statements and opinions expressed in the chapters are these of the individual contributors and not necessarily those of the editors or publisher. No responsibility is accepted for the accuracy of information contained in the published chapters. The publisher assumes no responsibility for any damage or injury to persons or property arising out of the use of any materials, instructions, methods or ideas contained in the book.

First published in London, United Kingdom, 2022 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, 5 Princes Gate Court, London, SW7 2QJ, United Kingdom
Printed in Croatia

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Additional hard and PDF copies can be obtained from orders@intechopen.com

Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR)
Edited by Michaela Teich, Cristian Accastello, Frank Perzl and Karl Kleemayr
p. cm.
Print ISBN 978-1-83969-325-0
Online ISBN 978-1-83969-326-7
eBook (PDF) ISBN 978-1-83969-327-4

Interreg
Alpine Space
GREEN RISK 4 ALPS
European Regional Development Fund

We are IntechOpen, the world's leading publisher of Open Access books

Built by scientists, for scientists

6,100+
Open access books available

167,000+
International authors and editors

185M+
Downloads

156
Countries delivered to

Our authors are among the
Top 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

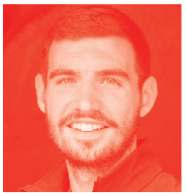
Selection of our books indexed in the Book Citation Index (BKCI)
in Web of Science Core Collection™

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Meet the editors

Dr. Michaela Teich is a forest scientist with a special interest in working in inter- and transdisciplinary teams, aiming to contribute to the sustainable management of protective forests and natural hazard risks in mountain areas. She earned a master's degree from Technische Universität Dresden in 2006, before joining the WSL Institute for Snow and Avalanche Research SLF in Switzerland as a research assistant. In 2014, she completed her PhD on forest-avalanche interactions at ETH Zurich, and then studied the snowpack in bark beetle- and fire-disturbed forests for four years at Utah State University, USA. Dr. Teich is currently leading the Unit of Snow and Avalanches at the Department of Natural Hazards of the Austrian Research Centre for Forests (BFW).



Dr. Cristian Accastello is a forester from Torino, Italy. After a master's degree in forest and environmental sciences, he earned his Ph.D. in 2020 at the University of Turin, focusing on the economic value of mountain forest ecosystem services. During his research career, he has worked on various European projects related to forest management in mountain areas, promoting the recognition of forest's services for the protection against natural hazards and climate change mitigation through the development of methods and decision support systems for stakeholders. In 2021, he joined the Consorzio Forestale Alta Valle Susa, an association of public forest owners located in the Western Italian Alps, to explore the application of continuous-cover silviculture and climate-smart forestry in Alpine environments.

Dipl.-Ing. Frank Perzl completed his degree in forestry at the University of Natural Resources and Applied Life Sciences (BOKU), Vienna in 1995 and his diploma in geographic information systems in 2004, before joining the Austrian Research Centre for Forests (BFW) in 2005. His main topics are the forest and natural hazard inventory, protective functions and effects of forests in application-oriented projects, and expert reports for the public and private sectors. He has developed assessment procedures for the protective functions and effects of forests. Examples include guidelines for Austrian programs for the improvement of protective forests, natural hazard maps commissioned by major infrastructure operators, and modeling of the protective function of Austrian forests against snow avalanches, rockfall and shallow landslides.

Dr. Karl Kleemayr completed his studies in torrent and avalanche control at the University of Natural Resources and Applied Life Sciences (BOKU), Vienna in 1989 and worked for two years at the Austrian Service for Torrent and Avalanche Control (WLV). He then earned a Ph.D. at the BOKU in 1996. His further research included finite element calculations and avalanche dynamics modeling, but during his career, he advocated for an ecosystem-based risk management approach. From 2004 to 2021, Dr. Kleemayr led the Department of Natural Hazards at the Austrian Research Centre for Forests (BFW) with great dedication and commitment. He passed away in 2021, long before his time, and is greatly missed by the natural hazard and protective forest community.

Contents

Preface

"A protection [or protective] forest is a forest that has as its primary function the protection of people or assets against the impacts of natural hazards or adverse climate" [1].

This definition of protective forests sounds straightforward. However, their management for Ecosystem-based Disaster Risk Reduction (Eco-DRR) and utilization as an efficient mitigation measure within an integrated risk management process, requires a multitude of conflicting interests as well as social, economic, and ecological sustainability criteria to be integrated, taking different spatial and temporal scales into account [2].

Protective forests can reduce risks by preventing natural hazards or decreasing their frequency, magnitude and/or intensity. The two leading questions for risk-based and sustainable protective forest management are, "*Where and what does a forest protect?*" and "*How well does a forest protect?*" These questions translate into the terms protective function (where and what) and protective effect (how well) [3]. Research on the protective effects of forests has been ongoing since the 1950s. However, it is only where scientific knowledge is combined with practical experience and integrated into policy-making processes that opportunities for its actual utilization and implementation can be effective [4]. Moreover, changes in land use, expanding settlements, infrastructure and Alpine tourism, climate change-driven shifts in tree species composition and forest structure as well as in frequencies and magnitudes of natural hazard events and natural forest disturbances, cumulatively affect natural hazard risks [5]. Therefore, risk management decisions are complex, and the associated uncertainties are high, often preventing the full inclusion of protective forests as an effective and cost-efficient risk mitigation measure [6].

To facilitate risk-based protective forest management as part of an integrated management of natural hazard risks, twelve institutions[1] from five Alpine Space countries collaborated for three and a half years on the Interreg Alpine Space project GreenRisk4ALPs (ASP 635) [7], while also engaging in continuous dialog with practitioners and policy makers. This book summarizes the information that was collected and reviewed during the project; it also introduces the methods and decision support tools that were developed. Together with contributions highlighting current research achievements from other scientists outside of the GreenRisk4ALPs project, this book provides a condensed but comprehensive overview for practitioners, policy makers, scientists, and the public of state-of-the-art knowledge on the key role protective forests play for Eco-DRR.

This book is divided into three sections, each containing chapters addressing different topics. The chapters in the first section, "Natural Hazard Risks and Eco-DRR in the Alpine Space", guide the reader through the maze of existing definitions and concepts, and provide the basis for a common language regarding protective forests as Eco-DRR.

---

[1] Austrian Research Centre for Forests (BFW), Austrian Service for Torrent and Avalanche Control (WLV), Bavarian State Institute of Forestry (LWF), EURAC Research, Forestry Company Franz-Mayr-Melnhof-Saurau, Georg-August-Universität Göttingen, National Research Institute for Agriculture, Food and Environment (INRAE), Safe Mountain Foundation (FMS), Slovenia Forest Service (ZGS), Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), University of Ljubljana (UL), University of Turin (UniTo).

Also summarized in this section is the current knowledge about protective effects against gravitational and torrential natural hazards, emphasizing research gaps and the need for harmonized data collection protocols.

The chapters in the second section, "Supporting Integrated Natural Hazard Risk Management by Eco-DRR", introduce scientific knowledge, and the methods and practical tools that have been developed to support decisions in protective forest and risk management. They highlight opportunities for further improvement, which may include providing geodata of the required quality, spatial and temporal resolution, or explicitly considering the uncertainties in decision-making processes innate to inherently variable and complex systems.

Participation, communication, and integration are the topics of the last section, "From Risk Communication to Science-Based Political Action to Facilitate Eco-DRR", which underlines that the utilization of scientific knowledge in practice is not a one-way street but an active and iterative exchange that requires inter- and transdisciplinary collaboration. Moreover, the unique topographic, geomorphologic, and climatic diversity of mountain areas requires policies whose implementation acknowledges regional and local differences. Only then can local decision makers and practitioners manage their protective forests sustainably for Eco-DRR under changing climate and socio-economic conditions.

The work in this book took a tremendous amount of effort and time, involving a variety of partners and researchers – without their contributions, this project would not have been possible. We thank all contributors to the GreenRisk4ALPs project: Marc Adams, Jean-Baptiste Barre, Jurij Beguš, Fred Berger, Alessia Bono, Filippo Brun, Silvia Cocuccioni, Alice Crespi, Christopher D'Amboise, Willibald Ehrenhöfer, Helena Eiselse, Jan-Thomas Fischer, Jean Pierre Fosson, Matteo Garbarino, Christian Ginzler, Ameni Hasnaoui, Anne Hormes, Robert Jandl, Georg Kindermann, Michael Kirchner, Milan Kobal, Max Krott, Veronika Lechner, Renzo Motta, Michael Neuhauser, Domen Oven, Petra Pečan, Paolo Perret, Matthias Plörer, Francesca Poratelli, Monika Rabanser, Kathrin Renner, Stefan Schneiderbauer, Roland Schreiber, Samo Škrjanec, Stefan Steger, Anne Stöger, Barbara Žabota, and Mirjana Zavodja...

...as well as all the scientists, practitioners, and policy makers, who were not directly assigned to the GreenRisk4ALPs working group, but dedicated their time and expertise to share their knowledge at excursions, meetings and in fruitful discussion, or wrote and/or reviewed chapters for this book.

Michaela Teich, Frank Perzl and Karl Kleemayr
Department of Natural Hazards,
Austrian Research Centre for Forests (BFW),
Innsbruck, Austria

Cristian Accastello
Consorzio Forestale Alta Valle Susa (CFAVS),
Oulx, TO, Italy

References

[1] Brang P, Schönenberger W, Ott E, Gardner B. Forests as Protection from Natural Hazards. In: Evans J, editor. *The Forests Handbook: Applying Forest Science for Sustainable Management 2*. Oxford: Blackwell Science; 2001. pp. 53–81.

[2] Federal Office for Civil Protection (FOCP). *Integrated Risk Management. Its importance in protecting people and their livelihoods*. Bern, Switzerland: FOCP; 2014.

[3] Kleemayr K, Teich M, Perzl F, Hormes A, Markart G, Plörer M. Protection forest definition matrix. Innsbruck, Austria: Austrian Research Centre for Forests (BFW); 2019. Available from: https://www.alpine-space.eu/wp-content/uploads/2022/11/poster_grfa_schutzwald_englisch.pdf

[4] Kirchner M, Krott M. Integrating forest science into natural hazard management praxis: an international case study based on the innovative RIU approach. *International Forestry Review.* 2020;22(4):449–63. DOI: 10.1505/146554820831255524

[5] Alpine Convention. *Natural Hazard Risk Governance: Report on the state of the Alps. Alpine Signals – Special Edition 7*. Innsbruck, Austria: Permanent Secretariat of the Alpine Convention; 2019. 96 p.

[6] Sudmeier-Rieux K, Arce-Mojica T, Boehmer HJ, Doswald N, Emerton L, Friess DA, et al. Scientific evidence for ecosystem-based disaster risk reduction. *Nat Sustain*. 2021;4(9):803–810. DOI: 10.1038/s41893-021-00732-4

[7] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. [cited 2022 Sep 22]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

Section 1

Natural Hazard Risks and Eco-DRR in the Alpine Space

Chapter 1

The Concept of Risk and Natural Hazards

Cristian Accastello, Silvia Cocuccioni and Michaela Teich

Abstract

Risks have always shaped the way society has grown and evolved. Consequently, the risk concept has been studied and applied by different disciplines such as natural sciences as well as by economic, engineering, health, and insurance sectors. However, its definition and application are heterogenous and often vary among research communities. This chapter introduces the concept of risk and provides an overview of definitions and interpretations by key policy actors, including associated terms such as hazard, exposure, and vulnerability. Its use and the general importance of "risk" in the Alpine Space are emphasized, especially in the light of the increasing impacts of socioeconomic, environmental, and climatic changes on natural hazard risk by discussing resulting consequences and challenges. Furthermore, we provide an overview of the main policy actors, organizations and networks that address integrated natural hazard risk management in the Alpine Space.

Keywords: risk concept, hazard, exposure, vulnerability, disaster risk reduction, climate change adaptation, mountain areas

1. Introduction

Since the beginning of time, social developments were driven by the need to respond and adapt to different challenges such as natural hazards and the resulting risks [1, 2]. Only recognizing, accepting, and dealing with risks and their consequences has allowed us to grow and evolve to the society we know today by passing through an endless process of trials and errors. Therefore, every achievement or modification of the surrounding environment can be evaluated from a risk perspective [2]. Being part of the past and current developments of our society, the generic concepts of risk, risk assessment and risk management are well established in many disciplines, from technical applications (e.g., in industrial plants and airports), to project management, the finance sector or civil protection [3, 4]. However, their considerations and definitions are not as coherent as one might think [5]. Risk and its associated concepts have been defined heterogeneously, in relation to their specific application in a certain field [2].

The broadest definition of risk is given by the International Organization for Standardization ISO Norm 31000 on risk management, mainly addressing organizations and enterprises. ISO defines risk as the "effect of uncertainty on objectives" [6]. This ISO Norm further specifies that "Risk is usually expressed in terms of risk sources [element which alone or in combination has the potential to give rise to risk], potential events [occurrence or change of a particular set of circumstances],

their consequences [outcome of an event affecting objectives] and their likelihood [chance of something happening]" [5, 6].

In the context of natural hazards, the climate change adaptation (CCA) and the disaster risk reduction (DRR) communities have a common objective: addressing the prevention and reduction of risks related to extreme weather- and climate-related events [7], and disasters, which are defined as "Severe alterations in the normal functioning of a community or a society due to hazardous physical events [...]" [8]. However, in the past the two research communities have evolved autonomously, adopting complementary approaches [9, 10]. In general, DRR has a longer history and has mainly focused on the present, addressing existing risks. On the other hand, CCA focusses mainly on the future, addressing uncertainty and new risks, also related to slow changes [10]. Consequently, the two research communities have developed different definitions of the risk concept.

In the context of DRR, the definition of risk is primarily based on the Sendai Framework for Disaster Risk Reduction (2015–2030) [11]. The United Nations Office for Disaster Risk Reduction (UNDRR, formerly known as UNISDR) defines disaster risk as "The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity" [12]. Until 2018, the CCA community has instead mainly focused on the concept of vulnerability; however, efforts have been made recently to coordinate and integrate a common concept understanding among both research communities [13].

The Intergovernmental Panel for Climate Change (IPCC) has been key in proposing solutions for common definitions [10]. In its Fifth Assessment Report, the IPCC has introduced the risk concept with the aim to identify and evaluate the risk of impacts from climate change, which is in line with the DRR practice of understanding and addressing natural hazards (e.g., earthquakes, floods or landslides) [4]: risk is "The potential for consequences where something of value is at stake and where the outcome is uncertain, [..., and] results from the interaction of vulnerability, exposure, and hazard" [8] (**Figure 1**; see **Table 1** for IPCC definitions of vulnerability, exposure, and hazard).

This 2014 IPCC definition of risk introduces a new approach and terminology [5], which is based on the UNDRR and ISO Norm 31000 definitions, allowing for

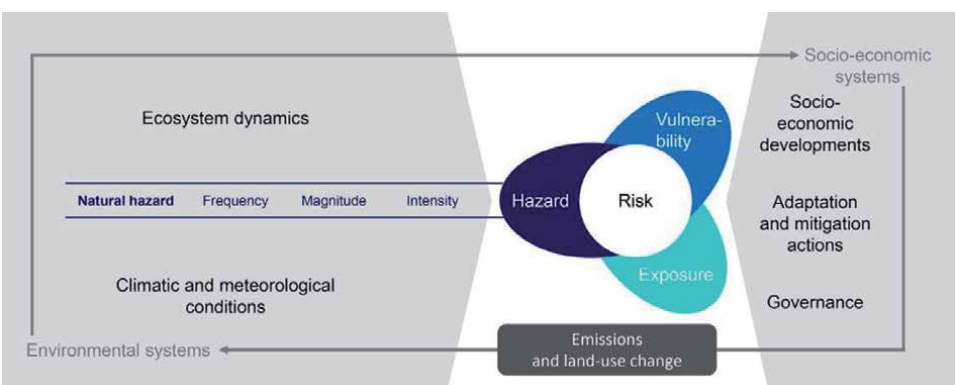


Figure 1.
Conceptual framework of the climatic, ecological, economic, and social impacts on climate-related and natural hazard risks resulting from the interaction of the three (natural) hazard components (frequency: number of times a natural hazard event occurs within a specified time interval, magnitude: energy released by a natural hazard event, and intensity: effects of a natural hazard event at a specific location or area [14]) with exposure and vulnerability of human and natural systems. Adapted from [8].

Hazard	"The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or […] damage and loss to property, infrastructure, livelihoods, service provision and environmental resources."
Exposure	The presence of people; livelihoods; environmental services and resources; infrastructure; or […] assets in places and settings that could be adversely affected."
Vulnerability	"The propensity or predisposition to be adversely affected."
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, […]."

Table 1.
Defining risk resulting from the interaction of hazard, exposure, and vulnerability [8].

an integration of climate risks into already existing risk management strategies and policies. Some of the terms used in this concept are newly introduced to the CCA community; others are now defined differently [4]. For example, the DRR community interprets vulnerability as the societal, physical, and natural factors which contribute to disaster risk [5], while the CCA community's vulnerability definition focuses on "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change […]" [15].

Since the late 1990s, the concept of risk has been successfully applied in the field of natural hazard management to evaluate protection measures [16–18]. In this context, risk results from the combination of natural hazards, exposure, and vulnerability (**Figure 1**) [19], similar to the approaches and practices of the DRR community and to the IPCC risk concept [8]. That is, a hazard alone does not constitute a risk, if occurring in an area with no consequences for humans, and not all elements at risk are necessarily impacted given their exposure and vulnerability [8, 20]. Therefore, risk assessment does not only consider the hazard but also the presence and vulnerability of potentially exposed elements (i.e., assets or people). This includes their physical attributes (i.e., building material of houses), their social, economic, and cultural characteristics (i.e., demographics) and their capacity to cope and adapt [4].

2. Coexisting with risk: the example of mountain areas

Understanding natural hazard processes and their potentially harmful consequences constitutes an essential prerequisite for developing and implementing efficient risk management strategies [21], including practices, plans and actions for reducing the natural hazard risk in an area by acting on one or more of the three risk components [22]. Disasters related to natural hazards such as floods, droughts, heat waves, cyclones, volcanic eruptions, earthquakes, rockfall, landslides and/or snow avalanches can vary widely in frequency, magnitude and intensity, mainly due to the environment they originate from [23]. The most severe disasters directly affect local, regional and national socioeconomic developments and livelihood improvements [10]. Their occurrence often reveals how differently vulnerable communities can be, since they are mitigated or amplified by a complex system of interacting factors such as the settlement in exposed areas, poor risk governance, environmental degradation, inadequate risk communication, or a lack of preparedness by public authorities [2, 24]. The trend in increasing numbers of occurring disasters is also linked to the increased exposure of populations, which is caused by socioeconomic factors such as population growth, rapid urbanization and the concentration of populations and economic assets in regions that are regularly affected by hazardous events [25].

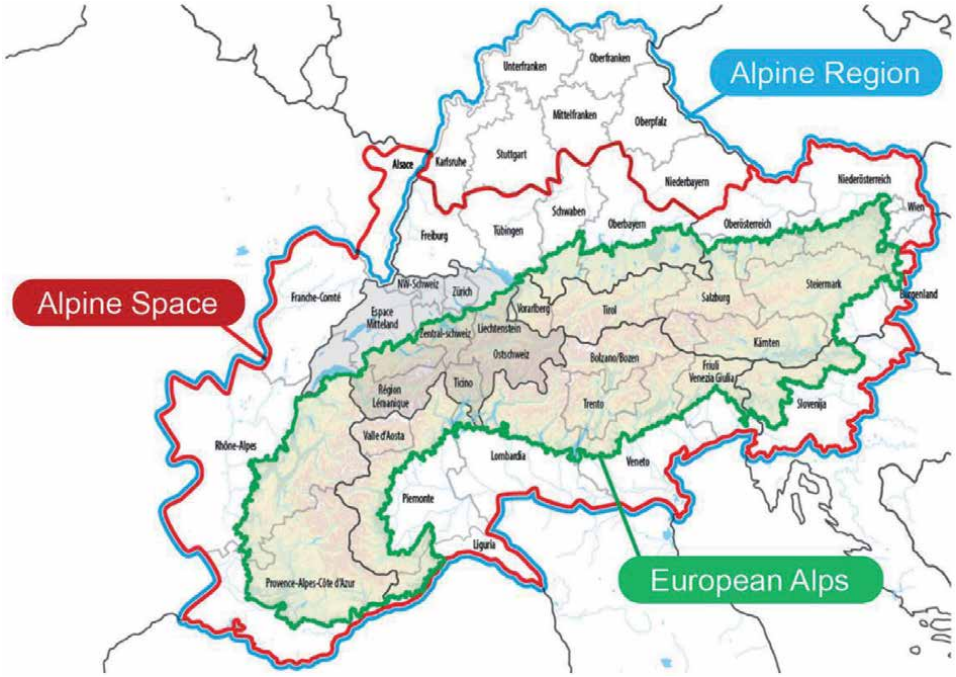


Figure 2.
Extents of the Interreg Alpine Space, the EUSALP Alpine Region and the European Alps (Alpine Convention). Adapted from [30].

One of these vulnerable regions are mountain areas, which occupy 22% of the Earth's surface [26]. Mountain areas vary largely in shape, altitude, vegetation, and climate across the globe [27, 28]. Despite these differences, mountain areas are globally renowned for the biodiversity they host and the ecosystem services they provide, including the provision of freshwater to about half of the world's population [28]. In addition to their acknowledged natural functions, mountain areas are home to more than 915 million people, representing 13 percent of the global population [29]. The inhabitants of mountain areas are particularly exposed and vulnerable to natural hazards as well as climate change [5].

Consistent with the global context, the European Alps (**Figure 2**) have been identified as one of the continent's most vulnerable areas to climate-related hazards [5]. Due to their high population density, the European Alps have always been affected by multiple natural hazard risks since time immemorial. Consequently, the mitigation of natural hazards (i.e., interventions aimed at reducing risks) has always been a major task in the Alpine Region [1, 31, 32]. Following the development of the risk concept and its integration into several international agreements, approaches for DRR in mountain areas have been progressively adopted, i.e., methodologies for identifying and planning mitigation and adaptation measures to reduce risk by reducing vulnerability or, eventually, exposure [33, 34].

However, significant changes in the Alpine landscapes over the last century caused by fast and profound socioeconomic developments, force mountain communities to continue facing new and complex challenges:

- Population expansion has led to high-density settlements located in areas that were previously considered to be unsafe [1, 31];

- Transportation infrastructure crossing the Alps have significantly increased, making this region one of the main thoroughfares in Europe [35]; and

- Alpine tourism has gained popularity, so that many remote mountain areas that were previously avoided are now expected to be permanently accessible [36, 37].

This increase in assets and people driven by urbanization and socioeconomic processes has led to an increase in the number of potentially exposed elements. The resulting damages to assets and infrastructures and losses to the residential, commercial, industrial, agricultural and public sectors are worth billions of Euros [36]. For example, at least 4,750 casualties were caused by snow avalanches alone in the Alps from 1970 to 2015, of which approximately 670 occurred in controlled terrain (settlements and transportation corridors) [38], and 1,370 people were killed by landslides and rockfall in Europe between 1995 and 2014 [39].

Recent disasters caused by floods, storms, avalanches, and other natural hazards have resulted in a shift towards an aware coexistence with such hazards and in a growing need for greater investments in protection measures [40, 41]. Limited space for settlement expansion, changes to frequencies and magnitudes of natural hazard events and natural forest disturbances as well as changes in traditional land

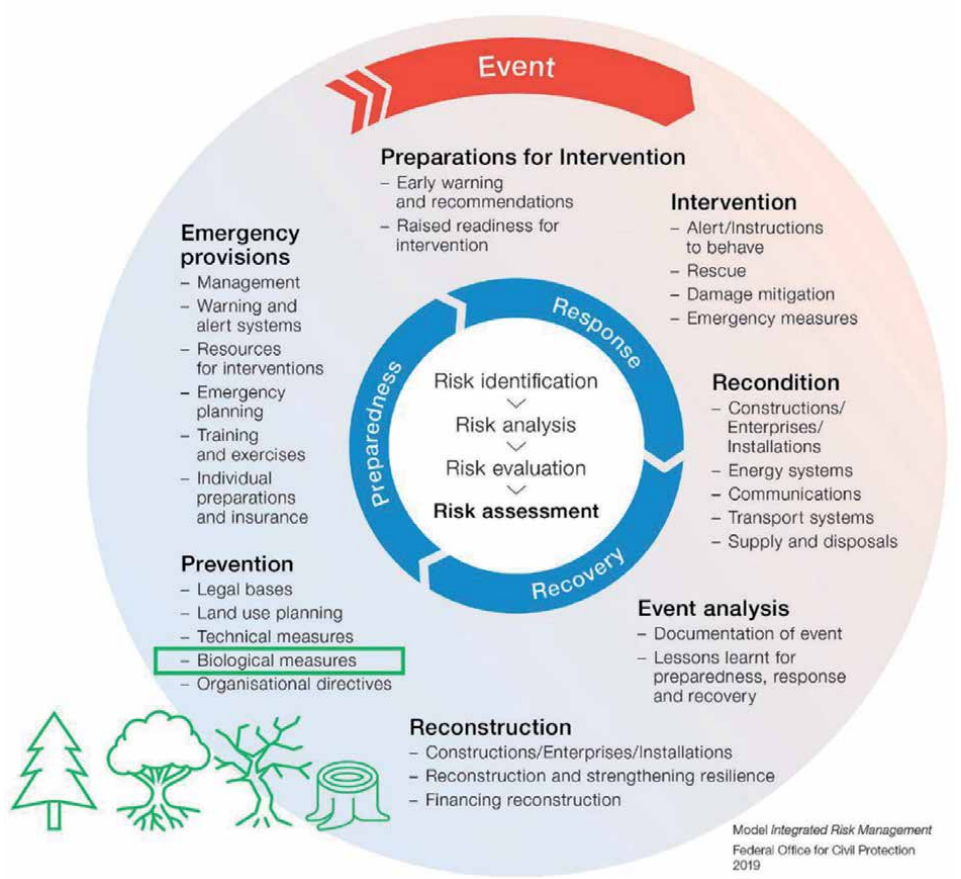


Figure 3.
The integrated risk management cycle. Forests are integrated as biological prevention measures. Adapted from [45].

use practices and land cover, including mountain forests, cumulatively affect natural hazard risks [42]. Thus, the safety of mountain populations needs to be ensured, in accordance with the preservation of precious mountain environments, a fundamental precondition for the sustainable development of the Alpine Space (i.e., the cooperation area of the Alpine Space programme covering the Alps and their surrounding lowlands [43]; **Figure 2**). Such challenges require risk governance concepts, including adaptive and integrated natural hazard risk management [1, 34, 40].

The concept of integrated risk management (IRM) refers to an overall risk management process in conjunction with the ISO Norm 31000 [6], including risk assessment (risk identification, analysis and evaluation), as well as risk treatment (preparedness, response and recovery) [44]. IRM is a systematic approach to cope with all societal-relevant hazards and related risks in an area by considering sophisticated damage indicators as well as ecological, economic and social sustainability criteria, the full spectrum of available measures, and all relevant decision-makers, experts, and those who are affected in a structured way (**Figure 3**).

3. Climate change risk in mountain areas

In the last decades, anthropogenic climate change has become the biggest threat to our society, and especially for the inhabitants of mountain areas [34]. Indeed, it was climate change's recognition and the assessment of its devastating effects which encouraged the latest international advancements in disaster risk management concepts and collaborations among scientists, practitioners, and policy makers. The increasing impacts and awareness of climate change were the motivation for the development of the IPCC's "risk of climate-related impacts" concept [8]. It is widely recognized how the adverse impacts of climate change on humans and nature are limiting the possibility to achieve global conservation and development objectives such as the Aichi Biodiversity Targets and the Sustainable Development Goals [46]. The diverse impacts of climate change, in terms of both subtle trends and abrupt events, are unprecedented over decades to millennia: the increased concentrations of greenhouse gases have led to higher air temperatures, the atmosphere and oceans have warmed, the amounts of snow and ice have diminished, and sea level has risen [8].

The reason for its big influence on developing risk-based evaluation and management approaches is climate change's peculiar nature of influencing all three components of the risk concept. That is, climate-related hazards such as extreme weather events are impacting our communities more frequently and with greater intensity, and changes in the climatic system can exacerbate disaster risk [19], a trend that is projected to continue with global warming [7, 47]. In addition, the currently unsustainable exploitation of ecosystems increases the vulnerability of humans and nature to natural hazards, provoking environmental (degradation, conversion, and other ecological changes), social (loss of adaptive capacities, knowledge, and institutions; loss of livelihood options and resilience), and economic (globalization, trade, markets) impacts [2, 48]. Furthermore, climate change is also driving socioeconomic processes by forcing people to migrate, weakening the economic basis of their livelihood, and/or threatening public health, and therefore enhancing their exposure [5].

The recent achievement by the IPCC of addressing climate change impacts in the framework of the risk concept is the direct outcome of decades of efforts from several research communities and policy makers. While the DRR community focuses on sudden hazardous events of a certain magnitude with immediate and severe consequences, climate change risks also include trends that evolve over long time periods. The adverse consequences of these trends are rather manifested in slowly increasing pressure on the environment and people's livelihoods than in

immediate impacts [2]. Therefore, the IPCC framework is particularly suitable for a global perspective on risk, which is needed to manage systemic climate change risk and its cascading effects [41, 49]. In parallel, several global agreements were signed to translate the IPCC findings into political action, such as the 'Sendai Framework for Disaster Risk Reduction 2015–2030' [11], the 'Paris Agreement' [50], the 'Addis Ababa Action Agenda' [51], the 'New Urban Agenda' [52], and ultimately the so far 17 Sustainable Development Goals (SDGs) [53].

Today, scientists agree that anthropogenic climate change is altering natural hazard patterns in mountain areas [23, 25, 33]. For example, melting of glaciers and permafrost due to rising air temperatures and changes to mountain hydrology amplify the release of rocks and debris, destabilizing slopes and leading to further erosion, resulting in increasing rockfall and landslide activities [54]. In recent years, several global policy initiatives agreed on the risk paradigm and helped mountain communities to face climate change impacts on their livelihoods by adopting risk mitigation strategies and more resilient lifestyles [41, 55]. An overview of the key scientific networks and policy actors involved in natural hazard risk management in the Alpine Space is given in **Table 2**.

Name	Acronym	Scope	URL
International Commission for the Protection of the Alps	CIPRA	Non-governmental and non-profit umbrella organization which promotes the protection and sustainable development of the Alps at the international level. One of its initiatives was the establishment of the Alpine Convention.	[56]
Disaster Risk Management Knowledge Centre of the European Commission	DRMKC	Instrument to support the knowledge transfer from science into EU policies and to provide informed and evidence-based advice for disaster risk management	[57]
European Strategy for the Alpine Region	EUSALP	Alpine macro-regional strategy to improve the cooperation in the Alpine Region by identifying common goals and implementing them through transnational collaborations	[58]
Global Mountain Safeguard Research	GLOMOS	Collaborative program and scientific alliance between the UN University's Institute for Environment and Human Security (UNU-EHS) and Eurac Research for developing resilient mountain communities	[59]
Interreg Alpine Space programme	—	EU-funded transnational program to facilitate the cooperation between economic, social, and environmental key actors as well as between academia, administration, business and innovation sectors, and policy making	[60]
Mountain Partnership	—	Food and Agriculture Organization (FAO) supported UN voluntary alliance to improve lives and livelihoods of mountain people and to protect mountain environments	[61]
Mountain Research Initiative	MRI	Swiss-based international network for research in mountain environments conducted across borders and disciplines	[62]
Platform on Natural Hazards of the Alpine Convention	PLANALP	Alpine Convention platform to develop common strategies designed to prevent natural hazards in the Alps and to exchange on adaptation strategies	[63]

Table 2.
*Key networks and organizations addressing natural hazard risk management in the Alps, the Alpine Space, and the Alpine Region (**Figure 2**).*

All these initiatives are contributing to transform mountain areas into living laboratories of risk mitigation and management. However, the unique topographic, geomorphologic, and climatic diversity of the European Alps necessitates that policies are implemented by acknowledging regional and local differences [33, 34]. Only then climate-proof and efficient risk management strategies can be provided to local decision makers and practitioners to foster tangible improvements in the safety and livability of the Alpine Space [20, 54].

4. Conclusions

In the light of fast and profound socioeconomic, environmental, and climatic changes, the Interreg Alpine Space project GreenRisk4ALPs (GR4A; [64]) aimed at supporting natural hazard risk governance by developing decision support tools for practitioners and policy makers to include Ecosystem-based solutions for Disaster Risk Reduction (Eco-DRR) into affordable and long term-oriented integrated risk management. Moreover, GR4A supported overcoming conflicts and resistances by addressing all relevant actors involved in natural hazard risk management, providing science-based communication support, and developing harmonized transalpine recommendations – for municipalities as well as governance institutions. To establish efficient and proactive risk reduction measures, it is key to consider potential implications of current and future developments that determine the natural hazard risk [1, 23, 65]. Besides changes associated with elements potentially at risk, an improved understanding of past, current and future climatic trends is vital to achieve an efficient risk reduction, also due to 1) the known influence of climatic and meteorological dynamics on the occurrence of natural hazards, 2) the dependency of mountain ecosystems on climatic conditions, and 3) their interactions with (gravitational) natural hazards [54], such as landslides [66, 67], rockfall [68, 69], and snow avalanches [70, 71].

Supporting an ecosystem-based integrated risk management and the acknowledgment of the key role forests have for risk reduction in mountain areas, the findings of GR4A help identifying mitigation strategies and subsequently efficient risk reduction measures through an improved and participative risk governance system. How forests can act as a solution for Eco-DRR is the subject of the following three chapters of this book [72–74]. Moreover, the methodologies and decision support tools related to the risk concept that were developed and applied within GR4A are presented in [75, 76], the book chapters [77–79], and are explained in detail in the GR4A project reports [20, 65, 80, 81].

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by Interreg Alpine Space programme, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy. We thank Stefano Terzi for valuable comments on an earlier version of this chapter.

Conflict of interest

The authors declare no conflict of interest.

Author details

Cristian Accastello[1,2*], Silvia Cocuccioni[3] and Michaela Teich[4]

1 Department of Agriculture, Forest and Food Sciences (DISAFA), University of Turin, Grugliasco, TO, Italy

2 Consorzio Forestale Alta Valle Susa (CFAVS), Oulx, TO, Italy

3 Eurac Research, Institute for Earth Observation, Bolzano, BZ, Italy

4 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

*Address all correspondence to: accastello54@gmail.com

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Keiler M, Fuchs S. Challenges for Natural Hazard and Risk Management in Mountain Regions of Europe. Oxford Research Encyclopedia of Natural Hazard Science. Oxford University Press; 2018

[2] UNDRR. Global assessment report on disaster risk reduction. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNDRR); 2019. Available from: https://gar.undrr.org/sites/default/files/reports/2019-06/full_report.pdf

[3] Slovic P. The risk game. J Hazard Mater. 2001;**86**(1-3):17-24. DOI: 10.1016/S0304-3894(01)00248-5

[4] GIZ and EURAC. Risk Supplement to the Vulnerability Sourcebook. Guidance on how to apply the Vulnerability Sourcebook's approach with the new IPCC AR5 concept of climate risk. Bonn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; 2017

[5] GIZ and EURAC. The Vulnerability Sourcebook. Concept and guidelines for standardised vulnerability assessments. Bonn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; 2014

[6] ISO. UNI ISO 31000 "Risk Management guidelines." Geneva, Switzerland; 2018

[7] McPhillips LE, Chang H, Chester M V., Depietri Y, Friedman E, Grimm NB, et al. Defining Extreme Events: A Cross-Disciplinary Review. Earth's Futur. 2018;**6**(3):441-455. DOI: 10.1002/2017EF000686

[8] IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri RK, Meyer LA Meyer LA, editors. Geneva, Switzerland: IPCC; 2014. 151 p. Available from: https://www.ipcc.ch/report/ar5/syr/

[9] Thomalla F, Downing T, Spanger-Siegfried E, Han G, Rockström J. Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. Disasters. 2006;**30**(1):39-48. DOI: 10.1111/j.1467-9523.2006.00305.x

[10] EEA. Climate change adaptation and disaster risk reduction in Europe. EEA Report. Luxembourg: Publications Office of the European Union; 2017. Available from: https://www.eea.europa.eu/publications/climate-change-adaptation-and-disaster

[11] UNDRR. Sendai Framework for Disaster Risk Reduction 2015-2030. Geneva, Switzerland; 2015

[12] UNDRR. Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction. Geneva, Switzerland; 2016

[13] Giupponi C, Biscaro C. Vulnerabilities - Bibliometric analysis and literature review of evolving concepts. Environmental Research Letters. 2015;**10**(12):123002. DOI: 10.1088/1748-9326/10/12/123002

[14] Jackson LE. Frequency and Magnitude of Events. In: Bobrowsky PT, editor. Encyclopedia of Natural Hazards Encyclopedia of Earth Sciences Series. Dordrecht: Springer; 2013. pp. 359-363

[15] IPCC. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate

Change. Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Cambridge, UK: Cambridge University Press; 2007. 976 p

[16] Wilhelm C. Wirtschaftlichkeit im Lawinenschutz: Methodik und Erhebungen zur Beurteilung von Schutzmassnahmen mittels quantitativer Risikoanalyse und ökonomischer Bewertung. Mitteilungen des Eidg. Institutes für Schnee- und Lawinenforschung. 1997;**54**:309

[17] Wilhelm C. Kosten-Wirksamkeit von Lawinenschutz-Maßnahmen an Verkehrsachsen: Vorgehen, Beispiele und Grundlagen der ProjektevaluationVollzug Umwelt, Praxishilfe, Bundesamt für Umwelt, Wald und Landschaft BUWAL. Bern, Switzerland; 1999

[18] Fuchs S, McAlpin MC. The net benefit of public expenditures on avalanche defence structures in the municipality of Davos, Switzerland. Nat Hazards Earth Syst Sci. 2005;**5**: 319-330

[19] Doswald N, Estrella M. Promoting ecosystems for disaster risk reduction and climate change adaptation: Opportunities for integration. Nairobi, Kenya: UNEP; 2015

[20] Cocuccioni S, Renner K, Steger S, D'Amboise C, Hormes A, Plörer M, et al. D.T3.2.1 Report on "Preparation for risk analysis and strategy workshops". Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[21] Teich M, Accastello C, Poratelli F, Cocuccioni S, Renner K, Rabanser M, et al. D.T2.4.2 Identification of potentially endangered assets and functional assessment of protection measures in the PARs. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 2 Actina)

[22] Renaud FG, Sudmeier-Rieux K, Estrella M. The role of ecosystems in disaster risk reduction. Tokyo, New York, Paris: United Nations University Press; 2013. 486 p

[23] Einhorn B, Eckert N, Chaix C, Ravanel L, Deline P, Gardent M, et al. Climate change and natural hazards in the Alps. Journal of Alpine Research | Revue de géographie alpine. 2015:103-112. DOI: 10.4000/rga.2878

[24] IPCC. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, et al., editors. Cambridge, UK, and New York, NY, USA: Cambridge University Press; 2012. 582 p

[25] Hock R, Rasul G, Adler C, Cáceres B, Gruber S, Hirabayashi Y, et al. High Mountain Areas. In: Pörtner H-O, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, et al., editors. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Geneva, Switzerland; 2019. pp. 131-202

[26] UNEP-WCMC. Mountains and Forests in Mountains [Dataset]. 2000. Available from: https://www.unep-wcmc.org/resources-and-data/mountains-and-forests-in-mountains

[27] Martín-López B, Leister I, Lorenzo Cruz P, Palomo I, Grêt-Regamey A, Harrison PA, et al. Nature's contributions to people in mountains: A review. PLoS One. 2019;**14**(6):e0217847. DOI: 10.1371/journal.pone.0217847

[28] UNESCO. Mountain ecosystem services and climate change: A global

overview of potential threats and strategies for adaptation. Paris, France; 2017

[29] FAO. Mapping the vulnerability of mountain peoples to food insecurity. Romeo R, Vita A, Testolin R, Hofer T, editors. Rome; 2015

[30] European Union. EUSALP, Alpine Space Programme and Alpine Convention [Internet]. 2021. Available from: https://ec.europa.eu/regional_policy/sources/cooperate/alpine/eusalp_alpine_space_alpine_convention.pdf

[31] Alpine Convention. Demographic changes in the Alps: Report on the state of the Alps. Innsbruck, Austria; 2015. Available from: www.alpconv.org

[32] Weber K, Dopler A, Lexer W, Damyanovic D. Mainstreaming CCA and DRR in the Alpine Macro-Regions. EUSALP Action Group 8; 2019.

[33] Kohler T, Maselli D. Mountains and Climate Change: From Understanding to Action. Bern, Switzerland: Geographica Bernensia; 2009

[34] Palomo I. Climate Change Impacts on Ecosystem Services in High Mountain Areas: A Literature Review. Mt Res Dev. 2017;**37**(2):179-187. DOI: 10.1659/MRD-JOURNAL-D-16-00110.1

[35] Alpine Convention. Report on the State of the Alps RSA1: Transport and Mobility in the Alps. Innsbruck, Austria; 2007. Available from: www.alpconv.org

[36] Pfurtscheller C, Thieken AH. The price of safety: costs for mitigating and coping with Alpine hazards. Hazards Earth Syst Sci. 2013;**13**:2619-2637. DOI: 10.5194/nhess-13-2619-2013

[37] Nehren U, Sudmeier-Rieux K, Sandholz S, Estrella M, Lomarda M, Guillén T. The Ecosystem-Based Disaster Risk Reduction Case Study and Exercise Source Book. Nairobi, Kenya: Geneva and Cologne: Partnership for Environment and Disaster Risk Reduction and Center for Natural Resources and Development; 2014. 99 p

[38] Techel F, Jarry F, Kronthaler G, Mitterer S, Nairz P, Pavšek M, et al. Avalanche fatalities in the European Alps: long-term trends and statistics. Geogr Helv. 2016;**71**:147-159. DOI: 10.5194/gh-71-147-2016

[39] Haque U, Blum P, da Silva PF, Andersen P, Pilz J, Chalov SR, et al. Fatal landslides in Europe. Landslides. 2016;**13**(6):1545-1554. DOI: 10.1007/s10346-016-0689-3

[40] Alpine Convention. Guidelines for Climate Change Adaptation at the local level in the Alps. Innsbruck, Austria; 2014

[41] PLANALP. Alpine strategy for adaptation to climate change in the field of natural hazards. 2013. Available from: https://climate-adapt.eea.europa.eu/metadata/publications/alpine-strategy-for-adaptation-to-climate-change-in-the-field-of-natural-hazards

[42] Alpine Convention. Natural Hazard Risk Governance: Report on the state of the Alps. Innsbruck, Austria: Permanent Secretariat of the Alpine Convention; 2019. Available from: www.alpconv.org

[43] Alpine Space Programme. Interreg Alpine Space - Which area is covered? [Internet]. 2021. Available from: https://www.alpine-space.eu/about-us/cooperation-area/

[44] FOCP. Integrated Risk Management. Its importance in protecting people and their livelihoods. Bern, Switzerland: Federal Office for Civil Protection (FOCP); 2014. Available from: https://www.babs.admin.ch/en/aufgabenbabs/gefaehrdrisiken.html

[45] FOCP. Integrated Risk Management Cycle [Internet]. Bern, Switzerland:

Federal Office for Civil Protection (FOCP); 2019. Available from https://www.babs.admin.ch/en/aufgabenbabs/gefaehrdrisiken.html

[46] Lo V. Synthesis report on experiences with Ecosystem-based approaches to climate change adaptation and disaster risk reduction. CBD Technical Series No.85. Montreal, Canada: Secretariat of the Convention on Biological Diversity; 2016. Available from: https://www.cbd.int/doc/publications/cbd-ts-85-en.pdf

[47] MEA. Global Assessment Report vol. 1: Current State and Trends Assessment. New York; 2005. Available from: https://www.millennium assessment.org/en/Condition.html

[48] Raza Rizvi A, Baig S, Verdone M, IUCN, et al. Ecosystem Based Adaptation: Knowledge Gaps in Making an Economic Case for Investing in Nature Based Solutions for Climate Change. Gland, Switzerland: IUCN; 2015. Available from: http://www.iucn.org/sites/dev/files/content/documents/the_economic_case_for_eba_en_1.pdf

[49] Sudmeier-Rieux K, Arce-Mojica T, Boehmer HJ, Doswald N, Emerton L, Friess DA, et al. Scientific evidence for ecosystem-based disaster risk reduction. Nat Sustain. 2021 Jun 28; DOI: 10.1038/s41893-021-00732-4

[50] UN. Report of the Conference of the Parties to the United Nations Framework Convention on Climate Change (21st Session, 2015: Paris). Paris, France: UN; 2015

[51] UN. Addis Ababa Action Agenda of the Third International Conference on Financing for Development. Addis Ababa, Ethiopia: UN; 2015

[52] UN. New Urban Agenda. Quito, Ecuador: UN; 2017

[53] UN. 2030 Agenda for Sustainable Development. New York, New York: UN; 2015

[54] Steger S, Teich M, Crespi A, Kindermann G, Jandl R, Hormes A, et al. D.T1.1.1 Report on 'New climate impact scenarios based on CC-FC-HC links'. Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[55] UNDP. Making the Case for Ecosystem-based Adaptation: The global mountain EBA programme in Nepal, Peru and Uganda. New York; 2015. Available from: https://portals.iucn.org/library/sites/library/files/documents/2015-061.pdf

[56] CIPRA [Internet]. Available from: https://www.cipra.org/en

[57] DRMKC Disaster Risk Management Knowledge Centre of the European Commission [Internet]. Available from: https://drmkc.jrc.ec.europa.eu/

[58] EUSALP European Strategy for the Alpine Region [Internet]. Available from: https://www.alpine-region.eu/

[59] GLOMOS Global Mountain Safeguard Research [Internet]. Available from: https://ehs.unu.edu/about/departments/glomos#overview

[60] Interreg Alpine Space [Internet]. Available from: https://www.alpine-space.eu/

[61] Mountain Partnership [Internet]. Available from: http://www.fao.org/mountain-partnership/en/

[62] MRI Mountain Research Initiative [Internet]. Available from: https://www.mountainresearchinitiative.org/

[63] PLANALP Platform on Natural Hazards of the Alpine Convention [Internet]. Available from: https://www.alpconv.org/en/home/organization/thematic-working-bodies/detail/

natural-hazards-working-group-planalp/

[64] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

[65] Cocuccioni S, Poratelli F. D.T 3.4.1: Report on Development of TEGRAV risk management strategies in relation to CC and SC. [Internet]. Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[66] Schmaltz EM, Steger S, Glade T. The influence of forest cover on landslide occurrence explored with spatio-temporal information. Geomorphology. 2017;**290**:250-264. DOI: 10.1016/j.geomorph.2017.04.024

[67] Wood JL, Harrison S, Reinhardt L. Landslide inventories for climate impacts research in the European Alps. Geomorphology. 2015;**228**:398-408. DOI: 10.1016/j.geomorph.2014.09.005

[68] Dupire S, Toe D, Barré JB, Bourrier F, Berger F. Harmonized mapping of forests with a protection function against rockfalls over European Alpine countries. Appl Geogr. 2020;**120**:102221. DOI: 10.1016/j.apgeog.2020.102221

[69] Moos C, Thomas M, Pauli B, Bergkamp G, Stoffel M, Dorren L. Economic valuation of ecosystem-based rockfall risk reduction considering disturbances and comparison to structural measures. Sci Total Environ. 2019;**697**:134077. DOI: 10.1016/j.scitotenv.2019.134077

[70] Bebi P, Kulakowski D, Rixen C. Snow avalanche disturbances in forest ecosystems—State of research and implications for management. For Ecol Manage. 2009;**257**(9):1883-1892. DOI: 10.1016/j.foreco.2009.01.050

[71] Teich M, Marty C, Gollut C, Grêt-Regamey A, Bebi P. Snow and weather conditions associated with avalanche releases in forests: Rare situations with decreasing trends during the last 41years. Cold Reg Sci Technol. 2012;**83-84**:77-88. DOI: 10.1016/j.coldregions.2012.06.007

[72] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

[73] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[74] Markart G, Teich M, Scheidl C, Kohl B. Flood protection by forests in alpine watersheds: lessons learned from Austrian case studies. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. 10.5772/intechopen.99507

[75] Neuhauser M, D'Amboise C J L, Teich M, Kofler A, Huber A, Fromm R, Fischer J-T. Flow-Py: routing and stopping of gravitational mass flows. Zenodo. 2021. DOI: 10.5281/zenodo.5027274

[76] D'Amboise CJL, Neuhauser M, Teich M, Huber A, Kofler A, Perzl F, et al. Flow-Py v1.0: A customizable, open-source simulation tool to estimate runout and intensity of gravitational mass flows. Geosci Model Dev.

2022;**15**(6):2423-2439. DOI: 10.5194/gmd-15-2423-2022

[77] D'Amboise C J L, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[78] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise C J L, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[79] Cocuccioni S, Plörer M, Kirchner M. Stakeholder integration and participative processes as part of ecosystem-based risk management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99516

[80] Cocuccioni S, Renner K, Steger S. D.T 3.5.1: Report on Results of the risk analysis and the strategy prioritization [Internet]. Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[81] D'Amboise CJL, Žabota B, Poratelli F, Pecan P, Plörer M, Accastello C, et al. A.T1.6 Construction of the innovative and new protective forest assessment tool (FAT). Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

Chapter 2

Protective Forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space

Michaela Teich, Cristian Accastello, Frank Perzl and Frédéric Berger

Abstract

Mountain forests are an efficient *Forest-based Solution* (FbS) for Ecosystem-based Disaster Risk Reduction (Eco-DRR) by lowering the frequency, magnitude, and/or intensity of natural hazards. Technical protection measures are often poor solutions as stand-alone measures to reduce disaster risk limited by material wear and fatigue or financial resources and aesthetical values. Protective forests should therefore be considered as key elements in integrated risk management strategies. However, the definition of protective forests and the understanding and assessment of their protective functions and effects differ greatly among Alpine Space countries. In this chapter, we present a short introduction to the concept of Eco-DRR and companion terms and propose a definition of FbS as a specific case of Nature-based Solutions for an ecosystem-based and integrated risk management of natural hazards. That is, we guide the reader through the maze of existing definitions and concepts and try to disentangle their meanings. Furthermore, we present an introduction to forest regulations in the Alpine Space and European protective forest management guidelines. Our considerations and recommendations can help strengthen the role of protective forests as FbS in Eco-DRR and the acknowledgment of the key protective function they have and the crucial protective effects they provide in mountain areas.

Keywords: Ecosystem-based Disaster Risk Reduction, Nature-based Solutions, *Forest-based Solutions*, protective forests, protection forests, forest management guidelines

1. Introduction

The adverse impacts of climate change on societal and environmental systems are serious threats to the habitability and development of mountain areas worldwide by impacting the three components of the risk concept: hazard, vulnerability, and exposure [1]. The negative correlation between climate change impacts and ecosystems' health and vitality is becoming increasingly evident. Many studies and first-hand accounts have shown that overexploited and/or degraded ecosystems are less resistant to external stressors, leading to disasters caused by more frequent and intense natural hazards of greater magnitude [2, 3]. Given the strong link between

climate change adaptation and disaster risk reduction—actions aimed at reducing hazard, vulnerability, and/or exposure—a preventive and integrated risk management (IRM) is essential [4, 5] (see also chapter [6] of this book).

In the era of overpopulated risk-prone areas and settlement expansion into previously uninhabited regions [7, 8], implementing more and bigger technical measures (also called "gray infrastructure") for protection against natural hazards cannot be the sole answer to the rising disaster risk. Engineers such as Alexandre Surell (1813–1887) and Prosper Demontzey (1831–1898) came to this conclusion as early as the nineteenth century. They used grassing and afforestation of deforested slopes in the Alps to supplement structural measures, protecting against soil erosion, torrential floods, and snow avalanches. Limited by hazard resistance, material wear and fatigue, available space, financial resources, and aesthetical values, gray infrastructure as a stand-alone protection measure is an inadequate solution for risk reduction, especially in rural and nonurban areas [9, 10]. In contrast, Nature-based Solutions (NbS) take advantage of ecosystems and the services they provide to address societal challenges such as climate change, food security, or natural disasters (see **Figure 1**) [11–14].

Nature-based Solutions are an umbrella term that appeared in the 2000s to overarch all "actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits," as defined by the International Union for Conservation of Nature (IUCN; [15]). NbS therefore encompass various established climate change adaptation and disaster risk reduction approaches [13], such as:

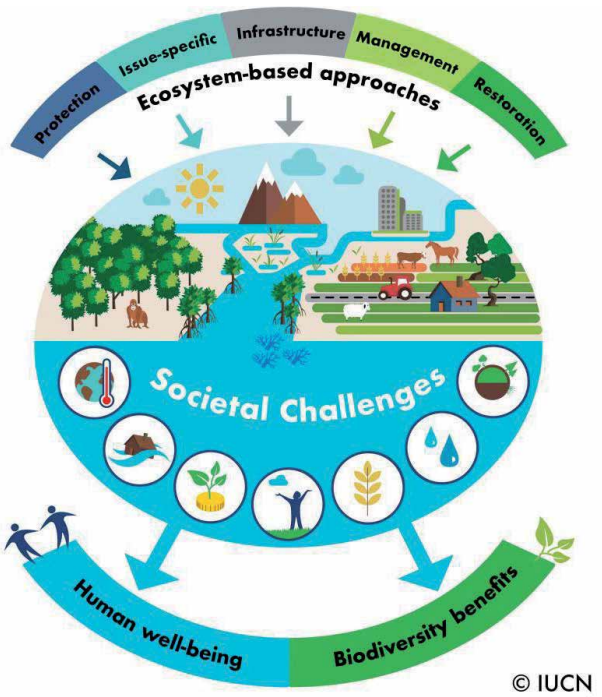


Figure 1.
The concept of Nature-based Solutions (NbS) as defined by the International Union for Conservation of Nature (IUCN). NbS are accompanied by benefits from healthy ecosystems, targeting societal challenges such as climate change, disaster risk reduction, food and water security as well as health and are critical to economic development. Adapted from [15].

- Ecosystem-based Adaptation (EbA) measures, which use biodiversity and ecosystem services as part of an overall strategy to help communities adapt to climate change impacts by, for example, reducing carbon emissions from ecosystem degradation and enhancing carbon sequestration. EbA recognizes the importance of equity and gender and the role of local and traditional knowledge as well as species diversity and the provision of other co-benefits that are crucial for livelihoods and human well-being [16, 17];

- Green infrastructure (GI), a strategically planned network of natural and seminatural areas with environmental features designed and managed to deliver a wide range of ecosystem services, including green spaces and other physical features in terrestrial, coastal, and marine areas [11, 18]; and

- Ecosystem-based Disaster Risk Reduction (Eco-DRR), which is the "sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim to achieve sustainable and resilient development" [4]. Well-managed ecosystems can therefore act as Eco-DRR measures by influencing one or more of the three (natural) hazard components (**Figure 2**) and by providing additional ecosystem services, which are essential to increase the socio-economic resilience and sustain the livelihoods of people and communities [21, 22]. Therefore, this concept, which first appeared in 2009 and was defined in 2013 [22], fits the objectives and principles of managing forest ecosystems in mountain areas for protecting people and assets against natural hazards, similar to the long-existing concept of multifunctional mountain forest management (e.g., [23]).

Mountain areas and their inhabitants are particularly vulnerable to climate change while also being exposed to several natural hazards. This requires enhancing mountain communities' ability to manage the involved risks while being conscious of the tremendous natural capital mountain landscapes provide.

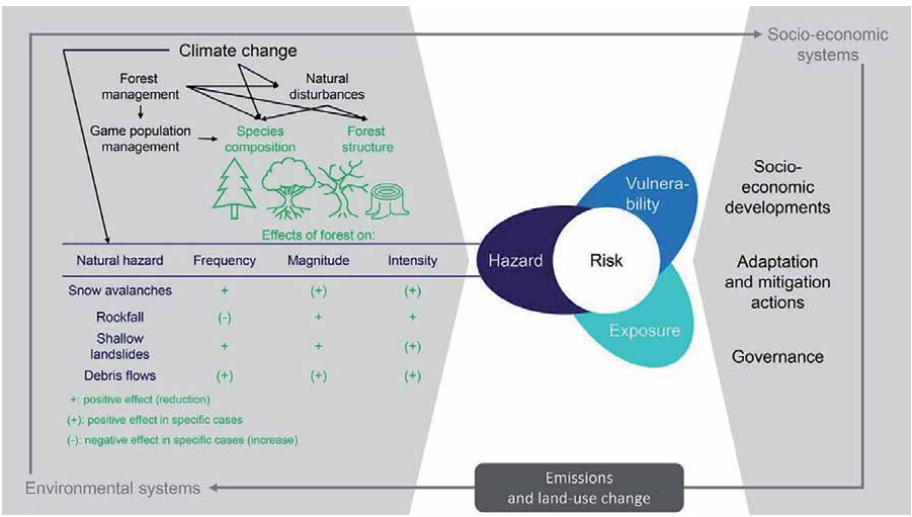


Figure 2.
Conceptual framework of the climatic, ecological, economic, and social conditions that influence the risk of gravitational natural hazards in mountain areas resulting from the interaction of a hazard (hazard potential) with exposure and vulnerability (damage potential) of human and natural systems. The effects of forest on the three hazard components frequency (i.e., onset probability), magnitude (i.e., propagation probability), and intensity are highlighted in green. Adapted from [1, 6, 19, 20].

Mountain forests can prevent natural hazards or lower their frequency, magnitude, and/or intensity by reducing onset (release) and/or propagation (runout) probabilities [19, 24–26]. Making the Alpine Region inhabitable, these so-called protective forests (or protection forests [27]) therefore represent an effective solution for Eco-DRR and should have a key role within the portfolio of IRM measures.

However, actions related to NbS are often not compatible with managing protective forests for the sustainable provision of their protective effects. NbS are applied at landscape scales aiming at simultaneously providing human well-being and biodiversity benefits. In contrast, protective forests as "*Forest-based Solutions*" (FbS) are a specific case of NbS, which is dedicated to preventing and mitigating natural hazard risks. They are mainly implemented at the slope scale together with spatial planning (hazard zoning) and technical measures as part of an IRM.

Nevertheless, a sustainable management of protective forests to improve their resilience and protective effects generates important co-benefits, such as carbon sequestration and aesthetical values, and supports local communities' livelihoods [21, 28]. Given the similarities between Eco-DRR and EbA measures, protective forests are an excellent example for no-regret actions, i.e., solutions "that will always have a positive impact on livelihoods and ecosystems regardless of how the climate changes" [29]. Furthermore, a sustainable and risk-based management of protective forests can achieve both disaster risk reduction and climate change adaptation [30, 31]. Nonetheless, the recognition of these forest stands as effective and cost-efficient Eco-DRR measure is still in need of improvement [4]. Despite acknowledging the important functions mountain forests have for the protection against natural hazards since at least the eighteenth century [8], only 60 out of 10,357 peer-reviewed scientific publications published between 1980 and 2019 that address risk management of gravitational natural hazards (snow avalanches, rockfall, shallow landslides, and debris flows) also include "ecosystem-based solutions" (including search terms such as Nature-based Solutions, Eco-DRR, green infrastructure, and protective forest) [32]. However, additional documents were published, for example, by international organizations such as the IUCN, the Food and Agriculture Organization of the United Nations (FAO), and the Partnership for Environment and Disaster Risk Reduction (PEDRR) [4, 22, 29, 33], endorsing the protective function of mountain forests and their inclusion into current natural hazard risk management strategies toward an ecosystem-based and integrated risk management.

The application of IRM in mountain areas makes it possible to incorporate FbS as Eco-DRR measures including protective forests to prevent or mitigate natural hazards, which allows creating resilient landscapes as the overarching goal [4]. Of course, also FbS have limitations, which are still inhibiting their application on large spatial scales. Green infrastructure needs enough space and favorable ecologic conditions to thrive and will degrade, if not properly managed, which leads to a decline in their performances [10, 17]. From a decision-maker perspective, few economic evaluation methods are currently available to compare the cost-effectiveness of green and gray infrastructures [29, 34–36] (see also chapters [37–40] of this book). The available methods often lack in accurate performance assessment, long-term effectiveness monitoring, and a definition of environmental, economic, and/or societal impact evaluation indicators [14]. For these and other reasons, implementing a mix of gray and green infrastructures is often the best solution, benefiting from the advantages of both measures to enhance the sustainability and resilience of risk management strategies [11, 22].

To include protective forests in IRM strategies throughout the Alpine Space, science, practice, and policy need to address the above-mentioned deficits and knowledge gaps. However, the foundation for a clear communication among scientists, practitioners, policy makers, and with the public as well as a common

understanding of existing protective forest management guidelines need to be established first.

2. Defining protective forests as Eco-DRR measure

"*A protection [or protective] forest is a forest that has as its primary function the protection of people or assets against the impacts of natural hazards or adverse climate*" [24].

That is, in the context of natural hazard risk, 1) a hazard that may cause damage, 2) people or assets that may be damaged, and 3) a forest that has the potential to prevent or mitigate this damage must be present, so that this forest can have a protective function [41]. In addition to the general need for the protection of people and assets by forest, the protective function is also associated with the protective potential of a location (either currently covered by forest vegetation or not), which is the "protective effect that a forest is likely to have if properly managed" [27]. That is, the "protective effect" refers to the degree of hazard mitigation by forest, which depends on the current canopy cover and stand structure (see also chapter [42] of this book).

However, the terms "protective function" and "protective effect" are often used inconsistently, synonymously, and sometimes misleadingly throughout the Alpine Space, which originates from country-specific forest legislations [43–45]. To support a common understanding, Kleemayr et al. proposed a consistent protective forest definition matrix (originally "Protection forest definition matrix"; [46]) with the aim to disentangle and illustrate the similarities and differences between existing terms (**Figure 3**) [47].

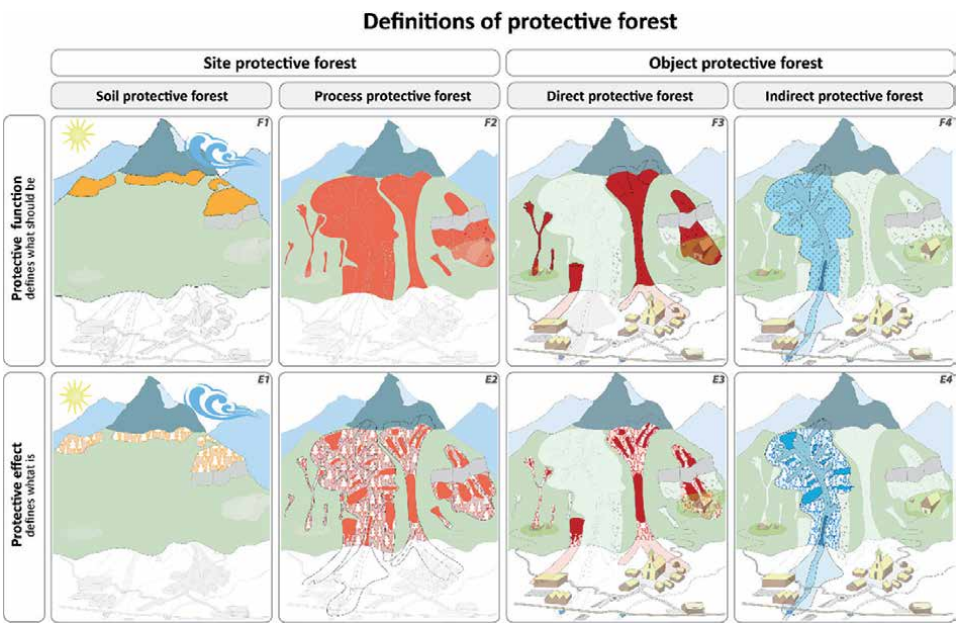


Figure 3.
Adapted reprint of the main figure from the "Protection forest definition matrix" [46]—An illustration of similarities and differences between sometimes contrarily defined and used terms regarding protective forests in the Alpine Space. Column 1: orange = soil protective forest (F1 = protective function, E1 = protective effect); column 2: red = protective forest growing in natural hazard starting, transit and runout zones; column 3: dark red = direct object protective forest; column 4: blue = indirect object protective forest; green = current forest or potential forest (land) use area; E1–E4 show forest areas that have a protective effect (tree elements) and forest gaps without a protective effect (full color). For details, see [46, 47].

The term protective function is mainly applied in land use and strategic forest management planning, such as the forest development plan in Austria ("Waldentwicklungsplan" WEP; [48]) or the forest function maps in Germany ("Waldfunktionskarten" based on § 1 and 12 BWaldG [49]). That is, to control land use development, plan silvicultural interventions and regulate harvesting, desired forest functions such as protection, recreation, timber production, or climate and water regulation (i.e., forest ecosystem services) are spatially defined and mapped. The concept of forest functions therefore translates social and economic interests into land use regulations and forest management practices and is commonly applied, for example, in Italy where "Forests having the function of direct protection of inhabitants, of strategic assets and infrastructures, identified and recognized by Regions and Autonomous Provinces, cannot be transformed and the land use cannot be changed [...]" (Legislative Decree 34/2018 "Consolidated Law on forests and forestry chains," Article 8, Subparagraph 7; [43]). This understanding of the protective function is, for example, translated into the definition by the Konferenz der Kantonsoberförster (KOK 2007; conference of the Swiss cantonal head foresters): a protective forest is a forest that can protect an acknowledged damage potential against a recognized natural hazard or reduce the associated risks [50, 51]. This definition is one of the most particular ones of de facto legality specifically including the terms natural hazard and risks. In contrast, in French or Slovenian forest legislations, protective forests can also be "[...] forests located on the periphery of large urban areas" (French Forest Code, Code forestier; [43]), or "Forests in adverse ecological conditions which protect themselves, their land and lower-lying land [...]." (Slovenian Forest Act; ZG, Article 43 [52]), or have additional tasks such as to protect the soil from degradation and erosion, and to ensure forest growth capacity as stated in the Austrian Forest Act (ForstG [53]).

The protective forest definition matrix by Kleemayr et al. [46] combines elements from existing national legislations; however, it does not include all environmental conditions and criteria that define protective forests in national forest laws of the Alpine Space. The matrix defines "A forest with a protective function designation [as] a forest or potential forest area intended to protect against soil degradation and/or natural hazards" and uses the term "protective effect" in the context of disaster risk reduction. That is, "the protective effect describes the actual protective capacity of a forest against natural hazards and/or soil degradation" in dependence of its structure, which is a regulating ecosystem service according to the Millennium Ecosystem Assessment framework [54]. Applying the term protective effect therefore implies an evaluation of the forest structure, which allows one to assess the actual degree of provided protection against natural hazards. For example, a high protective effect against rockfall is only possible, if a forest has a certain number of stems, basal area, stem diameter distribution, or tree species composition in rockfall transit and/or deposit zones to stop falling rocks (see chapter [42] of this book); however, even if the protective effect of a forest stand is low or the vegetation cover is temporarily absent, it could still have an important protective function due to its uphill location above assets.

The national definitions that are combined in the protective forest definition matrix imply that not only a hazard (potential), but also a natural hazard risk, i.e., a damage potential (the assets to be protected by forest and their entities, which are called "objects" in the context of protective function mapping; see chapter [55] of this book), must be present when declaring a forest area as an object protective forest. Object protective forests are forests, which are located in process areas of natural hazards that endanger objects below and can have 1) a direct protective function and, if applicable, protective effect against gravitational natural hazards such as rockfall, shallow landslides, or snow avalanches, allowing to directly link the

precise locations of the hazard and the endangered objects; or 2) an indirect object protective function (and effect) for floods and other water-related natural hazards [51]. The latter relationship is defined as indirect since an entire forested catchment can contribute to flood protection (see chapter [56] of this book), and it is not straightforward to establish a direct connection between a precisely located forest area and a flooding scenario, especially when applying protective forest models (see chapter [57] of this book).

The matrix of definitions and classifications proposed by Kleemayr et al. [46] can support incorporating protective forests as Eco-DRR solution into IRM concepts, distinguishing direct and indirect object and site protective forests for prioritizing management activities that maintain and/or enhance their protective effects—actions that would promote the recognition of these forests as Eco-DRR measure and facilitate their utilization in IRM strategies. Nonetheless, the shift toward an IRM that includes FbS into the portfolio of available measures is still incomplete, also due to difficulties in translating research results into policy and further into useful and harmonized information for practitioners (see also chapter [58] of this book).

3. Regulations and guidelines for managing protective forests in the Alpine Space

3.1 Forest policy needs to utilize *Forest-based Solutions* for Eco-DRR

The mid-nineteenth century marked an important turning point for raising concerns about large-scale deforestation impacts on soil erosion and flood events in several Alpine countries. The following debate began, for example, in France and Austria, realizing that it was necessary to reestablish the protective functions and effects of mountain forests that have been impaired by centuries of overgrazing and overexploitation [59, 60]. France introduced the first nation-wide legal regulation on protective forests in 1803, which was perpetuated in 1827 with the Code forestier; however, the regulations were not comprehensive and were limited to a ban on deforestation of mountain slopes. The absence of specific legislations for mountain areas was strongly felt by politicians and forest managers as, for example, proven by the declaration of Ludovic Beaussire, special editor and contributor to the first volume of the Annales forestières (Forest Annals) of 1842: "The considerations, which make the reforestation of the mountains a necessity, impose on the government, as one of its most pressing and sacred duties, the obligation to provide for it [61]." In Austria, it was catastrophic flood events (e.g., 1847 in Salzburg) that increased the awareness for the need of a sufficient forest cover to mitigate the devastating effects of natural hazards. This led to the implementation of the first Austrian Forest Act in 1852 ("Reichsforstgesetz"), which was replaced in 1975 [53], ensuring the conservation of forests and their soils to best provide the forest effects, namely timber production; protection against natural hazards and other damaging environmental impacts including soil erosion; regulation of climate, water, and air; and recreation (ForstG 1975 idF 2002, § 1 (2), § 6 (2) [53]). Few years after the implementation of Forest Acts with special regulations on protective forests in Austria and Bavaria in 1852, the French government of the Second Empire implemented a definition of forests to be protected from deforestation because of their protective effect in 1859 in the Code forestier and established the first law mandating Alpine reforestation in 1860. However, this law was negatively perceived by mountain peasants since it threatened their pasturing, a necessity for their livelihood [62]. This law has therefore been modified in 1882 to the law on restoration and conservation of Alpine lands and the word reforestation was omitted from the

title, shifting the focus of forest management activities from extending forest areas to "restore mountain land by correcting torrents, regulating pastures and planting eroded watersheds" [63]. This law is the basis of French legislation dedicated to the sustainable management of the ecosystem service "protection against natural hazards" and was the model for legislations of many Alpine Space countries such as the Austrian Act of 1884 on torrent control, laying the foundation of Alpine land restoration. However, it was the 1922 Chauveau law that established the legal status of "protective forestry," acknowledging the major role of forests in natural hazard prevention and risk mitigation for lowland areas, which were becoming more and heavily industrialized [59]. The acknowledgment of the protective effects of forests is one factor, but its implementation in forest management practices is often impeded by the lack of a comprehensive mapping of forests with a protective function (see also chapter [55] of this book). Eventually, any legislation can be improved, considering the increase in knowledge and changes in the paradigms of the implementation of measures.

One objective of the Interreg Alpine Space project GreenRisk4ALPs [64] was to propose ways to improve current forestry policies in the Alpine Space. Hence, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was conducted by experts for (protective) forest legislations in Austria, France, Bavaria (Germany), Italy, and Slovenia [65]. A summary, based on this SWOT analysis, of the general existence of regulations, tools, and standardized methods to support the management of protective forests as an FbS for Eco-DRR is given in **Table 1**.

Based on this SWOT:

- Clearly defining protective forests and their functions in forest legislations,
- Specifying methods, data, and tools to be applied for protective forest mapping,
- Defining and legitimizing operational protection targets and priorities for assets related to risk,
- Increasing the quality of geodata necessary to assess protective functions effectively,
- Spatially covering all relevant hazard and damage potentials in hazard and risk zoning,
- Implementing common standards to assess protective effects and the stability of protective forests,
- Collecting high-quality data on past natural hazard events and pre-event forest condition in a harmonized way to improve protective effect assessments,
- Developing and implementing an efficient participatory approach for land use and forest planning,
- Bundling competences in hazard and forest ecosystem services' assessments to improve their results and acceptance,
- Connecting key stakeholders in the field of natural hazard risk management and, whereby, harmonizing their interests with societal demands,

DOI: http://dx.doi.org/10.5772/intechopen.99505

	Administrative level	Austria		France		Germany		Italy		Slovenia	
Existence of:		**YES**	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
Regulations for risk prevention	national	X			X	X			X	X	
	regional	X		X			X	X		X	
Protective forest definition and/or classification	national	X		X		X			X	X	
	regional		X	X			X	X		X	X
Comprehensive mapping of natural hazards	national	X			X	X		X			X
	regional	X		X		X		X			X
	local	X		X		X		X			X
Comprehensive mapping of natural hazard risks	national		X		X		X	X			X
	regional		X		X	X		X			X
	local		X		X	X		X			X
Comprehensive mapping of the ecosystem service "protection"	national	X		X		X			X	X	
	regional	X		X		X			X	X	
	local	X		X		X			X	X	
Funding for the provision of the ecosystem service "protection"	EU	X			X	X		X		X	
	national	X			X	X			X	X	
	regional	X			X	X			X		X
	local	X		X			X		X		X
Natural hazard risk prevention documents that integrate the ecosystem service "protection"	national	X			X		X		X	X	
	regional	X			X		X		X	X	
	local	X			X		X		X	X	

	Administrative level	Austria		France		Germany		Italy		Slovenia	
Existence of:		**YES**	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
Standardized methodology for risk zoning	national	X		X		X			X	X	
	regional	X		X			X	X		X	
	local	X		X		X		X		X	
Protective forest management guidelines	national	X		X		X			X	X	
	regional	X		X		X		X		X	
	local	X		X		X			X	X	
Societal demand for valuing *Forest-based Solutions*		X		X		X		X		X	

Table 1.
Summary of the general existence of regulations, tools, and standardized methods in selected Alpine Space countries, supporting the management of protective forests as FbS for Eco-DRR. Adapted from [65].

- Addressing the current lack of adapted financial funds and of clear rules to allocate these funds dedicated to protective forest managements,

- Legally combining hunting and forestry regulations,

- Increasing public awareness for protective forests and their key function, and

- Developing clear communication and dissemination strategies about the efficiency and limits of FbS,

are only a few recommendations to enhance current (protective) forest policies and legislations to support improving the relevance of FbS in IRM (for further information and details see [65]).

3.2 Risk in current European protective forest management guidelines

It was early recognized by those responsible for natural hazard and forest management in the Alpine Space that reducing the risk from natural hazards endangering people and damaging assets requires the expansion of forest areas [66], especially at high altitudes and in torrent catchments [67], as well as special silvicultural treatments of forests with a protective function. However, first regional regulations and measures were limited to restrict or ban deforestation, grazing by farm animals, and timber removal in forests on steep mountain slopes. These regulations were formulated in the medieval concept of protected forests (so-called Bannwälder), which are still a legal category of direct object protective forests in Austria and Bavaria. Deforestation and forest thinning, which increased with population growth, required actions to protect against natural hazards but also to secure local timber supply in a phase of increasing economical protectionism. Following devastating flood disasters and increasing demand for timber in the nineteenth century, national forest laws with special regulations for protective forests and torrent control were introduced and extensive reforestation programs were launched (see Section 3.1).

Even if regulations and silvicultural measures in the nineteenth and early twentieth century focused on (protective) forest conservation, reforestation, and afforestation, it was known that the protective effects of forests depend on their structure and thus on their management. However, despite emphasizing the importance of protective forest management in the literature, clear concepts for determining the object protective functions and protective effects based on site-specific hazard susceptibilities, damage potentials, and forest conditions were still missing until the end of the twentieth century.

After the Second World War and until the end of the 1980s, structural river regulation, and technical torrent and avalanche control boomed in the European Alps. These measures were further developed and implemented at great expense. Meanwhile, hardly any approaches were developed to quantify the protective effects of forests against gravitational natural hazards. In this period, only a few studies mainly from Japan (e.g., [68, 69]) and Switzerland (e.g., [70, 71]) addressed the influence of forest structure on snowpack stabilization based on systematic observations or snow mechanical considerations. However, the results of these early and valuable studies are difficult to integrate into avalanche risk analysis since they lack important factors as well as the large variation in forest conditions influencing the protective effects. In addition, they did not offer methods for calculating the impact of forest on onset and propagation probabilities that are required to determine the risk (see section 1).

The first experimental study on the influence of forest on the runout of rockfall did not appear until 1988 [72]. While studies on the protective effects of forests against landslides were carried out early in Japan (e.g., [73]) and in North America (e.g., [74–76]), this topic was reduced to bioengineering measures and taken up rather late in Europe. Moreover, studies about landslide-forest interactions mainly focused on the differences between forest and other land cover types and the effects of clear cutting, that is, the presence or absence of forest cover was treated as a general parameter. Although approaches to predict slope stability considering the canopy coverage of woody vegetation appeared in the 1970s (see [77]), the influence of its structural characteristics on the probability of landslide occurrence has been rarely investigated.

Mountain forest research in Europe mainly addressed silvicultural topics such as forest type identification, natural regeneration, reforestation, high-altitude afforestation, and stand tending for stability. The first comprehensive books published by Mayer (1976) in Austria [78] and Bischoff (1984) in Switzerland [79] giving practical advice for the management of Alpine mountain forests provided some checklists for assessing the protective functions and effects of forests but were still little oriented toward natural hazard risk assessment [80]. Perhaps the economic and technical possibilities for implementing gray infrastructures and their great success have contributed to the fact that forest research was limited to silvicultural questions and that hardly any research funding has been made available to study the protective effects of forest. However, by the end of the 1970s, the limited effects and capacities for disaster risk reduction by gray infrastructures only were increasingly recognized, especially in flood and torrent control, which can be observed in many regions worldwide and is called the paradigm shift in flood risk management (see also chapter [56] of this book). Disaster prevention and mitigation strategies were supplemented through spatial planning (hazard zoning), which indirectly led to an increasing need to assess the protective functions and effects of forest. Furthermore, the consequences of forest dieback in Europe caused by air pollution in the 1980s and the adverse impacts of climate change became increasingly apparent in mountain areas in the 1990s. Considerable forest damages by storm and bark beetle outbreaks in the 2000s as well as questions of funding policies in hazard mitigation and forestry pushed new studies about protective effects of forests (e.g., [81, 82]), protective forest management planning, and a second generation of silvicultural guidelines including procedures for hazard-related forest assessment and management [80].

In the frame of the Interreg Alpine Space project GreenRisk4ALPs [64], Perzl and Kleemayr [80] analyzed the general concepts of five of these current European protective forest management guidelines—the Swiss guideline NaiS [83], the Italian SFP [84], the French GSM-N [85] and GSM-S [86], and the Austrian guideline ISDW [87]—in terms of applicability for hazard risk management. Furthermore, they evaluated the hazard-related criteria and thresholds proposed by the guidelines, which are protective effect-related indicators for hazard risk assessment and targets for forest management (see chapter [42] of this book).

All these guidelines follow the structure and the criteria of the Swiss guideline NaiS but differ in many crucial details considerably. According to Perzl and Kleemayr [80], they incorporated new scientific knowledge and structured the support of planning and decisions into 1) the assessment of the natural hazard risk (as hazard and damage potentials in terms of basic hazard susceptibilities or protective functions of forest, and in terms of forest conditions, which provide protective effects), 2) the assessment of stand stability and regeneration, and 3) general recommendations on silvicultural treatments. This concept of first classifying the protective functions of forests based on indicators for the hazard potential and

the exposure and vulnerability of assets (damage potential) and then classifying the protective effects based on silvicultural targets is a simplified risk-based approach suitable for protective forest management.

However, this concept is implemented to varying degrees of completeness in the guidelines. Some of these guidelines do not fully support forest function mapping and, therefore, risk evaluation since they do not consider the damage potential. All guidelines provide little support for delineating spatial evaluation units, which remains an unsolved issue of spatial scales and fragmentation of management units situated between traditional forest stand mapping and appropriately resolved units for protective effect and hazard analyses. Furthermore, the results of the proposed methods for assessing the protective functions and effects of forests are still of limited value for risk analyses, as they only refer to hazard initiation, partly based on fuzzy indicators of hazard susceptibility, or, if considering hazard propagation as in the case of rockfall, they mainly neglect the cumulative effects of terrain and forest on the slope scale. Some of the guidelines even do not provide clear instructions for how to combine the proposed indicators and thresholds (targets) to quantify cumulative protective effects. Although they specify single objectives for forest conditions to be reached with silvicultural measures and indicators of how to monitor their success, which are the main aims of the guidelines, they are thereby ambiguous about the protective effect in terms of hazard probability and magnitude and thus about the natural hazard risk.

The validation of the protective effect-related forest characteristics proposed by the guidelines based on observed natural hazard events in forests shows the main limitation for their application in natural hazard risk management: the procedures, indicators, and thresholds to assess the protective effects of forest against gravitational natural hazards lead to either a considerable or an extremely low misclassification rate, the latter resulting primarily from high forest density targets (for further details, see chapter [42] of this book). This may result in over- or underestimating the protective effects of forests and thus in incorrect assessments of the risk from natural hazards endangering people and damaging assets.

Although research on protective effects of forests has increased since the late 1980s (e.g., [19, 88, 89]), but especially on rockfall-forest interaction in Switzerland and France [90], the current European protective forest management guidelines are still based on few data-driven studies without international survey and quality standards [80]. Therefore, they are difficult to interpret and to implement into risk-based protective forest management approaches. Moreover, uncertainties in assessing protective effects of forest are still considerable (e.g., [91]; see also chapter [40] of this book.), which could be the main reason affecting confidence in FbS in contrast to gray infrastructure.

4. Conclusions

Impacts of climate change on societal and environmental systems are serious threats to the development of mountain areas worldwide. Mountain forests can protect people and assets against natural hazards making the Alpine Region inhabitable. Protective forests are *Forest-based Solutions* (FbS) as a specific case of Nature-based Solutions (NbS) and are often implemented as Ecosystem-based Disaster Risk Reduction (Eco-DRR) measure together with spatial planning activities and gray infrastructure within an integrated risk management (IRM). However, few economic evaluation methods are currently available to compare the cost-effectiveness of protective forests and technical measures, despite implementing a mix of gray and green infrastructures is often the best solution, benefiting from the

advantages of both to enhance the sustainability and resilience of risk management strategies.

To facilitate the utilization of protective forests in IRM strategies throughout the Alpine Space, science, practice, and policy need to address the deficits and knowledge gaps that we identified in this chapter. They include 1) a common understanding and definition of protective forests, 2) existing national barriers for implementing Eco-DRR in the Alpine Space, and 3) the applicability of protective forest management guidelines in risk-based forest management approaches for prioritizing management activities that maintain and/or enhance the protective effects. Despite the societal demand for valuing FbS, the ecosystem service "protection against natural hazards" provided by mountain forests is currently often not considered in local, regional, national, and/or European policies and regulations.

Improving current (protective) forest legislations by financing and considering practice projects and research addressing protective functions and effects of mountain forests and changes in the paradigms of the implementation of protection measures can enhance the relevance of FbS in IRM. Moreover, although research on protective effects of forests has increased in recent decades, current European protective forest management guidelines are still based on few studies and are difficult to implement into risk-based protective forest management approaches. Establishing international survey and quality standards for assessing protective effects and, therefore, reducing the associated uncertainties could also significantly increase the trust in FbS compared with gray infrastructure.

Ultimately, the shift toward an IRM that includes FbS into the portfolio of available risk mitigation measures requires translating research results into useful and harmonized information for practitioners (see also chapter [58] of this book).

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by Interreg Alpine Space program, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy.

Conflict of interest

The authors declare no conflict of interest.

Author details

Michaela Teich[1*], Cristian Accastello[2,3], Frank Perzl[1] and Frédéric Berger[4]

1 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

2 Department of Agriculture, Forest and Food Sciences (DISAFA), University of Turin, Grugliasco, TO, Italy

3 Consorzio Forestale Alta Valle Susa (CFAVS), Oulx, TO, Italy

4 National Research Institute for Agriculture, Food and Environment (INRAE), Université Grenoble Alpes, Grenoble, France

*Address all correspondence to: michaela.teich@bfw.gv.at

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Team CW, Pachauri RK, Meyer LA, editors. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2014. p. 151

[2] Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, et al., editors. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, NY, USA: Cambridge University Press; 2012. p. 582

[3] UNDRR. Global Assessment Report on Disaster Risk Reduction. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction (UNDRR); 2019

[4] Nehren U, Sudmeier-Rieux K, Sandholz S, Estrella M, Lomarda M, Guillén T. The Ecosystem-Based Disaster Risk Reduction Case Study and Exercise Source Book. Geneva and Cologne: Partnership for Environment and Disaster Risk Reduction and Center for Natural Resources and Development; 2014. p. 99

[5] Sudmeier-Rieux K, Arce-Mojica T, Boehmer HJ, Doswald N, Emerton L, Friess DA, et al. Scientific evidence for ecosystem-based disaster risk reduction. Nature Sustainability. 2021;**4**(9):803-810. DOI: 10.1038/s41893-021-00732-4

[6] Accastello C, Cocuccioni S, Teich M. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[7] Ravazzoli E, Scuttari A, Streifeneder TP. Demographic Changes in the Alps: Report on the State of the Alps. Innsbruck and Bolzano, Austria: Permanent Secretariat of the Alpine Convention; 2015

[8] Keiler M, Fuchs S. Challenges for natural hazard and risk management in mountain regions of Europe. In: Oxford Research Encyclopedia of Natural Hazard Science. Oxford, England: Oxford University Press; 2018

[9] Cohen-Shacham E, Walters G, Janzen C, Maginnis S. Nature-Based Solutions to Address Global Societal Challenges. Gland, Switzerland: IUCN; 2016. DOI: 10.2305/IUCN.CH.2016.13.en

[10] Sudmeier-Rieux K. Ecosystem Approach to DRR: Basic Concepts and Recommendations to Governments, with a Special Focus on Europe. France: Strasbourg; 2012

[11] Browder G, Ozment S, Rehberger Bescos I, Gartner T, Lange G-M. Integrating Green and Gray: Creating Next Generation Infrastructure. Washington, DC: World Bank and World Resources Institute; 2019

[12] Naumann S, Davis M. Biodiversity and Nature-Based Solutions: Analysis of EU-Funded Projects. Luxembourg: Publications Office of the European Union; 2020

[13] European Environment Agency. Nature-Based Solutions in Europe: Policy, Knowledge and Practice for Climate Change Adaptation and Disaster Risk Reduction. Luxembourg: EEA Report No 01/2021; 2021. DOI: 10.2800/919315

[14] Raymond CM, Berry P, Breil M, Nita MR, Kabisch N, de Bel M, et al. An Impact Evaluation Framework to Support Planning and Evaluation of Nature-Based Solutions Projects. Wallingford, UK: Centre for Ecology & Hydrology; 2017

[15] IUCN. Nature-based Solutions [Internet]. Available from: https://www.iucn.org/theme/nature-based-solutions/about

[16] Lo V. Synthesis Report on Experiences with Ecosystem-Based Approaches to Climate Change Adaptation and Disaster Risk Reduction. CBD Technical Series No. 85. Montreal, Canada: Secretariat of the Convention on Biological Diversity; 2016

[17] Rizvi AR, Baig S, Verdone M. Ecosystem Based Adaptation: Knowledge Gaps in Making an Economic Case for Investing in Nature Based Solutions for Climate Change. Gland, Switzerland: IUCN; 2015 Available from: http://www.iucn.org/sites/dev/files/content/documents/the_economic_case_for_eba_en_1.pdf

[18] European Commission. Ecosystem services and green infrastructure [Internet]. 2020. Available from: https://ec.europa.eu/environment/nature/ecosystems/index_en.htm#:~:text=Green%20infrastructure%20is%20a%20strategically,and%20climate%20mitigation%20and%20adaptation

[19] Moos C, Bebi P, Schwarz M, Stoffel M, Sudmeier-Rieux K, Dorren LKA. Ecosystem-based disaster risk reduction in mountains. Earth-Science Reviews. 2018;**177**:497-513. DOI: 10.1016/j.earscirev.2017.12.011

[20] Lexer MJ. Zukünftige Entwicklung des Bergwaldes [Internet]. Innsbrucker Hofburggespräche: Wald und Lawine, 20.11.2019, Innsbruck, Austria: Austrian Research Centre for Forests (BFW); 2019. Available from: https://www.bfw.gv.at/wp-content/uploads/Hofburggespraech19_Lexer_klimawandel.pdf

[21] Renaud FG, Sudmeier-Rieux K, Estrella M, Nehren U, editors. Ecosystem-based disaster risk reduction and adaptation in practice. NTHR Vol. 42. Cham, Switzerland: Springer; 2016. p. 598. DOI: 10.1007/978-3-319-43633-3

[22] Renaud FG, Sudmeier-Rieux K, Estrella M. The Role of Ecosystems in Disaster Risk Reduction. Tokyo, New York, Paris: United Nations University Press; 2013. p. 486

[23] Schmidhauser A, Schmithüsen F. Entwicklung der Finanzierung einer multifunktionalen Waldbewirtschaftung in den Forstbetrieben öffentlicher Waldeigentümer im schweizerischen Alpenraum | Development of Financing of a Multi-Functional Forest Management for Forest Enterprises of Publicly Owned Forest in the Alpine Region of Switzerland. Schweizerische. Zeitschrift für Forstwesen. 1999;**150**(11):416-428

[24] Brang P, Schönenberger W, Frehner M, Schwitter R, Thormann JJ, Wasser B. Management of protection forests in the European Alps: An overview. Forest Snow Landscape Research. 2006;**80**:23-44

[25] Brang P. Resistance and elasticity: Promising concepts for the management of protection forests in the European Alps. Forest Ecology and Management. 2001;**145**(1-2):107-119. DOI: 10.1016/S0378-1127(00)00578-8

[26] Frehner M, Wasser B, Schwitter R. Sustainability and Success Monitoring in Protection Forests. Environmental Studies no. 27/07. Bern, Switzerland: Federal Office for the Environment (FOEN); 2007. 29 p. + 26 p. Available from: https://www.bafu.admin.ch/bafu/en/home/topics/forest/publications-studies/publications/sustainability-success-monitoring-protection-forests.html

[27] Brang P, Schönenberger W, Ott E, Gardner B. Forests as protection from natural hazards. In: Evans J, editor. The Forests Handbook: Applying Forest Science for Sustainable Management 2. Oxford: Blackwell Science; 2001. pp. 53-81

[28] European Commission. Forging a Climate-Resilient Europe - the New EU Strategy on Adaptation to Climate Change. COM (2021) 82 Final. Bruxelles, Belgium: European Commission; 2021. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN

[29] United Nations Development Programme. Making the case for ecosystem-based adaptation: the global mountain EbA programme in Nepal, Perù and Uganda. New York: UNDP; 2015. Available from: https://www.iucn.org/pt/content/making-case-ecosystem-based-adaptation

[30] Doswald N, Estrella M. Promoting Ecosystems for Disaster Risk Reduction and Climate Change Adaptation: Opportunities for Integration. Nairobi, Kenya: UNEP; 2015

[31] Egan PA, Price MF, editors. Mountain Ecosystem Services and Climate Change: A Global Overview of Potential Threats and Strategies for Adaptation. Paris, France: UNESCO; 2017

[32] Poratelli F, Cocuccioni S, Accastello C, Steger S, Schneiderbauer S, Brun F. State-of-the-art on ecosystem-based solutions for disaster risk reduction: The case of gravity-driven natural hazards in the alpine region. International Journal of Disaster Risk Reduction. 2020;**51**:101929. DOI: 10.1016/j.ijdrr.2020.101929

[33] Makino Y, Rudolf-Miklau F. The Protective Functions of Forests in a Changing Climate - European Experience. Forestry Working Paper No. 26. Rome: FAO and Austrian Federal Ministry for Agriculture, Regions and Tourism; 2021 Available from: http://www.fao.org/documents/card/en/c/cb4464en

[34] Reid H, Jones H, Porras I, Hicks C, Wicander S, Seddon N, et al. Is Ecosystem-Based Adaptation Effective? Perceptions and Lessons Learned from 13 Project Sites. IIED Resea. London, UK: IIED; 2019. Available from: www.iied.org

[35] Teich M, Bebi P. Evaluating the benefit of avalanche protection forest with GIS-based risk analyses—A case study in Switzerland. Forest Ecology and Management. 2009;**257**(9):1910-1919. DOI: 10.1016/j.foreco.2009.01.046

[36] Moos C, Fehlmann M, Trappmann D, Stoffel M, Dorren LKA. A method for integrating the mitigating effect of forests into quantitative rockfall risk analysis - two case studies in Switzerland. International Journal of Disaster Risk Reduction. 2018;**32**:55-74. DOI: 10.1016/j.ijdrr.2017.09.036

[37] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise CJL, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[38] Moos C, Dorren LKA. Cost-benefit analysis as a basis for risk-based rockfall protection forest management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99513

[39] Bebi P, Bast A, Helzel KP, Schmucki G, Brožová N, Bühler Y. Avalanche protection forest: From process knowledge to interactive maps. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99514

[40] Stritih A. Dealing with uncertainties in the assessment of the avalanche

protective effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99515

[41] Schönenberger W. Trends in Mountain Forest Management in Switzerland. Schweizerische Zeitschrift für Forstwesen. 2001;**152**(4):152-156

[42] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[43] Bono A, Motta R, Garbarino M, Hormes A, Perzl F, Plörer M, et al. D.T1.4.1 Report on "Protection Forest Management in Practice in the AS – A Silvicultural and Economical Survey". Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[44] Perzl F. Der Objektschutzwald – Bedeutung und Herausforderung. BFW-Praxisinformation. 2014;**34**:20-24

[45] Riegert C, Bader A. On uses, effects, meanings and tasks of German forests. Linking forest functions and ecosystem services. In: Solutions for Sustaining Natural Capital and Ecosystem Services International Conference and Workshop (June 7th 2010 – June 11th 2010). Kiel University: Salzau Castle and Kiel University; 2010. Available from: http://www.uni-kiel.de/ecology/projects/salzau/wp-content/uploads/2010/02/Background-Paper-Riegert_Bader.pdf

[46] Kleemayr K, Teich M, Perzl F, Hormes A, Markart G, Plörer M. Protection Forest Definition Matrix. Innsbruck, Austria: Austrian Research Centre for Forests (BFW); 2019. Available from: https://www.alpine-space.eu/wp-content/uploads/2022/11/poster_grfa_schutzwald_englisch.pdf

[47] Kleemayr K, Teich M, Hormes A, Plörer M, Perzl F. A consistent definition of site and object protection forest, and their protective effects. In: Beyer Portner NN et al., editors. 14th Congress Interpraevent. 2021. May 31st to June 2nd 2021. Virtual Congress Norway. Klagenfurt, Austria: Extended Abstracts, International Research Society INTERPRAEVENT; 2021. pp. 322-325

[48] BMLFUW. Waldentwicklungsplan – Richtlinie über Inhalt und Ausgestaltung. Wien: BMLFUW; 2012

[49] BWaldG. Gesetz zur Erhaltung des Waldes und zur Förderung der Forstwirtschaft (Bundeswaldgesetz vom 2. Mai 1975 (BGBl. I S. 1037), das zuletzt durch Artikel 112 des Gesetzes vom 10. August 2021 (BGBl. I S. 3436) geändert worden ist). 1975

[50] Losey S, Wehrli A. Schutzwald in der Schweiz. Bern: Vom Projekt SilvaProtect-CH zum harmonisierten Schutzwald; 2013

[51] Perzl F, Huber A. Verbesserung der Erfassung der Schutzwaldkulisse für die forstliche Raumplanung. Synthese und Zusammenfassung: Ziele, Grundlagen und Ergebnisse der Modellierung von Waldflächen mit Lawinen- und Steinschlag-Objektschutzfunktion. Technische Hilfe im Rahmen des österreichischen Programms LE 07-13. Projektbericht V1. Innsbruck: Austrian Research Centre for Forests (BFW); 2014. Available from: https://gruenerbericht.at/cm4/jdownload/download/28-studien/1644-78-schutzwaldkulisse

[52] ZG. Zakon o gozdovih (Uradni list RS, št. 30/93, 56/99 – ZON, 67/02, 110/02 – ZGO-1, 115/06 – ORZG40,

110/07, 106/10, 63/13, 101/13 – ZDavNepr, 17/14, 22/14 – odl. US, 24/15, 9/16 – ZGGLRS in 77/16)

[53] Österreichisches Forstgesetz. Bundesgesetz vom 3. Juli 1975, mit dem das Forstwesen geregelt wird. BGBl. Nr. 440/1975. Wien: Verlagspostamt 1030 Wien; 1975

[54] MEA. Global Assessment Report Vol. 1: Current State and Trends Assessment. New York: MEA; 2005. Available from: https://www.millenniumassessment.org/en/Condition.html

[55] Perzl F, Teich M. Geodata requirements for mapping protective functions and effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99508

[56] Markart G, Teich M, Scheidl C, Kohl B. Flood protection by forests in Alpine watersheds: Lessons learned from Austrian case studies. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99507

[57] D'Amboise CJL, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[58] Kirchner M, Stevanov M, Krott M. How to use scientific information: Road map for tailoring your own natural hazard risk management solution. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99518

[59] Whited TL. Forests and Peasant Politics in Modern France. New Haven & London: Yale University Press; 2000. p. 274

[60] Kleemayr K, Cech T, Fürst W, Hoch G, Ledermann T, Markart G, et al. Schutzwald und Extremereignisse. In: Glade T, Mergili M, Sattler K, editors. Extrem A 2019 Aktueller Wissensstand zu Extremereignissen alpiner Naturgefahren in Österreich. Vienna: Vienna University Press; 2020. p. 670

[61] Beaussire L. Voeux des Conseils Géneraux, sur les questions relatives aux bois et forêts. In: Bixio A, Beaussire L, editors. Annales Forestiéres. Paris: Bureau de la Maison Rustique; 1842. pp. 444-462

[62] Whited TL. Extinguishing disaster in alpine France: The fate of reforestation as technocratic debacle. Geo Journal. 2000;**51**:263-270. DOI: 10.1023/A:1017583121359

[63] Loi du 4 avril 1882 relative à la Restauration et à la Conservation des Terrains en Montagne, décret du 11 juillet 1882 et circulaire n°305 du 12 décembre 1882

[64] Interreg Alpine Space project Green Risk4ALPs (ASP635) [Internet]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

[65] Berger F, Beguš J, Garbarino M, Lingua L, Motta R, Perzl F, et al. National barriers identification and policy needs for improving forest ecosystem-based risk-management in the Alpine Space. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021.

Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 5 RIGOR)

[66] Mantero G, Morresi D, Marzano R, Motta R, Mladenoff DJ, Garbarino M. The influence of land abandonment on forest disturbance regimes: A global review. Landscape Ecology. 2020;**35**(12):2723-2744. DOI: 10.1007/s10980-020-01147-w

[67] Lechner V, Markart G, Stöger A, Oven D, Pečan P, Žabota B, et al. D.T.1.4.3 Report on "High Alpine Afforestation - Survey and Effectivity Assessment". Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[68] Arai H, Haibara Y. Number density of avalanche protective plantations. Journal of the Japanese Society of Snow and Ice. 1957;**19**(6):161-168

[69] Saeki M, Matsuoka H. Snow-buried young forest trees growing on steep slopes. Journal of the Japanese Society of Snow and Ice. 1969;**31**:19-23

[70] In der Gand H. Aufforstungsversuche an einem Gleitschneehang. Ergebnisse der Winteruntersuchungen 1955/56 bis 1961/62. Schweizerische Versuchsanstalt für das forstliche Versuchswesen, Mitteilungen. 1968;**44**(3):233-326

[71] De Quervain M. Wald und Lawinen. In: Proceedings IUFRO Seminar Mountain Forests and Avalanches, Davos, 1978. Berne. Swiss Federal Institute for Snow and Avalanche Research (SFISAR) 1979. pp. 219-239

[72] Jahn J. Entwaldung und Steinschlag. In: Internationales Symposium Interpraevent 1988 – Graz. Vol. 1. Tagungspublikation. Klagenfurt, Austria: International Research Society INTERPRAEVENT; 1988. pp. 185-198

[73] Kawaguchi T, Namba S, Takiguchi K, Kono T, Kishioka T. Landslides and soil losses at the mountain districts of Izu peninsula in the flood of 1958 and their control. Jap. For. Expt. Sta. Bul. 1959;**117**:83-120

[74] Croft AR, Adams JA. Landslides and Sedimentation in the North Fork of Ogden River, May 1949. US Forest Service, Intermountain Forest and Range Experiment Station; 1950 Research paper 21

[75] Bishop DM, Stevens ME. Landslides on Logged Areas in Southeast Alaska. Juneau, Alaska: USDA Forest Service Research Report NOR-I; 1964. p. 18

[76] O'Loughlin CL. An Investigation of the Stability of the Steepland Forest Soils in the Coast Mountains, Southwest British Columbia. Vancouver: University of British Columbia; 1972

[77] Rice RM, Pillsbury NH, Schmidt KW. A risk analysis approach for using discriminant functions to manage logging-related landslides on granitic terrain. Forest Science. 1985;**31**(3):772-784

[78] Mayer H. Gebirgswaldbau – Schutzwaldpflege. Ein waldbaulicher Beitrag zur Landschaftsökologie und zum Umweltschutz. Stuttgart, New York: Gustav Fischer Verlag; 1976. p. 435

[79] Bischoff N. Pflege des Gebirgswaldes. Leitfaden für die Begründung und forstliche Nutzung von Gebirgswäldern. Bern: Eidgenössische Drucksachen- und Materialzentrale; 1987. p. 379

[80] Perzl F, Kleemayr K. D.T.1.3.2 Report Assessment of Forest Protection Effects and Functions for Natural Hazard Processes. Innsbruck, Austria: Interreg Alpine Space project

GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[81] Wohlgemuth T, Schwitter R, Bebi P, Sutter F, Brang P. Post-windthrow management in protection forests of the Swiss Alps. European Journal of Forest Research. 2017;**136**(5-6):1029-1040. DOI: 10.1007/s10342-017-1031-x

[82] Teich M, Giunta AD, Hagenmuller P, Bebi P, Schneebeli M, Jenkins MJ. Effects of bark beetle attacks on forest snowpack and avalanche formation – Implications for protection forest management. Forest Ecology and Management. 2019;**438**:186-203. DOI: 10.1016/j.foreco.2019.01.052

[83] Frehner M, Wasser B, Schwitter R. Nachhaltigkeit und Erfolgskontrolle im Schutzwald. Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL); 2005

[84] Berretti R, Caffo L, Camerano P, De Ferrari F, Domaine A, Dotta A, et al. Selvicoltura nelle foreste di protezione: esperienze e indirizzi gestionali in Piemonte e Valle d'Aosta. Arezzo: Compagnia delle Foreste S.r.l; 2006. p. 220

[85] Gauquelin X, Courbaud B. Guide des Sylvicultures de Montagne. Alpes du Nord Françaises: Cemagref CRPF Rhône-Alpes, ONF; 2006. p. 289

[86] Ladier J, Rey F, Dreyfus P, editors. Guide des Sylvicultures de Montagne Pour les Alpes du sud Françaises. Fontainebleau, France: ONF Office National des Forêts, Département des Recherches Techniques; 2012. p. 306

[87] Perzl F. Ein Minimalstandard für die Dokumentation der Schutzwirkungen des Waldes im Rahmen der Österreichischen "Initiative Schutz durch Wald". In: Conference Proceedings – Internationales Symposion Interpraevent. Dornbirn. Klagenfurt, Austria: International Research Society INTERPRAEVENT; 2008. pp. 551-562

[88] Bebi P, Kulakowski D, Rixen C. Snow avalanche disturbances in forest ecosystems—State of research and implications for management. Forest Ecology and Management. 2009;**257**(9):1883-1892. DOI: 10.1016/j.foreco.2009.01.050

[89] Motta R, Haudemand J-C. Protective forests and silvicultural stability. Mountain Research and Development. 2000;**20**(2):180-187. DOI: 10.1659/0276-4741(2000)020[0180,PFASS]2.0.CO;2

[90] Briones-Bitar J, Carrión-Mero P, Montalván-Burbano N, Morante-Carballo F. Rockfall research: A bibliometric analysis and future trends. Geosciences. 2020;**10**(10):403. DOI: 10.3390/geosciences10100403

[91] Stritih A. Risk-based Assessments of Ecosystem Services: Addressing Uncertainty in Mountain Forest Management. ETH Zürich: Planning of Landscape and Urban Systems; 2021. p. 157

Chapter 3

Protective Effects of Forests against Gravitational Natural Hazards

Frank Perzl, Alessia Bono, Matteo Garbarino and Renzo Motta

Abstract

In this chapter, we give a short overview of the protective effects of forests against snow avalanches, landslides and rockfall hazards in mountain areas. The overview is based on the protective mechanisms provided by forest and connects them to the effect-related indicators of forest structure from literature and European protective forest management guidelines. The thresholds of the effect-related indicators are hazard-related silvicultural targets for forest management and critical values for hazard risk assessment. The assessment of the protective effects of forests is a central part of natural hazard risk analysis and requires information on different spatial levels from single tree to slope-scale attributes. Forests are efficient in preventing snow avalanche and landslide initiation; however, they are usually unable to stop large masses of snow, soil and rock in motion. Therefore, guidelines on silvicultural targets and practices must focus on the mitigation of hazard onset probabilities at the stand-scale; however, existing guidelines under- or overestimate the protective effects of forests. Effects of forests on hazard propagation are difficult to implement in forest and risk management practice. Hence, the European protective forest management guidelines do not contain any or only general specifications that simplify the determining factors and their relationships.

Keywords: protective forest, natural hazards, snow avalanche, rockfall, landslide, nature-based solutions

1. Introduction

The protection of settlements and infrastructures by so called protective forests (protection forests) against gravitational and hydrological natural hazards is of particular relevance in the mountain areas of Europe, as they are densely populated and used intensively by the population of other regions for recreation [1]. Therefore, special legal regulations and public funds have been introduced to maintain and improve the protective effects of forests in many European countries [2, 3]. The protective effects of forests are also addressed in literature by the terms protective function and protective role which are often used synonymously. Brang et al. [4] clearly differentiated the meanings of the terms protective function, potential, and effect of forest (see also chapter [5] of this book).

The term "protective function" refers to the task of forests to protect something of value like people, settlements or infrastructures from the impacts and damage by adverse climate or natural hazards [4, 6]. This task is assigned to forests or to other land use appropriate for afforestation by society, if there is a damage potential to people or assets, and the forest is or will be located on sites where a forest can give rise to mitigation of hazards and climate impacts. The allocation of protective functions to existing or future forests does not consider the present forest conditions and effectiveness in protection but refers to the societal demand for protection by forest due to environmental conditions and public interest as well as to a protective potential on this location. The "protective potential" of a forest is "a protective effect that a forest is likely to have if properly managed" [4]. This capability of forests to prevent or mitigate natural hazards depends on the (prospective) hazard type and intensity, on the location in the process area and the natural growth capacity of the site to produce protective forest structures.

The term "protective effect" refers to the degree of mitigation of hazards by forest [4] which ranges from no or low reduction of hazard frequencies and/or intensities to total hazard prevention. The term is also used to designate the protective mechanisms which generate the hazard mitigation by interaction of woody vegetation and abiotic components which control environmental processes [6]. The protective effects result from the current forest conditions and in the long-term from the stability of the forest [4]. The term may also imply the reduction of the damage risk to people and assets by forest. However, hazard and damage risk analysis are approaches beyond the determination of the protective effect of the forest including further steps of analysis.

In this context, this chapter will give a short overview of the protective effects of forests against gravitational natural hazards in mountain areas. The overview is based on the presentation of the protective mechanisms provided by woody vegetation and connects them to the effect-related indicators of forest composition and density. Protective effect-related indicators and thresholds have been issued by several European guidelines for protective forest management [7]. The thresholds of the protective effect-related indicators are hazard-related silvicultural targets for forest management on stand-scale and critical values required for hazard risk assessment at stand- and slope-scale. Therefore, we relate knowledge from the literature and hazard observations to these common concepts on protective forests. We limit the presentation to the protective effects of forest against snow avalanches, landslides and rockfall which may be mitigated by forest effectively on slope-scale, whereas the effectiveness of forest in mitigating hydrogeomorphic hazards like (torrential debris) floods is more dependent on the temporal and spatial scale of view as well as on the total share of forest use at the watershed-scale (see chapter [8] of this book).

2. Protective effects of forests and related forest conditions

Forests prevent and mitigate gravitational natural hazards by two mechanisms: 1) they prevent hazard initiation or reduce mass displacements in potential starting zones by the retainment of solid materials on site, and 2) they break down, narrow laterally and eventually limit the propagation of the mass movement [9–11]. The prevention or limitation of hazard initiations is clearly the most efficient and therefore important protective effect of forest to be considered by forest management. Forests are usually unable to stop large masses of snow, soil, and rock [9]. However, the importance of release prevention in potential starting zones in relation to mass deceleration in possible transit zones by forest is strictly related to the hazard type.

Furthermore, the magnitude of the mass movement, the conditions of materials in motion, the distance, and the terrain relief from the starting zone to assets at risk as well as the proportion of the runout zone covered by high and dense enough forest impact hazard propagation.

2.1 Protective effects of forests against snow avalanches

Avalanches may be classified into canyon avalanches (nowadays, they are called channelized avalanches) and slope avalanches, according to their physiogeographic situation and spatial relation to forest, with many intermediate forms [12]. A canyon avalanche originates on the head of a canyon above the current timberline or in areas of open forests and follows the gorge. Because of the frequent occurrence and damaging effects, the upper flow path is usually free of taller woody vegetation, or only overgrown by bushes, but, dependent on the frequency and intensity of the mass movement and the terrain, the hazard zone may also be stocked by high timber. In case of infrequent high snow accumulation, these situations are difficult in risk management, as the hazard and damage potentials are not obvious due to the condition of the woody vegetation. Slope avalanches occur outside of canyons on steep mountain slopes. As they are mainly covered by high and dense forests, damage to infrastructure by naturally triggered slope avalanches is less frequent in the Alps even in snow rich winters. Snow avalanches which originate in forests are called forest avalanches (**Figure 1**) [13, 14].

Most avalanches that are perceived in Alpine settlement areas as coming from forested terrain originate from slopes or canyon heads above the current timberline or from currently open areas [15]. Nevertheless, forests on steep mountain slopes should never be considered as areas not prone to avalanche formation [16]. The basic avalanche release susceptibility of forested slopes in the Alps is not evident in hazard and damage statistics, as it is masked by the protective effect of the mainly dense woody vegetation and by artificial snow supporting structures which already have been established at the beginning of the 20th century in forests with high protective functions and low protective effects [7].

Figure 1.
Muddy snow avalanches from forest triggered in March 1988 by rain after 38 cm snowfall within 3 days. Photo: K. Perzl, 1988.

2.1.1 Prevention and reduction of snow avalanche release by forest

A forest cover prevents snow avalanche initiation by stabilizing the snowpack on the ground as a result of these mechanisms: A) reduction of the formation of firm bed surfaces and weak snow layers (crusts, faceted snow, depth and surface hoar) by balancing the radiation and temperature budget of the snowpack, B) disturbance of the stratification of the snowpack and C) reduction of the snow depth by canopy interception of snow precipitation, D) reduction of the accumulation of wind-driven snow by deceleration of wind speed, E) reduction of the formation of basal gliding (ice and wet snow) planes due to the usually high infiltration capacity and roughness of the forest floor, and F) support of the snowpack by stems, snags, stumps, logs and low woody vegetation [13, 15, 17–22].

The mechanisms A to D are forest canopy effects, and therefore the foliar cover of the forest in winter regulates the snowpack stabilization. However, leafless twigs, branches and stems contribute to the modification of the radiation and temperature regimes of the snowpack as well as to the interception of snowfall. The density and spatial distribution of stems and coarse woody debris, which are the main controllers of the mechanism F, also reduce the formation of weak layers. In addition to soil properties, coarse woody debris, and the understory, all of them influenced by forest composition and density, and finally by forest management, control the mechanism E.

Because of the complex interaction of these mechanisms with snow and terrain characteristics, it is difficult to differ main and minor protective mechanisms and controllers of the protective effect of forests against avalanche release. A forest is largely able to prevent new and old snow avalanche releases except for small loose snow avalanches by the mechanisms A to C. The preconditions for this are a rather dry and cohesive snowpack as well as a sufficient forest canopy cover. A foliated canopy cover by evergreen conifers is most effective but may be substituted by the surface area of branches and stems of deciduous trees and snags. The woody area of the canopy, especially the branchwood surface area, plays an important role in the modification of radiative, thermal, and hydrologic conditions [23]. The similar protective canopy cover observed in both evergreen and deciduous coniferous stands [14] and the little influence of the leaf area on the spatial variability in snow stratigraphy [24] may be an effect of the woody area of the canopy. However, avalanche initiations are observed more frequent in deciduous forests than in evergreen forests and occur under closed deciduous canopies [13, 14, 19], which indicates a limited protective effect of trees without leaves in case of heavy and stormy snowfall or other than cold-dry conditions.

Tree canopies prevent avalanche release when they overtop the snowpack. On steep slopes prone to avalanche formation, young trees and bushes are bent down by the snow load and the pressure of the snowpack. As a result, they can be uprooted, broken and overlaid by weak snow layers and cohesive snow slabs. However, it is not clear and easy to determine how large and tall trees or bushes must be to have a protective effect. This depends on numerous factors such as slope inclination, surface roughness, tree species composition and stand structure, and ultimately also on the risk-analytical assessment basis of possible (design) snow depths. In addition, the protective height and/or diameter of trees likely depends on the density of the woody vegetation. Observations indicate that trees overtop the snow cover when the tree height exceeds the maximum snow height by one to two times [25–27]. These relationships lead to quite different protective tree heights up to over 5 m, depending on the design snow depths used in risk analysis, as well as to questions on the method and accuracy of stand height and snow depth assessments. These relationships do not directly refer to the avalanche activity. Observations of

snow avalanche activity caused by logging indicate a protective height of the woody vegetation of about 2 m [28]. This may be an effect of the increased surface roughness at loggings. The snowpack support by stumps, logs and other terrain roughness features may considerably mask the protective height and density of young growth.

Usually, a canopy cover of upright-growing woody plants with an average height of about 5 m may overtop and shade the snowpack. Hence, they provide the protective effects A to C and F. The recommendations of the European guidelines for protective forest management for the protective stand height and canopy cover differ considerably [7]. These expert-based guidelines from four European countries suggest a range of canopy cover targets from 30 to 70% for a high level of protection which is not defined clearly but may refer to a low release probability (**Table 1**). Furthermore, the guidelines refer either to the total (TCCP) or to the wintergreen canopy cover percentage (WCCP). Guidelines, which refer to the WCCP, use the total stem density for inferring the protective effect in case of forests with low proportions of evergreen canopies.

A validation of these targets based on a sample of observed snow avalanche initiations in Alpine forests (total sample size 295) shows a low misclassification of all approaches in terms of false negative rates [7]. The false negative rate (FNR) is the proportion of observed hazard releases that would not have been classified as critical situations based on the forest and site condition according to the criteria of a guideline. The FNRs in the range of 22 to 30% of the approaches using a critical TCCP of 50% are considerably higher than those of the guidelines using the WCCP (0 to 2%) (**Table 1**). This indicates an overestimation and limited protective effect of leafless canopies, whereas the high targets in terms of the WCCP, ranging from 30 to 70%, clearly underestimate effects of the foliar cover and of the woody area in deciduous stands. 75% of all snow avalanches in the sample initiated on sites with a WCCP smaller than 16%, and initiations under evergreen canopy cover of more than 40 to 60% were rare outliers. Therefore, even a small proportion of evergreen trees can significantly reduce the likelihood of avalanche formation and deciduous trees also provide a reduction of the release width (RRW) in relation to low canopy covers (**Table 1**).

The comparatively high miss rates (FNR) of assessments based on the total canopy cover are an effect of the presence of deciduous forests in the sample, especially of the high broadleaved forests with small surface roughness [7]. In broadleaved deciduous stands, with a low proportion of evergreen trees and low total stem density, avalanches may initiate even when the canopy is fully closed [13, 14, 34]. This is a result of several limitations of the protective effect of (deciduous) canopies. In some special conditions, the ability of forest to prevent avalanche formation by the mechanisms A to C is reduced. Such conditions are heavy and enduring snowfall at low temperatures without intermittent radiation, (heavy) snowfall followed by rain-on-snow (**Figure 1**) or strong sudden air temperature rise (**Figure 2**) [13, 15, 35].

A cohesionless snow layer or snowpack of fluffy or wet snow outer performs the mechanisms A and B. The mechanics C to D, especially the snow depth reduction by interception effects, become more important. However, snow depth reduction is limited in deciduous forests. In addition, snowpack support by stems (mechanism F) is reduced for both cohesionless and cohesive but heavy and moist snowpack. Supporting the snowpack by upright stems requires contact with the snowpack [19]. Thus, paradoxically, this mechanism is more effective for large snow depths than for small ones [36]. However, in all situations with low effectiveness of the mechanisms A to C, and especially in deciduous forests, the anchoring and therefore an adequate stem density is important to stabilize the snowpack. The protective effect of deciduous forests is more dependent on stem density and surface roughness than clearly connected to the canopy cover [16, 34, 37, 38].

Guideline	**NaiS**	**SFP**	**GSM-N**	**GSM-S**			**ISDW**			
Level of protec-tion	**"high"**	**"high"**	**"high"**	**high**	**medium**	**low**	**no**	**high**	**medium**	**low**
Slope	TCCP	TCCP	WCCP	WCCP	WCCP	WCCP	WCCP	WCCP	WCCP	WCCP
≥30°	>50%	>50%	>30%	>70%	>30%	>10%	≤10%	≥45%	≥35%	<35%
≥35°	>50%	>50%	>50%	>70%	>30%	>10%	≤10%	≥55%	≥35%	<35%
≥40°	>50%	>50%	>70%	>70%	>30%	>10%	≤10%	≥65%	≥35%	<35%
FNR CC	22–30%		0–2%	0–1%					0–2%	
RRW	−40 m		—	−30 m					−30 m	
FNR all	43%	42%	32%	6%	—	—	—	5%	—	—

TCCP, total canopy cover percentage (all tree species); WCCP, canopy cover percentage of evergreen species; FNR, false negative rate in percent of the sample; "CC" refers to the validation of canopy cover targets, "all" to the combination of all indicators (canopy cover, gap size, stem density); RRW, maximum reduction of slab release width in relation to the non-target (low) canopy cover.

Table 1.
Canopy cover targets to prevent avalanche initiation in forests according to the European protective forest management guidelines NaiS [29], SFP [30], GSM-N [31], GSM-S [32] and ISDW [33], and false negative rates of avalanche occurrence and reductions of release widths calculated based on a sample of observed forest avalanches (total sample size 295) (for details see [7]).

Figure 2.
Release of a snow avalanche in a spruce forest triggered by air temperature rise from −12 to 6°C within few hours. The 208 m long avalanche with a vertical drop of 147 m buried a local road. Photo: F. Perzl, 2021.

The literature on protective stem densities is based on different analytical approaches and they vary considerably. They refer to different caliper thresholds and mean diameters of the stems at breast height (DBH). Thresholds of protective stem densities are usually related to slope inclination. Approaches based on mechanical calculations show stem densities needed to stabilize the snowpack, for example with an average DBH of 5 cm, from about 2,000 on gentle slopes to more than 10,000 stems per hectare on steep slopes [34, 36]. These calculations are very sensitive to slope, DBH and snow conditions. Observations and statistical approaches [14, 16, 26] usually do not confirm them. **Figure 3** shows stem densities recommended by the European guidelines to stabilize snowpack versus a sample of 142 observed snow avalanche initiations in forests mainly provided by a Swiss database [14]. Based on this sample, the miss rates (FNR) of the guidelines are low, not exceeding 15%. However, most of the guidelines tend to propose quite higher stem densities than observed and underestimate the effects of the trees [7]. Snow avalanche initiations in forests with stem densities of more than 900 per hectares (DBH >6 cm) seem to be statistical outliers allocated to deciduous broadleaved and mixed forests on very steep slopes [7].

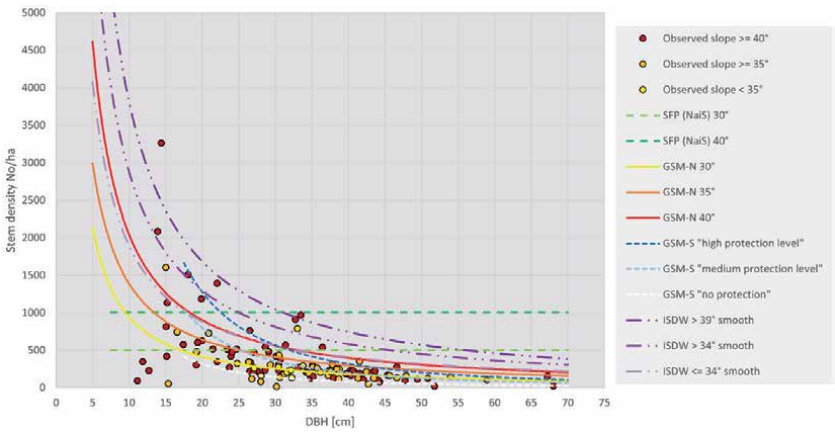


Figure 3.
Targets of critical stem densities for snow avalanche initiation in relation to observed stem densities dependent on slope [7]. Acronyms in the legend refer to the national European guidelines NaiS [29], SFP [30], GSM-N [31], GSM-S [32] and ISDW [33]. NaiS and SFP propose fixed values without considering the natural reduction of stem densities with increasing mean tree diameters. However, in NaiS, the stem density is mentioned but not part of the assessment criteria.

Stem density observations in avalanche initiation sites are rare and difficult to compare, as they refer to different measurement methods. Additionally, the effects of trees depend on their spatial distribution. Most avalanches in high forests initiate in canopy openings. The term "gap" is usually used for small openings, but the term may also refer to all openings ranging from the size of a tree crown to large clear-cut areas. The size of canopy openings is an important issue for the management of forests with an object-protective function. Forest regeneration may be suppressed by too small canopy openings because of light deficiency, but inappropriately large openings carry the risk of avalanche formation.

One approach to assess critical canopy openings followed by some European guidelines assumes that limiting the length of cuts in the flow direction will reduce the probability of avalanche release as well as the avalanche propagation. This assumption and the recommended critical gap (opening) lengths in the range of 25 to 60 m depending on slope are based on physical calculations [39–41]. The validation of the implementations in the European guidelines delivered FNRs in the range of 36 to 49% [7]. These results show low influence of the proposed critical gap lengths on the probability of avalanche release but a reduction of runout lengths by 50 m on average which is statistically not significant. The reduction of the release probability in cuts as well as avalanche propagation is not primarily a question of the gap length in the release zone, but also dependent on the gap width, the surface roughness in the opening and the density of woody vegetation at the lower edge of the opening [13, 14, 42]. The terrain and forest conditions along the total flow path are crucial for the runout length.

2.1.2 Reduction of snow avalanche propagation by forest

The European guidelines for protective forest management do not consider the avalanche braking effect of the forest in the transit zone as normally slab avalanches with critical fracture size will flow through forests or destroy them until they run out on slopes of low inclination or the energy is dissipated by the fall over steep cliffs [12, 17, 40, 41, 43]. Trees are unfavorable resistance elements against avalanches due to their small obstacle width, shape and material properties. Depending on the elasticity of the species and the diameter of the plants, powder cloud avalanches with a pressure of about 3–5 kN/m^2 and higher, and flow avalanches of about 10–50 kN/m^2, which are possible even with small snow masses, break or uproot the trees [39, 41] as soon as the trees lose the flexibility of the juvenile stage (**Figure 4**).

Forests can stop or significantly slow down small-to-medium avalanches starting within dense forests, in small gaps of dense forests or next to the upper timberline by snow detrainment [40, 44, 45]. The breakage, uprooting and overturning of trees as well as the entrainment of coarse woody debris and snow deposition behind trees (**Figure 5**) may cause a loss of energy and reduce runout lengths of medium to large avalanches originating from sites above the timberline or from large clear-cuts [46–48]. Indications on the distance from the release area (in forest cover openings or above the timberline) to forest cover penetration and on the release size which ensure braking effects of the forest cover vary from 30 to 200 m and from <5,000 to 30,000 m^3 [21, 22, 40, 44, 46, 49].

The allocation of (potential) hazard zones to avalanches that may or may not be slowed down by the forest, is difficult and not only an issue of the release size. It must be remembered that stopping an avalanche within the forest may not be an effect of the forest, but a consequence of snow and terrain conditions in the transit zone as well as the elevation of the starting zone. The reduction of damages by silvicultural interventions in the transit zones is limited to the enhancement of the

Figure 4.
Destruction of a young deciduous forest by an avalanche. Photo: K. Suntinger, 2009.

Figure 5.
Detrainment of avalanche snow by trees. Photo: F. Perzl, 2008.

surface roughness on short-slopes and to promoting stand stability by species selection, formation of resistant individuals and acceptance of shrub-dominated growth.

2.2 Protective effects of forests against (shallow-seated) landslides

2.2.1 Prevention and reduction of landslide initiation by forest

Effects of forests on deep-seated landslides are a debated issue, while it is widely accepted that forests can prevent the development of shallow-seated landslides. This topic is further complicated by the fact that there is no uniform definition of deep-seated landslides, and that the distinction from shallow to deep is transitional. Part of this problem are numerous different landslide classifications with fuzziness of process descriptions as well as different transcriptions of landslide type definitions from one language to another.

We refer to mainly deep-seated permanent landslides and mainly shallow-seated spontaneous regolith (debris) slides according to the Swiss approach of hazard risk assessment [50]. Permanent landslides are masses that have already been displaced and are therefore in motion with phases of activity or inactivity. The term

spontaneous landslide refers to first-time failures with no further movement of the deposits except secondary erosion.

Spontaneous debris slides may be classified for practical purposes into 1) slides and slumps without flow-like mass movements, 2) spoon, shell or wedge-shaped slides followed by material flows 2.1) without (debris avalanches) or 2.2) with linear erosion (debris flows) of the transit zone (**Figure 6**).

Spontaneous landslides of the flow type (2) are most common on steep mountain slopes and in mountain forests, because of the excessive release and runoff of subsurface and surface water from the scars of the initial slope failure. A further classification of landslides important for forest management is to distinguish hillside and channel bank failures. Slope stabilization effects of forest are limited at river embankments, as storm flows undercut root systems.

Many forest practices boards (e.g., [29, 51]) allocate limited effects of forests on deep-seated landslides or associate the effects to the water recharge and toe areas, which are prone to shallow landslide initiation. There are no studies that investigate or clearly show a cause-and-effect relationship between forest conditions and the reactivation of deep-seated landslides except one study [52] that showed that an increased velocity after clear-cut harvest was not correlated to change in precipitation [53]. Most authors (e.g., [10, 54, 55]) agree and silvicultural guidelines (e.g., [29, 31]) stating that a protective effect of forests is given especially in shallow-seated zones of potential depletion, as the roots do not stabilize soil layers deeper than 2 m. Although landslide inventories are biased by the forest cover, this is substantiated by studies on effects of forest practices and landslide inventories (e.g., [56]), which usually show a lower density of shallow-seated landslides on forested (forest cover) areas than on non-forested areas. However, there is no evidence that a high protective potential of forests is limited to depths smaller than about 2 m [7, 53]. Woody vegetation influence water budgets [53] and especially the moisture of soils rich in clay or silt, which are susceptible to slope failures, down to a depth of about 3 to 10 meters (e.g., [57–59]). On the other hand, shallow soils on steep slopes with a dense forest cover fail, if the bedrock below is impervious or pipeflow is blocked, and the pressure of the subsurface flow leads to an explosive collapse of the soil [60, 61]. Therefore, the protective effect of the forest cover is also limited in case of shallow soils.

Forests enhance slope stability by A) dewatering due to evapotranspiration, B) internal redistribution of water due to the hydraulic lift (maintenance of

Figure 6.
Left – soil clod grown by trees moving downslope on a permanent landslide, center – debris avalanche, right – debris flow in forest. Photos: F. Perzl.

conductivity), C) prevention of dry cracks in soils by shadowing, D) reduction of near-surface downflow and distribution of the soil water by impacting the infiltration capacity of the soil, and E) mechanical reinforcement of slopes through roots [57, 62–64].

The impact of evapotranspiration on soil saturation (A) and soil water distribution (B) is secondary for preventing (shallow-seated) landslides in humid-temperate and boreal mountain-ecosystems with limited depths of nearly saturated soils, as intense rainfall and snowmelt are the key-drivers of landslide occurrence, which saturate the soils rapidly without time for dewatering [57, 65].

Dry cracking is not evident to drive landslides in Alpine conditions and is limited to soils rich in clay or silt. But effects (B, C) reducing contraction-induced soil openings and swelling pressure [66] may be important for deep-seated regolith under temporarily dry conditions.

The protective potential of the mitigation of near-surface downflow by forest (D) may be secondary in relation to (E) for short slopes and shallow soils. However, the mitigation of flow from upslope contributing areas is not negligible for landslides of the flow type (2), depending on the characteristic of contributing areas and issues of hydrological connectivity [67].

The anchoring to bedrock, and the additional soil strength or cohesion provided by roots (E) are the most significant contributions of woody vegetation to slope stability [54, 65]. Deciduous broadleaved species generally show higher root resistance than conifers [68], and their tensile strength is influenced by root water status [69]. The influence of the tree load is rather small in relation to root reinforcement [70], whereas the transmission of wind loads by trees to soil may negatively affect slope stability. The weight of trees, combined with root decay and an imbalance of above- and below-ground biomass, may increase erosion by uprooting especially in abandoned coppice stands [71].

All protective effects (A-E) are dependent on the ground coverage by healthy woody vegetation. Additionally, the root reinforcement of soils (E) and seasonal dewatering by evapotranspiration (A, B) depend on the stage of development and the forest's species composition. It is frequently observed that clear-cutting or forest-dieback promote slope instability, although the effects of the remaining roots can stabilize the slope for several (3 to 15) years until root decay [57, 72].

Although the influence of forest management on landslide occurrence is addressed frequently in literature, only few authors provide information about the critical canopy cover and size of canopy openings like clear-cuts. The information useful for practice is limited to the recommendations in the European guidelines (**Table 2**); numerous erosion control guidelines avoid quantitative statements.

There are many references addressing the mitigation of landslide occurrence by a site-appropriate tree species composition. Although plausible, we could not find clear and direct evidence of a relationship between the proportions of tree species, their spatial distribution and landslide activity in the literature. That is, even if the root systems of broadleaved hardwoods seem to provide better soil reinforcement than conifers, statistical analysis do not show this clearly. Amishev et al. [73] propose small clear-cuts of maximum 1 ha to maintain the protective effect of forests. This is a much larger critical area than recommended by the European guidelines (**Table 2**). Moos [74] identified the canopy cover, the length of canopy openings ("gaps") and the distance to the next tree as the forest characteristics that influence landslide susceptibility; the area of openings was not included in the analyses. Her results indicate that a canopy cover (height >3 m) lower than 60% and a gap length longer than 20 m are critical especially on steep slopes. However, an influence of the gap length could only be ascertained in one of two study areas. **Table 2** shows canopy opening and canopy cover targets recommended by the European guidelines to avoid

	Canopy opening (gap)					Canopy cover [%]				
	No regeneration			regeneration						
Indicators and miss rates	NaiS minimal	SFP minimal	ISDW	NaiS minimal	SFP minimal	NaiS minimal	SFP minimal	GSM-N	GSM-S	ISDW
Gap area [m^2]	≤600	<600	—	≤1200	<1200	—	—	—	—	—
FNR Gap area [%]	25	25	—	34	34	—	—	—	—	—
Gap dimension link rule	—	AND	—	AND*	AND	—	—	—	—	—
Gap length [m]	—	<20	—	—	<25	—	—	—	—	—
FNR Gap length [%]	—	18	—	—	68	—	—	—	—	—
Gap width [m]	—	—	≤25	≤20*	—	—	—	—	—	—
FNR Gap width [%]	—	—	47	39	—	—	—	—	—	—
Trees h >10 m	—	—	—	—	—	≥40	≥40	—	—	—
All trees	—	—	—	—	—	—	—	>70	>70	>65
Large-sized trees	—	—	—	—	—	—	0	—	—	<25
FNR gap or cover [%]	25	19	47	34	31	42		38		42
FNR large-sized [%]	—	—	—	—	—	—	66	—	—	98
FNR combined [%]	—	—	—	—	—	45	21	38	38	39

h, stand height; FNR, false negative rate in percent of the sample, "combined" refers to the final assessment by the combination of all targets (canopy cover, gap size, canopy cover of large trees). *The combination rule is not clearly documented.*

Table 2.
Canopy opening and canopy cover targets to prevent shallow landslide initiation according to the European guidelines NaiS [29] and SFP [30] (minimal requirements), GSM-N [31], GSM-S [32] and ISDW [33], and results of a validation based on 555 observations of shallow-seated landslides in Alpine forests [7].

landslide initiation in forests and validation results based on a sample of 555 shallow landslides [7]. The guidelines assume that regeneration contributes to slope stabilization. Therefore, openings with secured regeneration that are twice the area of critical openings without regeneration are not considered as critical. The validation of the canopy opening targets showed significantly higher FNR even if the length of the gap was additionally restricted. A canopy cover of tall trees of only 40% yielded similar FNR to a canopy cover of 70% with young growth and shrubs considered. Very high miss rates (≥66%) arise from the target of low occurrence of large-sized timber to reduce tree load of slopes and landslide-induced log jams in rivers. However, similar to the case of snow avalanches, the overall result of the assessment of the protective effect against landslides is highly dependent on the combination of indicators. The FNR of the guidelines are higher than in case of snow avalanche. In line with literature, these results indicate a protective potential of closed (natural) mature and old-growth forests without disturbances but limited protective effects of young growth.

2.2.2 Reduction of debris flow runout by forest

Trees and coarse woody debris can retain mobilized sediments and therefore reduce hillslope and torrential debris flows [75–79]. Large-scale datasets indicate lower frequencies [80] and runout lengths [81] of debris flows and debris avalanches in mature forests in relation to other land uses or clear-cuts and young forest. However, the reduction of runout lengths may be an effect of smaller landslide densities and erosion volumes in mature forests rather than a barrier effect [76]. Results of [78] indicate a higher potential of trees and logs to retain debris at low-order section of rivers than on alluvial fans. Detrainment of debris on alluvial fans by forest depends on sediment concentration and tree density [82]. Trees increase the flow resistance and favor the deposition of materials due to detrainment of (coarse) debris, but the protective effect is difficult to assess (**Figure 7**).

Figure 7.
Detrainment of coarse debris from a debris flow by forest at the alluvial fan. Photo: F. Perzl, 2012.

2.3 Protective effects of forests against rockfall

The main function and effect of forests in rockfall protection is to stop or to mitigate rockfall propagation in the transit or deposition zone. Effects of forests in rockfall starting zones are ambiguous [83, 84], and presence of forest may increase the onset probability of rockfall by chemical rock weathering through root exudates, root pressure and transmission of loads. The mitigation of rockfall initiation

on steep and rocky release areas by silvicultural measures is limited to the removal of unstable trees to avoid block mobilization.

Forests reduce the propagation probability and the intensity of rockfall as impacts on trees and logs along the track dissipate kinetic energy as well as that rocks get caught by the stems [85]. Forests do not resist large rock masses in motion. Statements on single block volumes that might be stopped or slowed down by forest vary from about 1 m^3 to a maximum of 20 m^3 [86, 87]. However, the protective potential of forests in rockfall mitigation depends on the local situation and cannot be based on block volume alone. The protective effect is an issue at the stand-scale and especially at the slope-scale but influenced by single tree characteristics.

Trees absorb most of the impact energy of rocks by the root soil system followed by bending of stems and penetration into the wooden body [88]. The anchorage to soil correlates positively to stem and tree biomass [88]. Consequently, trees large in diameter and with long canopies are appropriate for energy dissipation. However, small trees are also able to stop larger rocks dependent on the hazard, terrain, and forest conditions, especially if the energy has already been dissipated along the trajectory by enough impacts on large trees (**Figure 8**) [85]. The protective effect of smaller trees depends on their spatial arrangement into interceptive collectives like coppice crops [89] and is adequate for smaller boulders (<0.5 m^3) [90]. The stem density targets in the European guidelines reflect the discussions on protective diameters which vary from a minimum DBH of 12 to 34 cm (**Table 3**) but may also be influenced by measurement conventions. Broadleaved hardwoods can absorb more energy than conifers and broadleaved softwoods [86]. Additionally, the capacity of broadleaved species to recover from rockfall damage due to wound healing and sprouting is higher than of conifers [91]. In high mountain areas, where growth capacities of angiosperms are limited, *Larix decidua* Mill. is an option to improve rockfall protection by tree selection, since European larch shows considerable resistance and damage recovery (**Figure 8**) [91, 92].

At the slope-scale, the protective effect of forest depends on the rock size, shape and energy, the terrain morphology and surface conditions like roughness and the damping potential of the soil, and the length of the forested slope as well as the density of the forest cover. The protective density of the forest is indicated by the (average) stem density or basal area (**Table 3**). Both approaches require the definition of the protective stem diameter. The usability of both approaches for risk assessments is limited by two facts: 1) forest density may vary considerably on a small spatial scale and stem distributions may change from random to clumped and 2) the length of the forested slope influences the protective density. Furthermore, concepts which are based on block diameters neglect that the block diameters of mobilizable rocks are

Figure 8.
Left – small beech and sycamore trees stopped a boulder of about 1.5 to 2 m^3 (Photo: F. Perzl), right – a wedge-shaped boulder caught by a larch and a spruce tree (Photo: K. Suntinger).

Guideline	NaiS & SFP "minimum"	GSM-N	GSM-S	ISDW
Spatial level	plot (stand)			site* (stand)
Starting zone	—	gap length ≤20 m	—	same values as in the transit zone
Transit zone	stem density	stem density	stem density & basal area	stem density & young growth
Block diameter <40 cm	≥400/ha DBH >12 cm	—	—	—
Block diameter 40–60 cm	≥300/ha DBH >24 cm	—	—	—
Block diameter 60–180 cm	≥150/ha DBH >34 cm	—	—	—
	—	≥796/ha DBH >20 cm (>25 m^2/ha)	>350/ha DBH >17.5 cm and >25 m^2/ha	>400/ha DBH >20 cm and CCPY ≥15%
	gap length	gap length	gap length	gap length
	<20 m	if coppice <20 m if high forest <40 m	—	≤20 m
Deposition zone	stem density	all criteria	all criteria	all criteria
—	≥400/ha DBH >12 cm	same as in the transit zone	same as in the transit zone	same as in the transit zone
—	gap length	—	—	gap length
—	<20 m	—	—	≤20 m
Length of the forested slope	—	>200 m	>200 m	—

DBH, diameter of stems at breast height [cm]; CCPY, canopy cover of "young" trees DBH <20 cm.
**Sites along the rockfall slope defined by different slope gradients.*

Table 3.
Protective effect-related targets of the forest structure against rockfall propagation according to the European guidelines NaiS [29], SFP [30], GSM-N [31], GSM-S [32] and ISDW [33].

difficult to predict, and that rockfall source areas usually deliver rocks of different sizes. Therefore, it is difficult to define applicable recommendations on silvicultural targets or critical values. A critical (average) forest density on the stand-scale does not indicate a low protection by forest inevitably as small-scale topographic features, stumps, logs or other stands may substitute the barrier effects or not. The gap concept implements the spatial variety in forest density but is affected by the same limitations. Kalberer [93] for example found a high rockfall risk reduction by forest in a study area, although the forest did not fulfill the requirements according to NaiS (**Table 3**). This was an effect of the length of the slope covered by forest and of cumulative effects of the woody vegetation [93]. Therefore, the recommendations in NaiS [29] have been replaced by an online tool, which implements the length of the forested slope, but refers to the average stem density or basal area on the slope-level [87].

The European guidelines consider the basal area (or stem density), some also a minimum length of the forested slope and the gap length, but they do not refer to effects of cumulative gap lengths and basal areas as proposed by [93, 94]. Some of the guidelines do not clearly disclose the relation of the targets to the considered spatial level [7]. However, a protective function (and effect) should not be allocated

to a minimum slope length covered by forest as the protective potential also depends on the terrain morphology. It is not possible to define a forested slope length that has no relevant protective effect and thus no protective function [94].

3. Conclusions

Forests can prevent the formation of snow avalanches. They may also reduce the likelihood of shallow-seated slope failures and mitigate smaller rockfall. But they are unable to stop large masses of snow, soil and rock in motion. Therefore, natural hazard risk and forest management focus on the mitigation of onset probabilities at the stand-scale. The state of knowledge on protective effects of forests has been condensed into expert-based guidelines with quantitative forestry objectives. Forest effects on hazard propagation are difficult to implement in forest and risk management via guidelines, as local conditions vary considerably. The existing assessment procedures consider the protective mechanisms and their controlling conditions to varying degrees, depending on the state of knowledge and the complexity of data collection and process assessment that can be applied. Even in terms of hazard initiation, the guidelines propose quite different silvicultural targets which may result in under- or overestimations of protective effects. Recommendations on critical canopy covers, stem densities and sizes of openings should be treated with caution, even though they are frequently quoted and applied in a multitude of scientific and practical studies. The assessment of the protective effects of forest is still associated with uncertainty which also arise from the considered risk acceptance level, spatial scale and data issues.

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by Interreg Alpine Space programme, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy. We thank Peter Bebi for providing the dataset on observed forest avalanche initiations in Switzerland.

Author details

Frank Perzl[1*], Alessia Bono[2], Matteo Garbarino[2] and Renzo Motta[2]

1 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

2 Department of Agriculture, Forest and Food Sciences (DISAFA), University of Turin, Grugliasco, TO, Italy

*Address all correspondence to: frank.perzl@bfw.gv.at

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Wehrli A, Brang P, Maier B, Duc P, Binder F, Lingua E, Ziegner K, Kleemayr K, Dorren L. Schutzwaldmanagement in den Alpen – eine Übersicht. Schweizerische Zeitschrift für Forstwesen. 2007;**6**: 142-156

[2] Motta R, Haudemand J-C. Protective forests and silvicultural stability: An example of planning in the Aosta Valley. Mountain Research and Development. 2000;**20**(2):180-187

[3] Makino Y, Rudolf-Miklau F. The protective functions of forests in a changing climate. European experience. Rome: FAO and the Austrian Federal Ministry for Agriculture, Regions and Tourism, Forestry Working Paper 20; 2021. 123 p. DOI: 10.4060/cb4464en

[4] Brang P, Schönenberger W, Ott E, Gardner B. Forest as protection from natural hazards. In: Evans J, editor. The Forest Handbook Volume 2, Applying Forest Science for Sustainable Management. Blackwell Science; 2001. pp. 53-81. DOI: 10.1002/9780470 757079.ch3

[5] Teich M, Accastello C, Perzl F, Berger F. Protective Forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI:10.5772/intechopen.99505

[6] Perzl F. Der Objektschutzwald. Bedeutung und Herausforderung. BFW-Praxisinformation. 2014;**34**: 20-24

[7] Perzl F, Kleemayr K. D.T.1.3.2 Report Assessment of forest protection effects and functions for natural hazard processes. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[8] Markart G, Teich M, Scheidl C, Kohl B. Flood protection by forests in Alpine watersheds – lessons learned from Austrian case studies. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99507

[9] Brang P, Schönenberger W, Frehner M, Schwitter R, Thormann J-J, Wasser B. Management of protection forests in the European Alps: An overview. Forest, Snow and Landscape Research. 2006;**80**(1):23-44

[10] Sakals ME, Innes JL, Wilford DJ, Sidle RC, Grant GE. The role of forests in reducing hydrogeomorphic hazards. Forest, Snow and Landscape Research. 2006;**80**(1):11-22

[11] Bebi P, Kulakowski D, Rixen C. Snow avalanche disturbances in forest ecosystems – State of research and implications for management. Forest Ecology and Management. 2009;**57**: 1883-1892. DOI: 10.1016/j.foreco. 2009.01.050

[12] Munger TT. Avalanches and forest cover in the northern Cascades. Washington: U.S. Department of Agriculture, Forest Service Circular 173; 1911. 12 p

[13] Konetschny H. Schneebewegung und Lawinentätigkeit in zerfallenden Bergwäldern. München: Informationsberichte Bayerisches Landesamt für Wasserwirtschaft. 1990; 3/90. 218 p

[14] Meyer-Grass M, Schneebeli M. Die Abhängigkeit der Waldlawinen von Standorts-, Bestandes- und Schneeverhältnissen. In: Internationales Symposion Interpraevent 1992 – Bern, Tagungspublikation, Band 2; 1992. pp. 443-455

[15] SLF. Der Lawinenwinter 1999. Ereignisanalyse. Davos: Eidg. Institut für Schnee- und Lawinenforschung (SLF); 2000. 588 p

[16] Viglietti D, Letey S, Motta R, Maggioni M, Freppaz M. Snow avalanche release in forest ecosystems: A case study in the Aosta Valley region (NW-Italy). Cold Regions Science and Technology. 2010;**64**:167-173. DOI: 10.1016/j.coldregions.2010.08.007

[17] Frey W. Wechselseitige Beziehungen zwischen Schnee und Pflanze – eine Zusammenstellung anhand der Literatur. Davos: Mitteilungen des Eidg. Institutes für Schnee- und Lawinenforschung. 1977;**34**:223

[18] In der Gand H. Verteilung und Struktur der Schneedecke unter Waldbäumen und im Hochwald. In: Mountain Forests and Avalanches. IUFRO Working Party Snow and Avalanches. Proceedings of the Davos Seminar September 1978: SFISAR; 1978. pp. 97-119

[19] Imbeck H. Lawinenbildung im Wald und deren Wirkung in der Region Davos. Schlussbericht des Forschungsprojektes 307.80. Davos: Eidg. Institut für Schnee- und Lawinenforschung (EISLF); 1984. 21 p

[20] Stadler D, Bründl M, Schneebeli M, Meyer-Grass M, Flühler H. Hydrologische Prozesse im subalpinen Wald im Winter. Projektschlussbericht im Rahmen des Nationalen Forschungsprogrammes NFP31 "Klimaänderungen und Naturkatastrophen". Zürich: vdf Hochschulverlag AG an der ETH; 1998. 145 p

[21] Weir P. Snow Avalanche Management in Forested Terrain. Land Management Handbook No. 55. Victoria, BC: British Columbia Ministry of Forests; 2002. 190 p

[22] Schneebeli M, Bebi P. Snow and avalanche control. In: Burley J, Evans J, Youngquist J, editors. Encyclopedia of Forest Science. 1st ed. Oxford: Elsevier; 2004. pp. 397-402

[23] Weiskittel AR, Maguire DA. Branch surface area and its vertical distribution in coastal Douglas-fir. trees. 2006;**20**:657-667. DOI: 10.1007/s00468-006-0081-3

[24] Teich M, Giunta AD, Hagenmuller P, Bebi P, Schneebeli M, Jenkins MJ. Effects of bark beetle attacks on forest snowpack and avalanche formation – Implications for protection forest management. Forest Ecology and Management. 2019;**438**:186-203

[25] In der Gand H. Aufforstungsversuche an einem Gleitschneehang. Ergebnisse der Winteruntersuchungen 1955/56 bis 1961/62. Schweizerische Anstalt für das forstliche Versuchswesen Mitteilungen; Band 44, 3; 1968. pp. 233-326

[26] Saeki M, Matsuoka H. Snow-buried young forest trees growing on steep slopes. Seppyo. Japanese Society of Snow and Ice. 1969;**31**:19-23

[27] Frey W. Über das Abbiegen von Stämmen junger Lärchen durch Schneedruck. Mountain Forests and Avalanches. IUFRO working party snow and avalanches. Proceedings of the Davos Seminar September 1978: SFISAR; 1978. pp. 183-203

[28] McClung DM. Characteristics of terrain, snow supply and forest cover for avalanche initiation caused by logging. Annals of Glaciology. 2001;**32**:223-229

[29] Frehner M, Wasser B, Schwitter R. Nachhaltigkeit und Erfolgskontrolle im

Schutzwald. Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion. Bern: Bundesamt für Umwelt, Wald und Landschaft (BUWAL); 2005

[30] Berretti R, Caffo L, Camerano P, De Ferrari F, Domaine A, Dotta A, Gottero F, Haudemand J-C, Letey C, Meloni F, Motta R, Terzuolo PG. Selvicoltura nelle foreste di protezione: esperienze e indirizzi gestionali in Piemonte e Valle d'Aosta. Arezzo: Compagnia delle Foreste S.r.l.; 2006. 220 p

[31] Gauquelin X, Courbaud B, Editors. Guide des Sylvicultures de Montagne. Alpes du Nord Françaises. Cemagref, CRPF Rhône-Alpes, ONF; 2006. 289 p

[32] Ladier J, Rey F, Dreyfus P, Editors. Guide des Sylvicultures de Montagne. Alpes du Sud françaises. OFN, Irstea, Centre PACA; 2012. 301 p

[33] Perzl F. Ein Minimalstandard für die Dokumentation der Schutzwirkungen des Waldes im Rahmen der Österreichischen "Initiative Schutz durch Wald". In: Conference Proceedings – Internationales Symposion Interpraevent; 2008; Dornbirn; 2; 2008. pp. 551-562

[34] Breien H, Høydal ØA. (2013). Effect of high elevation birch forest on snow stability. In: Proceedings of the International Snow Science Workshop ISSW; October 7-11 2013; Grenoble Chamonix-Mont-Blanc France. ANENA-IRSTEA-Météo-France; 2013. pp. 23-30

[35] Zenke B, Konetschny H. Lawinentätigkeit in zerfallenden Bergwäldern. In: Internationales Symposion Interpraevent; 1988; Graz; 2; 1988. pp. 213-227

[36] Salm B. Snow forces on forest plants. In: Mountain Forests and Avalanches. IUFRO Working Party Snow and Avalanches. Proceedings of the Davos Seminar September 1978: SFISAR; 1978. pp. 157-181

[37] Pfister R. Modellierung von Lawinenanrissen im Wald. Nachdiplomkurs in angewandter Statistik [thesis]. Zürich: ETH Zürich; 1997

[38] Perzl F. Beurteilung der Lawinen-Schutzwirkung des Waldes. BFW Praxisinformation. 2005;**8**:27-31

[39] De Quervain M. (1978). Wald und Lawinen. In: Mountain Forests and Avalanches. IUFRO Working Party Snow and Avalanches. Proceedings of the Davos Seminar September 1978: SFISAR; 1978. pp. 219-239

[40] Gubler H, Rychetnik J. Effects of forests near timberline on avalanche formation. In: Snow, Hydrology and Forests in High Alpine Areas; Proceedings of the Vienna Symposium; August 1991; IAHS Publication No. 205; 1991. pp. 19-38

[41] Margreth S. Die Wirkung des Waldes bei Lawinen. Forum für Wissen. 2004:21-26

[42] Feistl T, Bebi P, Dreier L, Hanewinkel M, Bartelt P. Quantification of basal friction for technical and silvicultural glide-snow avalanche mitigation measures. Natural Hazards and Earth System Sciences. 2014;**14**:2921-2931. DOI: 10.5194/nhess-14-2921-2014

[43] Laatsch W. Die Entstehung von Lawinenbahnen im Hochlagenwald. Forstwissenschaftliches Centralblatt. 1977;**96**:89-93

[44] Teich M, Bartelt P, Grêt-Regamey A, Bebi P. Snow avalanches in forested terrain: Influence of forest parameters, topography, and avalanche characteristics on runout distance. Arctic, Antarctic, and Alpine Research. 2012;**44**:509-519.DOI:10.1657/1938-4246-44.4.509

[45] Feistl T, Bebi P, Teich M, Bühler Y, Christen M, Thoru K, Bartelt P. (2014). Observations and modelling of the braking effect of forest on small and medium avalanches. Journal of Glaciology. 2014;**60**:124-138. DOI: 10.3189/2014JoG13J055

[46] Bartelt P, Stöckli V. The influence of tree and branch fracture, overturning and debris entrainment on snow avalanche flow. Annals of Glaciology. 2001;**32**:209-216

[47] Anderson G, McClung D. Snow avalanche penetration into mature forest from timber-harvested terrain. Canadian Geotechnical Journal. 2012;**49**:477-484. DOI: 10.1139/T2012-018

[48] Feistl T, Bebi P, Christen M, Margreth S, Diefenbach L, Bartelt P. Forest damage and flow avalanche regime. Natural Hazards and Earth System Sciences. 2015;**6**:1275-1288. DOI: 10.5194/nhess-15-1275-2015

[49] Stitzinger KR. Snow Avalanche Risk and Decision Support for Clear-Cut Harvested Terrain [Thesis]. Edinboro: Edinboro University of Pennsylvania; 1999

[50] Keusen HR, Bollinger D, Rovina H, Wildberger A, Wyss R. Gefahreneinstufung Rutschungen i.w.S. Zollikofen: AG Geologie und Naturgefahren; 2004. 17 p

[51] Forest Practice Board Manual. Section 16: Guidelines for Evaluating Potentially Unstable Slopes and Landforms [Internet]. 2016. Available from: https://www.dnr.wa.gov/publications/bc_fpb_manual_section16.pdf

[52] Swanston DN, Lienkaemper GW, Mersereau RC, Levno AB. Timber harvest and progressive deformation of slopes in southwestern Oregon. Bulletin of the Association of Engineering Geologists. 1988;**25**(3):371-381

[53] Miller D. Literature synthesis of the effects of forest practices on non-glacial deep-seated landslides and groundwater recharge. Cooperative monitoring evaluation and research report CMER. Washington state forest practices adaptive management program. Olympia, WA: Washington Department of Natural Resources. 2017. Available from: https://www.dnr.wa.gov/publications/bc_cmer_ngdsl_lit_synth_20201119.pdf

[54] Swanston DN, Swanson FJ. 1976, timber harvesting, mass erosion, and steepland forest geomorphology in the Pacific northwest. In: Coates DR, editor. Geomorphology and Engineering. Stroudsburg, PA, Dowden: Hutchinson & Ross, Inc.; 1976. p. 199-221

[55] Johnson AC, Wilcock P. Association between cedar decline and hillslope stability in mountainous regions of Southeast Alaska. Geomorphology. 2002;**46**:129-142

[56] Miller DJ, Burnett KM. Effects of forest cover, topography, and sampling extent on the measured density of shallow, translational landslides. Water Resources Research. 2007;**43**. DOI: 10.1029/2005WR004807

[57] Ziemer RR. The role of vegetation in the stability of forested slopes. In: Proceedings of the International Union of Forestry Research Organizations, XVII world congress; 6-17 September 1981. Vol. I. Kyoto, Japan: IUFRO; 1981. pp. 297-308

[58] Canadell J, Jackson RB, Ehleringer JR, Mooney HA, Sala OE, Schulze ED. Maximum rooting depth of vegetation types at the global scale. Oecologia. 1996;**108**:583-595

[59] Li J, Chen B, Li X, Zhao Y, Ciren Y, Jiang B, Hu W, Cheng J, Shao M. Effects of deep soil desiccation on artificial forestlands in different vegetation zones on the loess plateau of China. Acta

Ecologica Sinica. 2008;**28**,4: 1429-1445

[60] McDonnell JJ. The influence of macropores on debris flow initiation. Quarterly Journal of Engineering Geology. 1990;**22**:325-331

[61] Uchida T, Mizuyama T. The contribution of pipeflow on shallow landslide initiation at steep hillslopes. In: International Congress Interpraevent 2002 in the Pacific Rim – Matsumoto/Japan; 2; 2002. pp. 559-569

[62] Gray DH, Sotir RB. Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control. New York: John Wiley & Sons; 1996. 400 p

[63] Graf F, Bebi P, Braschler U, De Cesare G, Frei M, Greminger P, Grunder K, Hählen N, Rickli C, Rixen C, Sandri A, Springman SM, Thormann J-J, von Albertini N, Yildiz A. Pflanzenwirkungen zum Schutz vor flachgründigen Rutschungen. Bern: WSL Bericht 56; 2017. 42 p

[64] Tichavský R, Ballesteros-Cánovas JA, Šilhán K, Tolasz R, Stoffel M. Dry spells and extreme precipitation are the main trigger of landslides in Central Europe. Scientific Reports. 2019;**9**:14960. DOI: 10.1038/s41598-019-51148-2

[65] Stokes A, Atger C, Bengough AG, Fourcaud T, Sidle RC. Desirable plant root traits for protecting natural and engineered slopes against landslides. Plant and Soil. 2009;**324**:1-30. DOI: 10.1007/s11104-009-0159-y

[66] Schulz WH, Smith JB, Wang G, Jiang Y, Roering JJ. Clayey landslide initiation and acceleration strongly modulated by soil swelling. Geophysical Research Letters. 2018;**45**. DOI: 10.1002/2017GL076807

[67] Lanni C, Borga M, Rigon R, Tarolli P. Modelling shallow landslide susceptibility by means of a subsurface flow path connectivity index and estimates of soil depth spatial distribution. Hydrology and Earth System Sciences. 2012;**16**:3959-3971. DOI: 10.5194/hess-16-3959-2012

[68] Stokes A, Mattheck C. Variation of wood strength in tree roots. Journal of Experimental Botany. 1996;**47**(298): 693-699

[69] Boldrin D, Leung AK, Bengough AG. Root biomechanical properties during establishment of woody perennials. Ecological Engineering. 2017;**109**:196-206

[70] Medicus G. Massenbewegungen und Vegetationsbedeckung [thesis]. Innsbruck: Universität Innsbruck; 2009

[71] Vergani C, Giadrossich F, Buckley P, Conedera M, Pividori M, Salbitano F, Rauch HS, Lovreglio R, Schwarz M. Root reinforcement dynamics of European coppice woodlands and their effect on shallow landslides: A review. Earth-Science Reviews. 2017;**167**:88-102. DOI: 10.1016/j.earscirev.2017.02.002

[72] Vergani C, Schwarz M, Soldati M, Corda A, Giadrossich F, Chiaradia EA, Morando P, Bassaneli C. Root reinforcement dynamics in subalpine spruce forests following timber harvest: A case study in Canton Schwyz, Switzerland. Catena. 2016;**143**:275-288. DOI: 10.1016/j.catena.2016.03.038

[73] Amishev D, Basher L, Phillips C, Hill S, Marden M, Bloomberg M, Moore J. New forest management approaches to steep hills. Wellington: MPI Technical Paper No: 2014/39; 2014. 109 p

[74] Moos, C. How Does Forest Structure Affect Landslide Susceptibility? Statistical Prediction Models for Shallow Landslides Integrating Forest Structure [Thesis]. Zürich: ETH; 2014

[75] Fetherston KL, Naiman RJ, Bilby RE. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. Geomorphology. 1995;**13**:133-144

[76] Robison EG, Mils KA, Paul J, Dent L, Skaugset A. Oregon Department of Forestry Storm Impacts and Landslides of 1996: Final Report. Forest Practices Technical Report No. 4; 1999. 145 p

[77] Johnson AC, Swanston DN, McGee KA. Landslide initiation, runout, and deposition within clearcuts and old-growth forests of Alaska. Journal of the American Water Resources Association. 2000;**36**(1): 17-30

[78] May CL, Gresswell RE. Processes and rates of sediment and wood accumulation in headwater streams of the Oregon coast range, USA. Earth Surface Processes and Landforms. 2003;**28**:409-424

[79] Lancaster S, Hayes SK, Grant GE. Effects of wood on debris flow runout in small mountain watersheds. Water Resources Research. 2003;**39**(6):1168. DOI: 10.1029/2001WR001227

[80] Sebald J, Senf C, Heiser M, Scheidl C, Pflugmacher D, Seidl R. The effects of forest cover and disturbance on torrential hazards: Large-scale evidence from the Eastern Alps. Environmental Research Letters. 2019;**114031**. DOI: 10.1088/1748-9326/ab4937

[81] Booth AM, Sifford C, Vascik B, Siebert C, Buma B. Large wood inhibits debris flow runout in forested Southeast Alaska. Earth Surface Processes and Landforms. 2020. DOI: 10.1002/esp.4830

[82] Bettella F, Michelini T, D' Agostiono V, Bischetti GB. The ability of tree systems to intercept debris flows in forested fan areas: A laboratory modelling study. Journal of Agricultural Engineering. 2018;**XLIX**(712):42-51

[83] Jahn J. Entwaldung und Steinschlag. In: Internationales Symposium Interpraevent 1988 – Graz; Tagungspublikation, Band 1; 1988. pp. 185-198

[84] Kalberer M. Waldwirkung gegenüber Steinschlag. Untersuchungen zur Quantifizierung und Optimierung der Schutzwaldleistung. Saarbrücken: VDM Verlag Dr. Müller; 2007. 221 p

[85] Dorren LK, Berger F, Le Hir C, Mermin E, Tardif P. Mechanisms, effects and management implications of rockfall in forests. Forest Ecology and Management. 2005;**215**:183-195. DOI: 10.1016/j.foreco.2005.05.012

[86] Dorren LKA, Berger F, Mermin E, Tradif P. Results of real rockfall experiments on forested and non-forested slopes. In: Proceedings of the Interpraevent International Symposium; September 25-29; 2006; Niigata, Japan; 2006. pp. 223-228

[87] Dorren L, Berger F, Frehner M, Huber M, Kühne K, Métral R, Sandri A, Schwitter R, Thormann J-J, Wasser B. 2015. Das neue NaiS-Anforderungsprofil Steinschlag. Schweizerische Zeitschrift für Forstwesen. 2015;**166**(1):16-23. DOI: 10.3188/szf.2015.0016

[88] Kalberer M, Ammann M, Jonsson M. Mechanische Eigenschaften der Fichte: Experimente zur Analyse von Naturgefahren. Schweizerische Zeitschrift für Forstwesen. 2007;**158**(6):166-175

[89] Ciabocco G, Boccia L, Ripa MN. Energy dissipation of rockfalls by coppice structures. Natural Hazards and Earth System Sciences. 2009;**9**:993-1001

[90] Radtke A, Toe D, Berger F, Zerbe S, Bourrier F. Managing coppice forests for

rockfall protection: Lessons from modelling. Annals of Forest Science. 2014;**71**:485-494. DOI: 10.1007/s13595-013-0339-z

[91] Stokes A. Selecting tree species for use in rockfall-protection forest. Forest, Snow and Landscape Research. 2006;**80**(1):77-86

[92] Schneuwly-Bollschweiler M, Schneuwly DM. How fast do European conifers overgrow wounds inflicted by rockfall? Tree Physiology. 2012;**32**(8):968-975. DOI: 10.1093/treephys/tps059

[93] Kalberer M. Protect Bio II. Fallbeispiel Steinschlag. Davos: tur gmbh, Bern: Bundesamt für Umwelt (BAFU); 2011. 31 p

[94] Zürcher K. Anforderungen an den Steinschlag-Schutzwald: Maximal zulässige Lückenlänge und minimal bewaldete Hanglänge? Agenda FAN. 2010;**2**:10-15

Chapter 4

Flood Protection by Forests in Alpine Watersheds: Lessons Learned from Austrian Case Studies

Gerhard Markart, Michaela Teich, Christian Scheidl and Bernhard Kohl

Abstract

This chapter highlights the influence of mountain forests on runoff patterns in Alpine catchments. We discuss the forest impact at different spatial scales and bridge to the requirements for an integrated natural hazard risk management, which considers forest as an efficient protection measure against floods and other water-related natural hazards. We present results from a wide range of research studies from Austria, which all reveal the runoff-reducing effect of forest vegetation in small and medium-size catchments (< 100 km^2). Forests also contribute to runoff reduction in heavy rainfall events in macro-scale catchments (> 100 km^2), e.g., by reducing surface runoff and delaying interflow, but above all by stabilising slopes and therefore reducing bedload transport during major runoff events. To avoid that forests become a hazard due to enhanced driftwood release, managing of steep riparian slopes for a permanent forest cover ("Dauerbestockung") is a basic prerequisite. Often protective effects of forests are impaired by man-made impacts like dense forest road networks, insensitive use (e.g., false design of skid roads, compacting machinery, forest operations during adverse weather on wet and saturated soils), and delayed or omitted reforestation and regeneration. Flood risk management in mountain regions should include Ecosystem-based Disaster Risk Reduction (Eco-DRR) measures, with particular emphasis on sustainable and climate change-adapted management of protective forests. This will require integrated and catchment-based approaches such as comprehensive management concepts coordinated with spatial planning, and verifiable, practicable and correspondingly adapted legal guidelines as well as appropriate funding of protective forest research to close the existing knowledge gaps.

Keywords: mountain hydrology, floods, landslides, protective forest, risk management, runoff

1. Introduction

Mountain forests and their soils serve an important role in preventive flood protection by ensuring that rainwater is retained over large areas during potential

runoff formation, which has been demonstrated for medium-sized flood events in numerous studies (e.g., [1–5]). In contrast to grasslands, forest vegetation can reduce average catchment discharge by higher rainfall interception, evapotranspiration, free soil pore volume and soil hydraulic conductivity, which also influence near-surface and subsurface runoff (e.g., [6, 7]; for definitions see **Table 1**).

These mitigating effects are however limited by either the intensity of a precipitation event or by the soil water storage (SWS) capacity of the forested catchment (**Figure 1**; for definition see **Table 1**). If SWS capacity is high, surface runoff from forested sites remains significantly below the surface runoff from comparable sites without forest vegetation. In case of precipitation intensities typical for triggering flood events, forest's interception capacities are reached rapidly, and evapotranspiration for such short duration and high intensity events can be neglected, so that especially subsurface runoff from forest areas may approach amounts from unforested sites – with a corresponding time delay. In addition, extensive deforestation

Terms and symbols	Definition
Antecedent soil moisture content (ASMC) [Vol%]	Degree of prefilling, i.e., water content of the soil before a precipitation event (determines the free available storage volume)
Soil hydraulic conductivity [m s^{-1}]	Ratio between the velocity vs. a hydraulic gradient in porous media (e.g., soils) indicating the permeability of the medium
Surface runoff coefficient SRC [–]	Ratio of surface runoff vs. precipitation
Runoff coefficient at discharge constancy RC_{const} [–]	Runoff coefficient when the discharge from a given area stops increasing, which is derived from rain simulation experiments
Soil pore volume [Vol%]	Empty pore space in the soil, that is filled with air and/or water
Soil water storage (SWS) capacity [Vol%]	Total amount of water that can be stored in the soil
Specific discharge [m^3 s^{-1} km^{-2}]	Discharge per unit area of a watershed

Table 1.
Definitions and symbols of used technical terms.

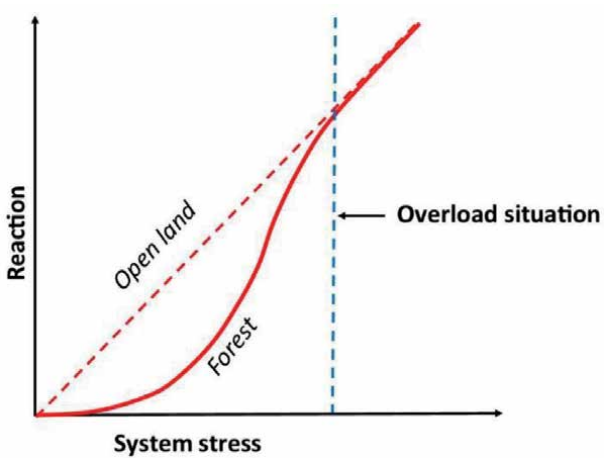


Figure 1.
Impact of forest on runoff formation compared to open areas depending on precipitation supply (amount and duration of event = system stress or load). Reaction = surface and subsurface runoff, which sometimes also results in (shallow) loose sediment landslides. Overload situations, which trigger flood events, occur when the capacity limits of interception and available SWS are exceeded – With high shares of subsurface stormflow, return flow and saturation overland flow (from: [8], modified).

can lead, especially on Leptosols, to a solum that is losing organic matter due to enhanced decomposition, which eventually results in less water absorption capacity. Thus, at sites where SWS capacity is naturally (e.g., shallow soils) or anthropogenically reduced, effects of forests on surface runoff formation are limited and an "overload situation" (i.e., a flood event) can occur much earlier, especially if soils are already saturated.

Besides the positive effects of forests on surface runoff, also near-surface and subsurface runoff are influenced by forest vegetation by allowing quick water flow along roots, and through channels formed by decayed roots. Concentrated subsurface flow is found in forest especially in soils with limited permeability or damming layers, i.e., when soil layers with ample porosity overlie hardpans or solid rock. For example, subsurface flow velocities of 5 to 35 m d^{-1} were measured in spruce- and beech-dominated forest stands on moderately inclined pseudogley soils [9], and intermediate flow velocities of 500 m d^{-1} are likely in forest soils with near-surface macro-pores induced by roots, fissures, or shrinkage cracks [10, 11]. That is, due to the macro-porous structure and propagation pressure of inclined forest soils, full saturation is hardly possible since rainwater infiltrating on the upper slope can force stored water out of the lower slope and into the watercourse. Under the same soil conditions, surface runoff and subsurface flow in unforested open land is generally higher caused by a lower proportion of rapidly permeable pores, soil compaction or dense root systems e.g., from *Nardus stricta* or some *Festuca* species, which have a hydrophobic effect ("Strohdach-Effekt") [12].

Forest and land use management can influence the timing and volume of water delivered to stream channels via various discharge routes such as surface runoff, but also the flow paths themselves [13]. Clear cuttings, for example, lead to increased runoff, especially in Alpine catchments that are highly sensitive to precipitation change [14, 15]. The Austrian Service for Torrent and Avalanche Control (WLV) and the Provincial Forest Services have therefore started programs to improve protective forests, and to initiate and maintain high-altitude afforestation after the Second World War. These measures were also implemented to reduce the high costs for new technical protection structures and to enhance the limited effects of existing "grey" (e.g., concrete) infrastructures downstream [16]. However, browsing of ungulate game species and grazing livestock often counteract forest's protective functions and effects in many Alpine countries [17].

2. Forest's protective effects from slope to catchment scales

2.1 Slope scale

On steep side slopes of torrents, protective effects of forests are key for soil conservation since significantly higher surface runoff and erosion can be expected on bare ground and in scarcely vegetated areas during heavy rainfall events. Targeted afforestation can greatly improve the hydrological response of such sites [18, 19]. For example, rainfall simulation experiments (where water is constantly applied over a certain area and time) on clear cuttings yielded surface runoff coefficients (RC_{const}; for definition see **Table 1**) up to 0.8, in contrast to RC_{const} of up to 0.5 in young spruce stands [20]. Moreover, findings from the ITAT4041 project BLÖSSEN [7] show that even in catchments with a low proportion of forested area, forest vegetation reduces runoff clearly on slope and sub-catchment scales (**Figure 2**). Results from other studies indicate that secondary forests (i.e., forests, which develop through natural succession after disturbance of primaeval forests) have lower SRCs and lower surface runoff velocities than single-species plantation forests or grassland (e.g., [23]).

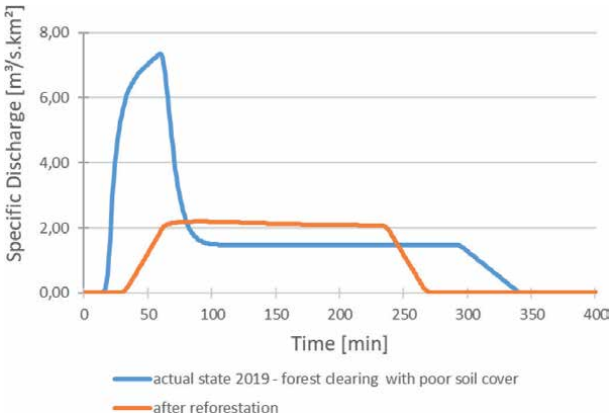


Figure 2.
Modeled specific discharge with ZEMOKOST [21] for a forest clearing with scarse ground vegetation cover and after reforestation of this site at Istalanzbach catchment in Tyrol, Austria, during a torrential rainfall event (58,3 mm precipitation in 60 min) yielded low surface runoff from reforested areas (orange) and high runoff peaks on forest clearing (blue) with poor ground cover (from [22]). Results were validated with data from rain simulation experiments.

Additional mechanical loads, e.g., from heavy and long-term grazing, can significantly worsen the surface runoff behaviour (amount and timing) in forested sites leading to similar surface runoff patterns as in grazed grasslands [12]. Comparisons of rainfall simulation data collected in twelve catchments in Austria with different types of land use and cover, including ski runs, showed that (forest) soils are strongly affected by compaction and/or grazing [24]. Levelled medium to fine textured forest soils are most affected when they are tilled during wet weather conditions and immediately as well as continuously compacted by vehicles or grazing. Consequently, they have very high runoff coefficients. However, forest road cuts in general largely disturb slope-scale surface runoff and cause erosion [25, 26] (**Figure 3**). In addition, high proportions of the uphill slope's surface and subsurface flows as well as the runoff from the road enter the receiving watercourse much faster than from undisturbed slopes [28].

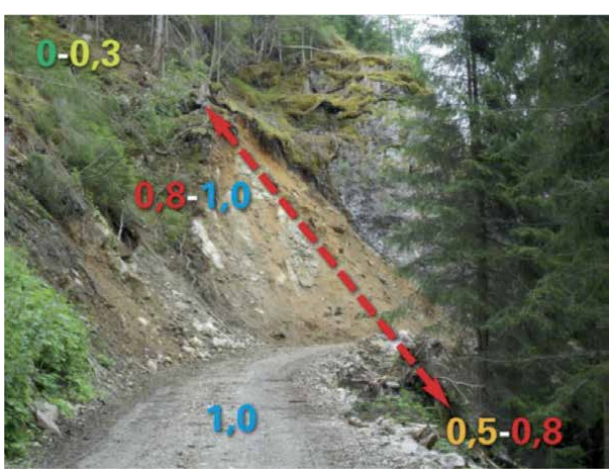


Figure 3.
Typical distribution of runoff coefficients at constant discharge for a slope segment with a forest road cut, representing results from rainfall simulation experiments. On average, RC_{const} between 0.8 and 0.9 can be expected for the entire width (red dotted line) and 1.0 for the road over a width of at least 5 m (from [27]).

Unfortunately, anthropogenic changes repeatedly outweigh the positive effects of measures to improve the hydrological function of protective forests. To partially compensate for 1 ha of disturbed and levelled forest soil, a minimum area of 5 ha of downslope forest must be optimised e.g., from RC_{const} = 0.2 to RC_{const} = 0.1. In fact, compensation is much more difficult and costlier, because runoff from roads and road outlets is concentrated in concave depth contour lines down slope and flow distances of hundreds of meters downhill are necessary to entrain such concentrated surface runoff at least partially [27].

2.2 Micro-catchment scale (< 10 km^2)

Peak flows in forested catchments (< 10 km^2) occur with a significant delay and are generally lower compared to unforested areas [22, 29]. This was also proven in a modeling experiment on the hydrological impact of land management changes implemented by the WLV between 1953 and 2003 in the Finsing Valley in Tyrol, Austria [3]. The largely forested control catchment of the Hundsbach (0.9 km^2) experienced little changes over the studied period. In the Taleggbach catchment (1.7 km^2), the area of alpine pastures was reduced by 75% after 1953 by afforestation measures, and conditions of forests were improved, e.g., by abandonment of forest pasture or closing of gaps by afforestation. Simulations of precipitation and runoff relationships (P/R) with the P/R model ZEMOKOST [21] showed no change in the discharge for the Hundsbach between 1953 and 2003 (**Figure 4**). In contrast, a significant reduction of the peak discharge by more than 50% was modeled for the Taleggbach catchment after the hydrological optimization measures became effective, i.e., the increased surface roughness (*c*) in the improved protective forest significantly reduced surface runoff velocity. Simulation results were validated by field data collected in 2007. In small mountain catchments, afforestation and forest structure improvements can considerably reduce surface runoff as also shown for other mountain areas, e.g., in Serbia [29].

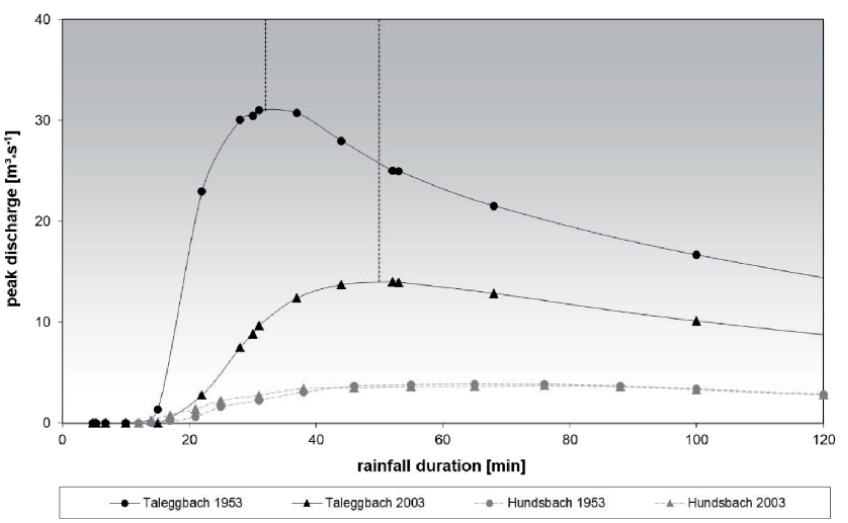


Figure 4.
Peak discharge modeled with ZEMOKOST [21] for torrential rainfall events of different duration from the Hundsbach and Taleggbach (Finsing Valley, Tyrol, Austria) before (1953) and after hydrological optimization measures were effective (2003) in the Taleggbach catchment, where critical event rainfalls lead to the highest peak discharge after 30 min in 1953 compared to 50 min in 2003 with a 50% discharge reduction (from [3], modified).

2.3 Meso-catchment scale (10-100 km^2)

We also assessed the hydrological impact of land management improvements (improvement of forest structure, extensive afforestation at high altitudes, reduction of pasture areas, etc.) and local deterioration with ZEMOKOST [21] for the entire Finsing valley (46.6 km^2) [30]. For the land use and management status of 2007 the critical design event rainfall (84 mm) lasted 64 min with a peak discharge of 122 m^3 s^{-1}. In 1953, the critical rainfall duration was 71 min with a peak discharge of 113 m^3 s^{-1} (**Figure 5**). Given this small difference in runoff behaviour, one could assume that the elaborate and costly measures did not have an adequate runoff reducing effect. However, land use and management additionally changed since 1953 due to deteriorating measures over large areas by converting meadows to pastures, constructing ski slopes, and sealing soils for touristic infrastructure. Without the improving land management measures by the WLV, peak discharge would have been about 160 m^3 s^{-1} in 2007 (see **Figure 5**). Therefore, forest vegetation controls runoff volume and timing also in mesoscale catchments.

Specifically, on the meso-catchment scale, sealing or grading and compaction of forest soils have devastating impacts on runoff and flood formation, which can only be compensated to a limited extent by improving protective forests located below or onsite [30]. In France, for example, deforestation in the headwaters of mountain rivers was blamed for extensive flooding in the valley floors in the late 18th century. The argument of increased runoff caused by deforestation was soon generalised and applied to the whole Alpine region. The so-called "Deforestation paradigm" [31], was born particularly due to the massive lobbying by forest associations. In Switzerland and other regions of the Alps, flood protection principles developed in the 19th century remained unchanged until the second half of the 20th century [32]. This was only changed by the emerging environmental debate and the occurrence of new severe flood events, despite massive defence and afforestation measures in the catchment areas [33].

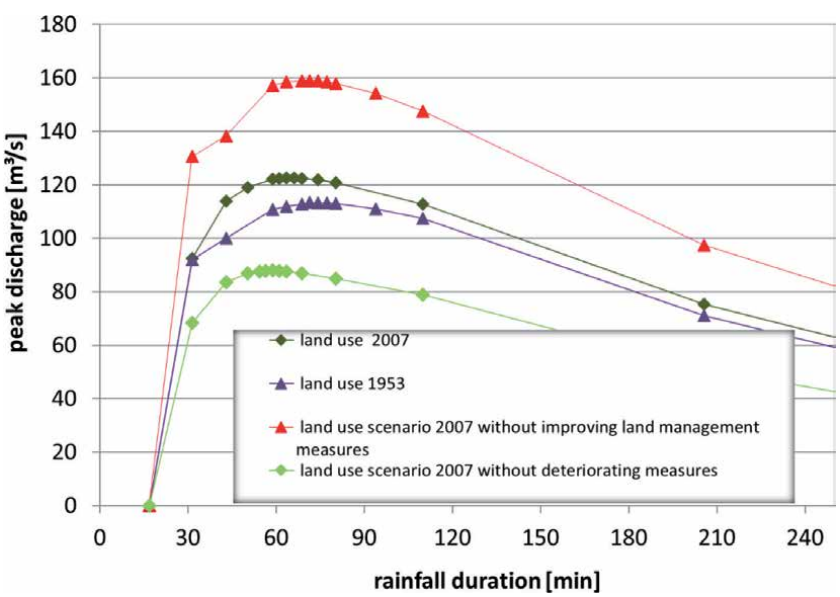


Figure 5.
Computed effects of land use and management on peak discharge in the Finsing Valley, Tyrol, Austria (from [31], modified).

2.4 Macro-catchment scale (> 100 km^2)

The retentive and runoff-reducing effect of forest vegetation during persistent and heavy rainfall events over large areas appears to be small, according to various studies (e.g., [8, 34, 35]); Forests have, however, an area-wide retentive effect on runoff formation, not only because of rainfall interception, but also because forest soils generally show better infiltration characteristics [36]. According to Wahren et al. [37] "the effectiveness of land-use changes in flood protection is limited but the biggest potential of decentral flood retention lies in the sum of effects (infiltration, pre-event soil moisture, soil storage, surface roughness, reduced erosion risk etc.)", however, "… the exact role of land use change in modifying river floods is still elusive…" [38].

During the devastating flood event of 22–23 August 2005 in Western Austria, up to 214 mm precipitation was measured in 24 h at Au in Vorarlberg. Almost area-wide indications for intensive surface runoff such as turned-over grass and traces of transported fine sediment were found on alpine pastures in the event analysis. Many shallow landslides indicated additional intensive subsurface flow above less permeable soil layer in the pastures. Surveys in the surrounding forest areas did not show any evidence of increased surface runoff, besides some temporary flow in small channels and runoff reactions from karst systems. The number of shallow landslides in forest covered areas was very low [39].

Ultimately, we repeatedly forget the multifunctionality of protective forests in technical discussions about forest's impact on runoff and, therefore, upon flood events in macro-scale catchments. Even during continuous or longer heavy rainfall events, adequately managed protective forests provide a stabilising effect on slopes and reduce the transport of solid material by lateral mass movements and thus the potential for mud- and debris flows.

3. Reducing mass movements vs. enhancing driftwood release

In addition to surface runoff reduction, forests can also influence erosion, transport, and deposition of coarse sediment and therefore fluvial bedload along streams as well as mud- and debris flows. In many cases, spreading of root systems contributes significantly to the stabilisation of slopes, preventing shallow landslides [39–41], and potentially reducing material supply for bedload transport. This effect may gradually decrease after the loss of forest cover and delayed reforestation, which can lead to a dramatic increase in subsurface flow up to 400% within the first four years and a loss of the soil-stabilising effects of the root system within 15 to 20 years after forest cover loss [39] (for details see chapter [42] of this book).

Especially in steep Alpine catchments, lateral erosion processes are related to mass movements such as landslides or avalanches, which can entrain and transport coarse and fine sediments and downed trees into streams [43, 44]. Through the release of driftwood (already lying large woody debris or debris downed during the flood event) and in-channel wood (transported during previous flood events), protective forests can also enhance danger for outburst flooding by clogging grey infrastructure, increasing damage from mud- and debris flows and causing dam breaks [43].

Several approaches to assess the potential damage driftwood can cause have been recently developed and applied in protective forest management (e.g., [43, 45, 46]). For example, the danger of potential driftwood release was explicitly included when modeling fluviatile hazard processes to identify forest areas in Switzerland that protect an acknowledged damage potential within the project SilvaProtect-CH [47]. GIS-based approaches to assess driftwood potential were developed for Bavaria, Germany [46], and Tyrol, Austria [48].

Figure 6.
Seigesbach catchment in Tyrol, Austria, after the heavy rainfall event from 7 to 8 June 2015, which released approx. 200,000 m² of solid material. Previous driftwood management adjacent to the torrent and large area salvage-logging following windthrow resulted in less driftwood, but more landslides were released from these areas.

To reduce the potential of driftwood release from old and mature forest stands along torrents, a more frequent harvest interval should be considered. During a disastrous precipitation event in the 4 km^2 Seigesbach catchment area in Tyrol, Austria, on 7–8 June 2015 approximately 200,000 m^3 of solids were discharged, but almost no driftwood was entrained in the channel. An analysis of the event showed that large areas of the catchment were unforested caused by previous windthrow and salvage-logging [49], and that regeneration was largely absent due to high pressure from ungulate browsing. However, the loss of the forest cover and the absence of a viable regeneration led to higher incidences and greater extents of landslides compared to the catchment area with undisturbed forest (**Figure 6**). Therefore, slopes with high driftwood potential should be managed for a permanent forest cover ("Dauerbestockung") and larger trees should be removed at shorter intervals. This approach still contradicts the current management practice, where clearings are recommended at distances of 1–1.5 tree lengths from the stream channel [50].

4. Integrated risk management and climate change

An analysis of almost 11,000 catchments in the Eastern Alps has shown that an increase in forest cover by 25% reduces the probability of torrent-related natural hazards by 8.7% ± 1.2% [5]. Thus, measures to maintain, improve and restore the hydrological buffering effect of forests are important for reducing natural hazard risks and for climate change adaptation. The problem, however, is to quantify the effectiveness of specific measures in the socio-ecological context [51]. "Risk management, communication and planning of forest ecosystem services are complicated by uncertainty, insufficient information or information of poor quality, limited cognitive capacity and time, along with value conflicts and ethical considerations" [52]. Thus Calder et al. [53] proposed an improved approach to river basin and flood management, combining land use management in watersheds with land use planning, technical measures, flood prevention and emergency management in the affected floodplains, which corresponds to the goals of Ecosystem-based Disaster Risk Reduction (Eco-DRR) [54] (for further information on Eco-DRR see chapter [55] of this book).

Traditional approaches of flood risk management must be adapted to changing conditions due to population growth linked to high area consumption and increased soil sealing, large-scale changes in land use and climate change. On sites not affected by drought, or extreme temperatures and/or substrates, targeted protective forest management should aim to achieve increased resistance and resilience of the forest vegetation against natural disturbances (e.g., windthrow, bark beetle outbreak) and climate change without reducing the protective effects against natural hazards [44, 56, 57]. Therefore, future flood risk management and disaster risk reduction requires more integrated, site adapted and catchment-based approaches [58], i.e., a better-balanced mixture of technical and ecosystem-based protection measures [59]. Near-natural flood protection measures such as small-scale forest management, timely reforestation, afforestation, avoidance of mechanical stresses to forest soils and the sustainable management of non-forested sites can significantly reduce volume, timing, and velocity of rapid runoff and shallow landslide disposition in small Alpine catchments [12, 27, 39, 60]. Such measures, therefore, can mitigate the potential impact of flood events and extend the time for disaster preparedness.

Climate change and associated increases of natural disturbances such as windthrow and insect infestations will alter the effectiveness of protective forests in preventing shallow landslides [61] (see also chapter [62] of this book). Landslide risk will increase and, thus, optimising forest management regarding climate change and natural hazards, including hydrological and geomorphological hazards, is a necessity [63]. Current protective forest management practices mainly view ecological conditions and site units as static but adapting to climate change requires a more dynamic approach [64].

The following steps are essential to ensure that findings from scientific research will be applied in catchment area management and to improve public acceptance of forest as an effective and cost-efficient protection measure against natural hazards [65]:

- Development of practical guidelines with generally understandable vocabulary,
- Adapted legislation and by-laws at national and local levels to apply and implement guidelines consistently and comprehensibly,
- Increased financial support for more applied research on forests and water as the basis for practical guidelines [53].

Based on results from the ITAT4041 project BLÖSSEN on "Effects of delayed reforestation on natural hazards", a stakeholder workshop, extensive field investigations, experiences of foresters in the test areas and results from other field surveys in 40 catchment areas as well as an extensive literature review, a first "Guideline to optimise the hydrological effect of protective forests" for mountain areas in the Eastern Alps was developed [27]. This guideline is an essential basis for future protective forest management and implementation of technical measures, e.g., by the Tyrolean Forest Service.

Integrated risk management should ensure the highest possible long-term protection from natural hazards [66]. Consequently, the instruments for spatial planning should be implemented in such a way that construction of new grey infrastructure does not adversely affect natural hazards and vice versa. This can only be achieved through efficient coordination and communication between all involved entities such as public authorities, forest services, and landowners during the planning phase. Such a participative process guarantees the acceptance of optimal

protection measures and the efficient allocation of financial resources in flood risk and watershed management [67].

In addition, research results, management strategies or planned measures should be communicated target-oriented to a broader audience of stakeholders using a common vocabulary and modern information and communication technologies [68]. In this context the action program "Forests protect us!" passed the Austrian Council of Ministers on 22 May 2019. The program identifies 35 specific activities to improve the current situation and to ensure the sustainability of protective forests in Austria [69].

Conflict of interest

The authors declare no conflict of interest.

Author details

Gerhard Markart[1*], Michaela Teich[1], Christian Scheidl[2] and Bernhard Kohl[1]

1 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

2 Institute of Mountain Risk Engineering, University of Natural Resources and Life Sciences, Vienna, Austria

*Address all correspondence to: gerhard.markart@bfw.gv.at

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Andréassian V. Waters and forests: From historical controversy to scientific debate. Journal of Hydrology. 2004;**291**: 1-27. Available from: https://elearning.unipd.it/scuolaamv/pluginfile.php/12799/mod_resource/content/1/Reading%20All%20Andreassian%20JoH%202004.pdf

[2] Jones A, Grant GE. Peak flow responses to clear-cutting and roads in small and large basins, Western Cascades, Oregon. Water Resources Research. 1996;**32**(4):959-974

[3] Kohl B, Sauermoser S, Frey D, Stepanek L, Markart G. Steuerung des Abflusses in Wildbacheinzugsgebieten über flächenwirtschaftliche Maßnahmen. In: Internationales Symposion INTERPRAEVENT 2004—RIVA/TRIENT, Tagungspublikation, Band 1, Thema III. 2004. pp. 159-169

[4] Mendel HG. Elemente des Wasserkreislaufs—Eine kommentierte Bibliographie zur Abflussbildung. Bundesanstalt für Gewässerkunde (Hsg.). Analytica; 2000. 244p

[5] Sebald J, Senf C, Heiser M, Scheidl C, Pflugmacher D, Seidl R. The effects of forest cover and disturbance on torrential hazards: Large-scale evidence from the Eastern Alps. Environmental Research Letters. 2019;**14**. DOI: 10.1088/1748-9326/ab4937

[6] Brown EA, Zhang L, McMahon AT, Western WA, Vertessy AR. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology. 2005;**310**:28-61

[7] Markart G, Rössler T, Scheidl C, Lechner V, Perzl F, Bunza G, et al. Verzögerte Wiederbewaldung—Auswirkung auf Abflussbildung und Hangstabilität im Schutzwald. Wildbach- und Lawinenverbau. 2020;**84**(186):148-164

[8] Hegg C. Waldwirkung auf Hochwasser. LWF Wissen. 2006;**55**:29-33

[9] Jost G, Schume H, Hager H, Markart G, Kohl B. A hillslope scale comparison of tree species influence on soil moisture dynamics and runoff process during intense rainfall. Journal of Hydrology. 2012;**420-421**:112-124

[10] Mosley MP. Subsurface flow velocities through selected forested soils, South Island, New Zealand. Journal of Hydrology. 1982;**55**:65-92

[11] Weinmeister HW. Die Bedeutung der flächenwirtschaftlichen Maßnahmen für die Wildbach- und Lawinenverbauung. In: Waldsanierung, Ideen-Vorschläge-Lösungen. Beiträge zur Hochschultagung, Wien/Österreich, 23-24 Oktober 1991, Univ. f. Bodenkultur. pp. 1-12

[12] Markart G, Kohl B, Sotier B, Klebinder K, Schauer T, Bunza G, Pirkl H, Stern R. A Simple Code of Practice for the Assessment of Surface Runoff Coefficients for Alpine Soil-/Vegetation Units in Torrential Rain (Version 2.0). Report in the frame of the Interreg-SEE-Project CC-WaterS (WP7—Water Supply Management Measures, Act 7.1). 2011. Available from: https://www.researchgate.net/publication/273761280_A_Simple_Code_of_Practice_for_the_Assessment_of_Surface_Runoff_Coefficients_for_Alpine_Soil-Vegetation_Units_in_Torrential_Rain_Version_20

[13] Eisenbies MH, Austa WM, Burgera JA, Adams MB. Forest operations, extreme flooding events and considerations for hydrologic modelling in the Appalachians—A review. Forest Ecology and Management. 2007;**242**:77-98

[14] Breitsameter J. Untersuchungen zum Feststoffaustrag aus unterschiedlich dicht bewaldeten

Kleineinzugsgebieten im Flysch und in den Kalkalpen der Tegernseer Berge. Forstliche Forschungsberichte München; 1996. p. 154

[15] Führer HW. Einflüsse des Waldes und waldbaulicher Maßnahmen auf Höhe, zeitliche Verteilung und Qualität des Abflusses aus kleinen Einzugsgebieten—Projektstudie im Krofdorfer Buchenforst. Forstliche Forschungsberichte München; 1990. p. 106

[16] Brugger O. Wildbachverbauung—Almsanierung—Integralmelioration, dargelegt am Großbeispiel Zillertal. Interpraevent; 1967. pp. 91-97

[17] Duguma LA, Gratzer G. Protection against natural hazards. In: Price MF, Gratzer G, Duguma LA, Kohler T, Maselli D, Romeo R, editors. Mountain Forests in a Changing World—Realizing Values, Addressing Challenges. Rome: FAO/MPS and SDC; 2011

[18] Bunza G, Schauer T. Der Einfluß von Vegetation, Geologie und Nutzung auf den Oberflächenabfluß bei künstlichen Beregnungen in Wildbacheinzugsgebieten der Bayerischen Alpen. München: Informationsbericht 2/89 des Bayerischen Landesamtes für Wasserwirtschaft; 1989. pp. 127-150

[19] Nordmann B. Einfluss der Forstwirtschaft auf den vorbeugenden Hochwasserschutz—Integrale Klassifizierung abflusssensitiver Waldflächen [dissertation]. TU-München: Fachgebiet für Waldernährung und Wasserhaushalt; 2011

[20] Mößmer EM. Wilde Wasser zähmt der Wald. In: Wald·Wasser·Leben. Stiftung Wald in Not. 2000:3-12 Available from: http://www.naturschutz-freiberg.de/index_htm_files/Wald-Wasser-Leben.pdf

[21] Kohl B. ZEMOKOST—Entwicklung eines praktikablen Niederschlag-/Abflussmodells zur Modellierung von Hochwasserabflüssen in Wildbacheinzugsgebieten unter Einbeziehung verbesserter Felddaten [dissertation]. Fakultät für Geo- und Atmosphärenwissenschaften: Institut für Geographie, Universität Innsbruck; 2011

[22] Rössler T. Hydrologische Beurteilung unterschiedlicher Reaktionseinheiten mit dem Fokus auf Waldstandorten und Übertragung der beobachteten Unterschiede auf zwei Einzugsgebiete (Istalanzbach bei See i.P.; Tanaser Bach bei Laas im Vinschgau) [Masterarbeit]. Institut für Geographie, Universität Innsbruck; 2020

[23] Wang S, Zhang Z, McVicar TR, Zhang J, Zhu J, Guo J. An event-based approach to understanding the hydrological impacts of different land uses in semi-arid catchments. Journal of Hydrology. 2012;**416-417**:50-59

[24] Baldauf E. Runoff Processes on Ski Slopes—Analyses Based on Rain Simulation Experiments [Master Thesis]. Department of Civil, Geo and Environmental Engineering, Institute of Hydrology and River Basin Management: TU-Munich; 2020

[25] Pereira P, Gimeìnez-Morera A, Novara A, Keesstra S, Jordán A, Masto RE, et al. The impact of road and railway embankments on runoff and soil erosion in eastern Spain. Hydrology and Earth System Sciences Discussions. 2015;**12**:12947-12985. DOI: 10.5194/hessd-12-12947-2015

[26] Cosandey C, Andréassian V, Martin C, Didon-Lescot JF, Lavabre J, Folton N, et al. The hydrological impact of the Mediterranean forest: A review of French research. Journal of Hydrology. 2005;**301**:235-249

[27] Markart G, Perzl F, Lechner V, Kohl B, Hauser P, Geitner C, Meißl G, Pircher G, Scheidl C, Stepanek L, Teich M. Handlungsanleitung—Optimierung der

hydrologischen Wirkung von Schutzwäldern. BFW. 2020. Available from: https://www.bfw.gv.at/wp-content/uploads/BFW_Handlungsanleitung_Optimierung_hydrologischer_Wirkung_Schutzwaeldern_2020.pdf

[28] Wemple BC, Jones JA, Grant GE. Channel network extension by logging roads in two basins, Western Cascades, Oregon. Water Resources Bulletin, American Water Resources Association. 1996;**32**(6):1195-1207

[29] Ristić R, Radić B, Nikić Z, Trivan G, Vasiljević N, Dragićević S, et al. Erosion control and protection from torrential floods in Serbia—Spatial aspects. Spatium. 2011;**25**:1-6. DOI: 10.2298/SPAT1125001R

[30] Kohl B, Sotier B, Klebinder K, Jochem A, Markart G. Hydrologie Finsing—Szenarienanalyse. Sektion Tirol: Bericht an den Forsttechnischen Dienst für Wildbach- und Lawinenverbauung. 2007

[31] Pfister C, Brändli D. Rodungen im Gebirge—Überschwemmungen im Vorland. Ein Deutungsmuster macht Karriere. In: Sieferle RP, Breuninger H, editors. Natur-Bilder. Wahrnehmungen von Natur und Umwelt in der Geschichte. Frankfurt a. M. 1999. pp. 297-324

[32] Summermatter S. Die Prävention von Überschwemmungen durch das politische System der Schweiz von 1848 bis 1991 [dissertation]. Historisches Institut, Universität Bern; 2012

[33] Salvisberg M. Der Hochwasserschutz an der Gürbe. Eine Herausforderung für Generationen (1855-2010). Schwabe Verlag Basel, Wirtschafts-, Sozial und Umweltgeschichte. Band 7. p. 2107

[34] Chandler KR, Stevens CJ, Binley A, Keith AM. Influence of tree species and forest land use on soil hydraulic conductivity and implications for surface runoff generation. Geoderma. 2018;**310**:120-127. DOI: 10.1016/j.geoderma.2017.08.011

[35] Soulsby C, Dick J, Scheliga B, Tetzlaff D. Taming the flood—How far can we go with trees? Hydrological Processes. 2017;**31**:3122-3126. DOI: 10.1002/hyp.11226

[36] Konold W. Inwieweit trägt eine angepasste Landnutzung zum Hochwasserschutz bei? LWF-Wissen. 2006;**55**:17-23

[37] Wahren A, Feger KH, Schwärzel K, Münch A. Landuse effects on flood generation-considering soil hydraulic measurements in modelling. Advances in Geosciences. 2009;**21**:99-107. DOI: 10.5194/adgeo-21-99-2009

[38] Rogger M, Agnoletti M, Alaoui A, Bathurst JC, Bodener G, Borga M, et al. Land use change impacts on floods at the catchment scale: Challenges and opportunities for future research. Water Resources Research. 2017;**53**:5209-5219. DOI: 10.1002/2017WR020723

[39] Markart G, Perzl F, Kohl B, Luzian R, Kleemayr K, Ess B, Mayerl J. Schadereignisse 22./23. August 2005—Ereignisdokumentation und -analyse in ausgewählten Gemeinden Vorarlbergs. BFW-Dokumentation No. 5

[40] Rickli C, Graf F. Effects of forests on shallow landslides—Case studies in Switzerland. Forest Snow and Landscape Research. 2009;**82**(1):33-44

[41] Schwarz M. Hydro-mechanical characterization of rooted hillslope failure: From field investigations to fiber bundle modelling. Diss ETH No. 19124. 2011

[42] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests

as Ecosystem-Based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[43] Mazzorana B. Woody debris recruitment prediction methods and transport analysis [PhD thesis]. Vienna: Institute of Mountain Risk Engineering, University of Natural Resources and Applied Life Sciences (BOKU); 2009

[44] Rudolf-Miklau F, Hübl J. Managing risks related to driftwood (woody debris). In: Symposium Proceedings INTERPRAEVENT 2010 Taipei/Taiwan. pp. 868-878

[45] Ruiz-Villanueva V, Díez-Herrero A, Bodoque JM, Bladé CE. Large wood in rivers and its influence on flood hazard. Cuardernos de Investigación Geográfica. 2014;**40**(1):229-246

[46] Meyer J, Rimböck A. GIS basierter Ansatz zur Abschätzung des Schwemmholzpotenzials in Wildbächen. In: Tagungsband Internationales Symposium in Zürich: Wasser- und Flussbau im Alpenraum. ETH-Zürich: Versuchsanst. f. Wasserbau, Hydrologie und Glaziologie; 2014. pp. 443-452

[47] Losey S, Wehrli A. SilvaProtect-CH: Prozessmodellierung. Anhang 1. Eidgenössisches Departement für Umwelt, Verkehr und Kommunikation. Bundesamt für Umwelt (BAFU). Available from: https://www.newsd.admin.ch/newsd/message/attachments/29559.pdf

[48] Lechner V, Markart G, Perzl F, Bunza G, Hagen K, Huber A, Klebinder K. Standortsangepasste und gefahrenorientierte Waldbewirtschaftung im Bereich steiler Grabeneinhänge—Grabeneinhangbewirtschaftung. Bericht an das Bundesministerium für land- und Forstwirtschaft, Umwelt und Wasserwirt schaft (BMLFUW), Abt. III/4. 2015

[49] Lechner V, Perzl F, Pirkl H, Sausgruber T, Sotier B, Markart G. Prozessanalyse nach dem Murereignis vom 7.-8. Juni 2015 Einzugsgebiet Seigesbach—Gemeinde Sellrain. Bericht an die Wildbach- und Lawinenverbauung, Gebietsbauleitung Mittleres Inntal. 2016

[50] Pichler A, Stöhr D. Gewässerbegleitwälder—10 Jahre Wildbachbetreuung Tirol. In: Stand der Technik im Naturgefahren-Ingenieurwesen. Schriftenreihe Department Bautechnik und Naturgefahren, Universität für Bodenkultur. 2018;**24**:29-30

[51] van Noordwijk M, Tanika L, Lusiana B. Flood risk reduction and flow buffering as ecosystem services—Part 1: Theory on flow persistence, flashiness and base flow. HESS. 2017;**21**:2321-2340. DOI: 10.5194/hess-21-2321-2017

[52] Blennow K, Persson J, Wallin A, Vareman N, Persson E. Understanding risk in forest ecosystem services: Implications for effective risk management, communication and planning. Forestry. 2014;**87**:219-228. DOI: 10.1093/forestry/cpt032

[53] Calder I, Hofer T, Vermont S, Warren P. Towards a new understanding of forests and water. Unasylva. 2007;**229**(58):3-10

[54] Estrella M, Saalismaa N. Ecosystem-based DRR: An overview. In: Renaud FG, Sudmeier-Rieux K, Estrella M, editors. The Role of Ecosystems in Disaster Risk Reduction. United Nations University Press; 2013. pp. 26-47

[55] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-Based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99505

[56] Bebi P, Bugmann, H, Lüscher P, Lange B, Brang P. Auswirkungen des Klimawandels auf Schutzwald und Naturgefahren. In: Pluess AR, Augustin S, Brang P, editors. Wald im Klimawandel. Grundlagen für Adaptionsstrategien. Bundesamt für Umwelt BAFU, Bern; Forschungsanstalt WSL, Birmendsdorf; Haupt, Bern, Stuttgart, Wien; 2016. 447p

[57] Sakals ME, Innes JL, Wilford DJ, Sidle RC, Grant GE. The role of forests in reducing hydrogeomorphic hazards. Forest Snow and Landscape Research. 2006;**80**(1):11-22

[58] Forbes H, Ball K, Mclay F. Natural Flood Management Handbook. SEPA—Scottish Environment Protection Agency; 2015. ISBN: 978-0-85759-024-4

[59] Moos C, Bebi P, Schwarz M, Stoffel M, Sudmeier-Riex K, Dorren L. Ecosystem-based disaster risk reduction in mountains. Earth-Science Reviews. 2018;**177**:497-513. DOI: 10.1016/j.earscirev.2017.12.011

[60] Rickli C, Zürcher K, Frey W, Lüscher P. Wirkungen des Waldes auf oberflächennahe Rutschprozesse. Schweizerische Zeitschrift fur Forstwesen. 2002;**153**(11):437-445

[61] Scheidl C, Heiser M, Kamper S, Thaler T, Klebinder K, Nagl F, et al. The influence of climate change and canopy disturbances on landslide susceptibility in headwater catchments. Science of the Total Environment. 2020;**742**. DOI: 10.1016/j.scitotenv.2020.140588

[62] Scheidl C, Heiser M, Kamper S, Thaler T, Rammer W, Seidl R, et al. Influence of canopy disturbances on runoff and landslide disposition after heavy rainfall events. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-Based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99511

[63] Kleemayr K, Czech T, Fürst W, Hoch G, Ledermann T, Markart G, et al. Schutzwald und Extremereignisse. In: Glade T, Mergili M, Sattler K, editors. ExtremA 2019—Aktueller Wissensstand zu Extremereignissen alpiner Naturgefahren in Österreich. Vienna University Press; 2019. pp. 623-665

[64] Füssel HM, Klein R. Climate change vulnerability assessments: An evolution of conceptual thinking. Climatic Change. 2006;**75**:301-329

[65] Berger F, Rey F. Mountain protection forests against natural hazards and risks: New French developments by integrating forests in risk zoning. Natural Hazards. 2004;**33**(3):395-404

[66] ÖROK: ÖROK-Empfehlung Nr. 54 "Risikomanagement für gravitative Naturgefahren in der Raumplanung"—Rahmen, Erläuterungen, Empfehlungen und Beispiele. Wien: Geschäftsstelle der Österreichischen Raumordnungs konferenz (ÖROK); 2016. Available from: https://www.oerok.gv.at/fileadmin/user_upload/Bilder/2.Reiter-Raum_u._Region/1.OEREK/OEREK_2011/PS_Risikom/2016-02-24-Brosch%c3%bcre_Risikomanagment_FINAL-54_Internetversion.pdf

[67] Zischg A. Participative planning processes in flood risk management in integrated watershed management. In: Wong T, editor. Flood Risk and Flood Management. NY: Nova Publishers; 2012

[68] Gustafson M, Creed I, Dalton J, Gartner T, Matthews N, Reed J, Samuelson L, Springgay E, Tengberg A. Gaps in science, policy and practice in the forest–water nexus. In: Sarre A, editor. Forests: Nature-Based Solutions for Water. Unasylva; 2019;**251**:36-45. Available from: http://www.fao.org/3/ca6842en/CA6842EN.pdf

[69] BMLRT—Federal Ministry for Sustainability, Regions and Tourism: Protective Forests. 2020. Available from: https://www.bmlrt.gv.at/english/forestry/Naturalhazards/protective-forests.html [Accessed: 07 October 2020]

Section 2

Supporting Integrated Natural Hazard Risk Management by Eco-DRR

Chapter 5

Geodata Requirements for Mapping Protective Functions and Effects of Forests

Frank Perzl and Michaela Teich

Abstract

Mapping of protective functions and effects of forests is subject to geodata on 1) natural hazard susceptibilities (hazard potential), 2) assets to be protected (damage potential), and 3) forest conditions, that is, forest use (legal extent) and cover (structure). Objectives in terms of legal definitions of assets and levels of risk acceptance (protection targets) as well as on the necessary and guaranteed reliability of the map products determine the mapping scale and the requirements for the methods and input data to be used. However, applied definitions of protection targets are often missing in the legislative bases and mapping approaches must rather be adapted to the existing geodata, their conceptual data model and quality, than simply using existing methods. Agreeing on the assets to be protected and the quality of their digital representation in terms of spatial resolution, positional accuracy, currentness, topological consistency, and entities is crucial for mapping object protective forests. The reliability of assessing protective effects of forests for large areas based on information acquired with remote sensing techniques depends on the temporal match, spatial and spectral resolutions, and limitations in representing current forest conditions by spectral and elevation data.

Keywords: protective (protection) forest, protection targets, protective function, protective effect, natural hazard risk, spatial modeling, mapping, geodata

1. Introduction

The protective function of forests defines their role in natural hazard risk mitigation that is required by society. To spatially determine the protective function of forests dependent on a hazard potential and a damage potential is the first level of risk analyses considering the protective capabilities of current or future forests. On this first level, delineating object protective forests (or object protection forests; see chapter [1] of this book) and areas to be potentially afforested, the effect of the current forest is not considered. The term "hazard potential" refers to the onset and propagation probabilities (frequency and magnitude) of natural hazards as well as to their intensity without considering the effects of the current forest cover (and other mitigation measures) on the hazard component of risk. The "damage potential" describes the probability and the relevance of damages to assets like infrastructures due to their exposure and vulnerability — the other two components of risk (see chapter [2] of this book). However, approaches of forest function mapping

IntechOpen

(e.g., [3–8] and see also book chapters [9–11]) often simplify the hazard intensity as well as the damage potential since they are difficult to assess reliably on a regional scale [5].

The protective effects of forests are their capacity to reduce natural hazard's frequency, magnitude, and/or intensity (see chapters [1, 12] of this book). The next crucial step of an ecosystem-based natural hazard risk management by forest is, therefore, to consider the effects of the existing woody vegetation on hazard frequency, magnitude, and intensity. However, the assessment of the protective effects may be limited to forests with an object protective function to focus on areas at risk, that is, areas with a damage potential.

Modeling and mapping protective functions and effects of forests require geodata on 1) the hazard potential, 2) the assets to be protected, and 3) forest locations and conditions as well as on forest growth capacities. The importance of appropriate geodata for mapping protective functions and the effects of forests are often obscured by presenting concepts, methods, and outputs of spatial hazard modeling and affected areas; however, without high-quality digital geodata (e.g., on the infrastructures to be protected, their type of use and vulnerability), protective functions and effects of forests and subsequently the natural hazard risk and its mitigation by forest cannot be determined efficiently. We introduce the main categories of thematic geodata required for protective function and effect mapping of forests and highlight specific issues linked to the use of geodata based on conceptual considerations and our experiences.

2. Spatial scale and the topographic baseline information

Although hazard and risk assessments can be carried out at all geographical scales depending on the intended use of the analyses [13], the mapping of protective functions and the effects of forests is mainly an issue of the spatial resolution and accuracy of the available topographical basis, especially of the digital terrain model (DTM), because of topographic characteristics such as elevation and slope control hazard susceptibility. The DTM is the key dataset for hazard assessments dictating all further steps of data acquisition and data processing, including the compilation of geodata on assets in raster and vector formats. In the case of a coarse resolution of the DTM, consideration should be given to whether it makes sense to include assets with very small footprints such as electricity pylons. They must be represented in the same resolution as the DTM in raster modeling. The coarser the resolution of the DTM, the less accurate is the hazard modeling and subsequently, the potential assets at risk are subject to larger uncertainty. Even at global levels, forest function mapping at (DTM) resolutions greater than approximately 30 m is not appropriate and limited to key infrastructure (e.g., in Europe [14]) since this is about the maximum width of main traffic infrastructures, the average width of residential units (with ancillary areas), for example, [15], and of gravitational hazards of significant magnitude. However, very high-resolution input data do not improve mapping results necessarily as shown for landslide susceptibility mapping, for example, by [16]. Very high resolutions may also be inappropriate for visualization of the results as they overstrain human capabilities of information perception and pretend that the results are highly reliable. Regardless of hazard type-specific requirements, a DTM resolution of 10 m, for example, derived from LiDAR returns based on a sample size of at least 0.2 ground classified points/m^2, is appropriate for modeling hazard and damage potentials to assess protective functions of forests on a regional scale. Furthermore, a 10-m resolution is suitable for the small-scale and heterogeneous land use in the Alpine Region as well as limits computation time.

3. Spatial data on hazard potential

To identify forests with protective functions, hazard potential indication maps for all types of natural hazards that may occur in an area, and which are clearly influenced by forest if managed properly, are required. Hazard potential indication maps are hazard maps that indicate areas, which may be affected by hazards without considering the potential protective effects of current forests or other protection measures such as technical defense structures [5]. Already including the effects of these protective green and gray infrastructures in the hazard assessment would exclude areas with protective forests or areas that are secured by technical measures, although a hazard susceptibility exists and despite potential and sudden changes of the forest conditions, for example, through windthrow.

There are five main requirements on hazard indication maps to be applied for the assessment of forests' protective functions, which are as follows:

1. they exclude all risk mitigation measures and their effects,

2. they are not limited to the observed hazard occurrence but also show the total basic hazard susceptibility due to climate, topography, and/or geology,

3. they do not only show the onset susceptibility but also the propagation probability of hazards,

4. they distinguish zones of onset (starting zone) and propagation probability (transit and runout zones) to consider different requirements on protective forest conditions in each zone dependent on the hazard type, and

5. they are based on the same ("global") scale of hazard probability.

In addition, appropriate hazard indication maps should provide at least a qualitative or preliminary zoning (ranking) of the damage potential, which is also a question of the elements at risk. The available hazard (indication) maps may not satisfy these criteria. For example, in contrast to snow avalanche and rockfall hazard maps, landslide hazard indication maps often only show onset susceptibilities (biased by data collection and forest effects [17]) based on local or regional probability scales, which are not comparable [8]. In addition, maps of permanent (deep-seated) landslides are usually difficult to interpret in terms of activity, reactivation, and zones susceptible to the influence of forest.

The methods and data requirements for producing hazard maps are described extensively in the literature, for example, in [18] for landslides and in [19] for qualitative rockfall assessments, but even the simplest approaches are data intensive. Therefore, we recommend to always critically question whether an approach is suitable for protective function mapping and if the costs for data collection are in relation to its benefits. In practice, time constraints and the availability of data and financial resources are the major decisive factors.

4. Spatial data on damage potential (assets to be protected)

The assets to be protected from impacts of natural hazards (hereafter referred to as "assets") are also referred to as "elements-at-risk" in disaster risk reduction (DRR) literature, which is not appropriate in any case. The latter term refers to "population, properties, economic activities, including public services, or

any other defined values exposed to hazards in a given area" [20]. According to this definition, the "elements-at-risk" is a subset of assets already including the spatial intersection with the hazard potential. Therefore, the term should not be used for the selection of "goods" to be protected because of a legal or another social convention and is no longer mentioned, for example, in [21]. In the context of forest function planning, a terminology different from the DRR community is used (see also book chapters [1, 12]); that is, the assets to be protected by forest and their entities are called "objects." A simple intersection of hazard maps and assets is sufficient to identify endangered objects (the damage potential) and for risk assessment but not for delineating forests with protective functions. That is, all relevant hazard runout, transit, and starting zones uphill of the potentially endangered assets must be identified and separated from those that do not endanger assets [3, 5].

Any form of risk analysis requires to preselect the assets (objects) to be protected and included, which are types of land use or planned land use (interest in future land use) and, in the case of assessing forests' object protective functions, located outside of forests. The preselection of objects may be supported by considering the susceptibility of assets to damage and the consequences of potential loss due to the probability of the presence of people, the economic and cultural value, the physical fragility, interruptions of access, or other criteria of vulnerability such as the possibility to evacuate. Note that vulnerability is a very complex risk-related characteristic of assets including physical, social, economic, and environmental properties [13, 22, 23] (see also chapter [2] of this book). Vulnerability summarizes "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" [21]. Physical vulnerability, that is, the fragility of physical assets, is hazard-specific and often evaluated in the exposure assessment of the risk analysis. For example, different construction types have different physical attributes (e.g., building material of houses), but their quantitative consideration depends on the hazard type. The physical vulnerability may be the most important criteria for preselecting assets. Direct costs of damages (buildings and infrastructure) are easier to estimate and give rise to indirect costs [24]. However, selecting assets as the first step to define the protection targets for mapping protective functions of forests is ultimately and always politically driven and influenced by cultural and ideological value attitudes linked to questions of justice and regional development [5, 25].

The specification of assets may be based on legal bases that governmental hazard risk and forest management agencies must comply with. However, legal specifications do not ensure expedient registrations of assets and risks. For example, according to the Austrian Forest Act of 1975 amended in 2002 [26], people and all their infrastructures as well as cultivated land are assets to be protected by forest. The law does not contain any clauses, rules, and administrative authorizations to exclude infrastructures or land use that are of low importance, where importance translates the public interest in the preservation and use of an object for society. Therefore, the lists of assets in the administrative directive for mapping protective functions of forests included infrastructures such as forest roads and "frequently used" hiking trails, and even land uses with low vulnerability such as meadows and pastures. A debate about the asset component of risk was started when spatially modeling hazard and damage potentials to support the Austrian-wide mapping of object protective functions of forests, which resulted in the new "Hinweiskarte Schutzwald in Österreich" (indication map of protective forests in Austria, [7]). The geodata collection [27] revealed the limited applicability, risk orientation, and data reconciliation of existing geodata as well as the high-editing efforts that were required

to complete, correct, and convert the available data into spatial information useful for this spatial modeling and to distinguish the protection targets according to the administrative guidelines for protective function mapping. Analyses of the Swiss [25] and Austrian [28, 29] natural hazard risk regulations also show a low coherence of the legal definitions of protection targets since there is no consensus on "the values at which a damage should be considered as a damage" in a risk context [25]. Discussions on assets and their vulnerability are often characterized by administrative traditions, anecdotic perceptions of hazards' consequences, and personal affinities, rather than by analysis of hazard inventories. Moreover, we experienced that geodata providers are often not aware of the key role their data have in natural hazard risk analyses.

The geodata and their entities about assets needed for mapping object protective functions of forests depend on the protection targets, the requirements on potential damage quantification and accuracy, and the data models. The information provided by available datasets may be incomplete or aggregated, but this can be bypassed by defining levels of spatial aggregation and comprehensiveness [27]. Furthermore, object protective function mapping may be a chance to coordinate data needs and concepts with geodata service providers as well as to complete geodata about infrastructures. Many different types of assets exist, which must be collected from numerous sources and can be classified and prioritized in various ways [13, 25]. Most of the spatial digital asset data are available in vector format since this format preserves the shape of infrastructures like buildings and road networks and meets the requirements of different administrative organizations. However, it is always recommended to consider the limitations of land use representation by different vector models and, in particular, of vector-to-raster and vice versa conversions in relation to requirements on the spatial resolution of the modeling. Most methods of risk assessment and visualization involve converting geodata from one format to another. For example, a polyline dataset of a road network can reflect the area and width of small roads at raster cell resolutions smaller than 10 m without any special adaptions, but polygon features may be necessary for the widths of highways and building footprints. Surprisingly and although GPS car navigation started by the end of the 1990s, the official (rural) road network topologies in Switzerland and Austria were proven to be incomplete and not sufficient for mapping object protective functions of forests [4, 5]. In Austria, for example, it was not systematically possible to derive the importance of the connectivity function of roads simply from the data attributes and to differentiate forest roads from local (public) access roads to inhabited settlements.

A frequently used method for determining the requirements on asset geodata appropriate for forest function mapping is to establish classes that translate the public interest in the preservation and use of an object for society. Such classes are called object classes and are often based on matrices of protection targets as, for example, proposed by BUWAL [30]. The object classes provide qualitatively determined priorities for protecting assets and subsequently prioritize the protective functions of forests. However, such lists often differ considerably. They incompletely cover the multitude of existing assets and the variety of their characteristics in terms of vulnerability as well as the information provided by the geodata.

In **Table 1**, we compare the rankings of objects (object classes) according to the Swiss BUWAL (now Federal Office for the Environment — FOEN) matrix [30], the French protective forest management guideline GSM-S [31], and the new Austrian concept for forest function mapping (WEP) based on [27]. All classification systems use a four-level ordinal scale of the need for protection from "high" (3) to "very low" (0). Although this is not clearly regulated by law, in Austria, forests with an object protective function are only allocated for object classes 3 and 2. However,

Asset types and entity codes of the Austrian A, French F, and Swiss S object classification system		**Object class (priority)**		
Settlement (residential and commercial) areas, buildings		**BUWAL**	**GSM-S**	**WEP**
S321	Settlement area; the area/number of buildings is not defined	3	—	*3*
F11	Settlement area, dense, more than 10 residential units	—	3	*3*
F12	Settlement area, scattered, 2–10 residential units	—	2	*3*
A01, S231, F13	Building suitable for residence (or multi-functional use)	2	1	3
S322, F51	Industrial area; the area/number of buildings is not defined	3	3	*3*
F52	Commercial area; the area/number of buildings is not defined	—	2	*3*
F53	Craft business area; the area/number of buildings is not defined	—	1	*3*
A02	Building for public service, commerce, factory, supply disposal	*3*	*3–1*	3
A03, S232, F63	Agricultural building (in A: except hayracks)	2	1	3
A04, S324, F41	Building for sports (recreation), cultural, religious use	3	3	3
F82	Historical building	?	2	*3*
A05, S325	Valley station of a cable car (lift) connected to public traffic	3	?	3
A06	Facility area of A01–A05, building direct adjacent to A01–A05 or a facility area of A01–A05	*3*	—	3
A27, S221	Other buildings than A01–A06	1	—	1
A07, S323	Land designated for housing (A01–A05) or special use	3	*0*	3
Special infrastructure				
A08	Facility – supply-disposal and communication except lines and pipes	3?	—	3
A09	Land designated for facilities (A08)	*0*	*0*	3
A10, S234, S223, S213, F32, F33	Above ground supply and disposal pipe	2–1	2–1	3
S234	Overhead utility line network of national importance	2	2	*0*
S223	Overhead utility line network of regional importance	1	2	*0*
S213	Overhead utility line network of local importance	1	1	*0*
A24	Utility pole of the high-voltage overhead line network	—	—	2
A29	Utility pole of other overhead line networks than A24	—	—	1

Asset types and entity codes of the Austrian A, French F, and Swiss S object classification system		**Object class (priority)**		
Settlement (residential and commercial) areas, buildings		**BUWAL**	**GSM-S**	**WEP**
Traffic infrastructure				
A11, A13, S311, F21	Road or railroad (of national importance)	3	3	*3*
S233, A13, F22	Road or railroad (of regional importance)	2	2	*3*
A18, S222, F23	Road of local importance	1	1	2
A13, S222, F23	Railroad of local importance	1	1	3
A25	Material railway and its facility area	?	?	2
A32	Forest road or road for farming (connecting to alpine pasture)	?	?	1
F24	Forest road	*0*	0	1
S211, S212, S12, S13, F44	Field path, hiking trail, climbing route	1–0	0	*0*
A12	Parking lots	?	?	3
A14	Cable car (tram) line and its facility area	2?	?	3
A28	Material ropeway and its facility area	?	?	1
A15	Airfield	3–2?	?	3
A16	Land designated for air traffic (A15)	*0*	*0*	3
Sports, culture, and recreation				
A19	Cemetery, park	?	?	2
A20, S324, F41	Outdoor sports facility (except the housings)	3	*3*	2
A21, S324, F41	Campground	*3*	3	2
A22, S236, C14, F43	Ski run, cross-country ski trail, or sled run	2–1	2	2
A23, S312, S235, F43	Line of aerial cable car or surface lift (ski lift)	3–2	*2*	2
A26	Land designated for parks or outdoor sports facilities (A19–A23)	*0*	*0*	2
Mining, disposal, cropland, pasture, forest				
A30, A31	Above ground mining area, open disposal/ waste processing	?	?	1
A33, S224, F63	Nursery, horticulture (except gardening houses → A03)	1	*1*	1
A34	Land designated for nursery or horticulture (A33)	*0*	*0*	1
A17, S224	Cropland	1	*0*	3**, 0
S225	Forest with protective function	1	*0*	0
A35, S214, F64	Agricultural land use other than A17, A33	1	0	1
S15, S16, F74	Natural environment	0	0	0

***If the soil is susceptible to wind erosion.*
? the allocation to an entity or priority is not clear.

Table 1.
Categories and rankings of assets according to the Swiss BUWAL matrix [30], the French protective forest management guideline GSM-S [31], and the new Austrian concept for forest function mapping (WEP) [27].

rankings of assets raise questions about legality and equality, and may not be in line with the views of property users and owners as shown by Hess [25].

Since the BUWAL rankings also include hazard (frequency and intensity) scenarios, we refer to the 30-year recurrence probability. *Italic numbers* refer to entities included in other categories of the respective system.

Table 1 shows considerable differences between the national systems in the categorization (degree of aggregation) and ranking of objects. For example, in contrast to the Austrian system only referring to their local or higher relevance, the Swiss and French concepts distinguish infrastructures of national, regional, or local importance. In addition, the Austrian system does not differ priorities due to the number of residential units but allocates a high priority also to single residential and agricultural buildings, since this would otherwise be counterproductive to rural development objectives.

Aspects that are hardly considered when selecting and mapping assets are how to deal with future land use and limitations of geodata topicality. Protection against natural hazards (by forest) and risk assessments (but not hazard zoning) are mostly related to the currently existing assets. However, zones of land use (development) plans express interests in future land use and may also show the current use for housing more accurately than the polygons of real property cadastres [27]. That is, geodata on legal designations of building land are often also necessary to identify its current use from property data [32]. Furthermore, it is advantageous to show that future housing on building land may be tied to the protective effect of forests, which, therefore, must be maintained as a prevention measure. Therefore, forest function mapping should consider specific entity types from land use planning [27], and meaningful mapping of the object protective functions of forests may distinguish between current and planned assets.

Adapting geodata on assets to the needs of forest function mapping and risk assessment in terms of information on the vulnerability, currentness, positional accuracy, and interoperability as well as the integration of local community knowledge is still in an initial stage. Studies recommend crowdsourced spatial data complementing governmental data to improve data availability and to include local knowledge [13, 33]. However, our experiences are ambiguous in terms of data models, quality, and consistency.

5. Spatial data on forest conditions

The term "forest" may refer to a forest cover-based or a forest use-based forest definition. The forest cover is land currently covered by trees depending on tree height and crown cover thresholds, whereas forest use refers to all land areas that are allocated to forestry to produce forest products and benefits, and not only to areas with a current tree cover or to currently managed woody vegetation. This includes clear-cut areas without a tree cover and may include shrubland or agroforestry land, depending on the (national) forest definition. In the countries of the European Alpine Space, the forest is legally defined in different ways as an area with current forest use.

Note that there is a different meaning of the wordings "object protective function of forest," since this may also refer to other current land use than forest, and "forest with an object protective function." To identify areas with an object protective function of forest hazard starting, transit and runout zones (hazard potential) that are associated with endangering assets (damage potential) are overlayed with the current forest use as well as with the areas suitable for future forest use (growth) (see also chapter [9] of this book). Current forest use land with an object protective and/or a site (soil) protective function (see also chapters [1, 12] of this book) is legally classified as

protective forest and protected from deforestation in the Alpine Space if the additional legal requirements dependent on national law are met (see [34]). It should be noted, however, that forests classified as protective forests may also have insufficient current protective effects. A map of the other land use than current forests appropriate for forest growth with an (object) protective function of forest indicates areas whose afforestation will contribute to the protection against natural hazards in the future as a nature-based solution (e.g., due to high altitude afforestation [35]).

Three basic requirements for spatial geodata sets on forest conditions can be derived from the above concept; that is, geodata need to provide information on the a) current forest use, b) capacities for forest growth also outside of the current forest use, and c) they need to be consistent with other land use information in terms of topology and interoperability. The available geodata on forest conditions often do not meet these criteria, because, for example, forest areas are mapped independently from other land use categories by different organizations, which can result in indistinct land use assignments. Furthermore, available forest layers may be based on different forest criteria, which do not always correspond to the legal forest definitions. Usually, the ability of remote sensing techniques to retrieve forest areas in line with legal definitions is limited. The often ambiguous forest criteria anchored in national forest acts hinder their full application. Therefore, we highly recommend checking the specifications of the available forest maps and the definitions that they are based on before selecting a specific map product in coordination with clients.

In contrast to forest function mapping, the protective effect of the woody vegetation, whose quantification is often the next step in natural hazard risk analyses, is not subject to forest use but an issue of the forest cover. Therefore, risk analyses that include the protective effect of forests or other woody land require information on forest cover characteristics based on appropriate spatial units (**Table 2**).

Characteristics of the forest (tree) cover	Influenced hazard types			Applicability of methods				
	Avalanche	Rockfall	Landslide	VIO	PIA	IEM	ACS	ACE
Mean height	+	+/-	?	L	M	M	L	H
Mean diameter	?	+	+	L	L	L	L	L
Canopy cover	+	+	?	M	M	M	M	H
Live canopy cover	+	+	+	M	M	L	H	L
Canopy depth	+/-	+/-	?	L	L	L	L	L
Stem density	+	+	?	L	L	L	L	M
Species composition	+	+	+	M	M	L	M	L
Area of opening	?	+/-	+	M	M	M	L	H
Width of opening	+	+	+/-	M	M	M	L	H
Length of opening	+	+	+	M	M	M	L	H
Woody debris under canopy	+	+	?	L	L	L	L	L
Woody debris	+	+	?	M	M	M	L	H

Notes: Influence of forest characteristic on hazard types: + decisive, +/- secondary, ? not clear.
Methods: VIO = visual interpretation of orthoimages, PIA = photogrammetric interpretation of aerial images, IEM = interpretation of elevation (canopy height) models, ACS = automated classification of spectral data, ACE = automated classification of elevation models.
Direct applicability: H = high, M = medium/limited, L = low/rather unsuitable.

Table 2.
Forest cover characteristics required to assess protective effects against gravitational natural hazards and direct applicability of methods to obtain reliable and objective information.

Little has been published on the resolution of forest geodata, that is, the minimum/maximum size of forest patches that are required to quantify the structural parameters influencing forest's protective effects, even though the strengths of key controlling factors such as the canopy cover depend on it. Note, that a "forest patch" (or evaluation unit) useful in hazard assessment does not refer to a "forest stand," which is a unit of forest management plans and may not be appropriate for that purpose [36], but to a "spatial analytical window." One concept for quantifying patch sizes is to consider the distribution of starting zone area sizes of observed hazard releases, for example, to define the minimum mapping unit of forest cover openings. However, required forest patch sizes for hazard assessments vary depending on the type of hazard.

For larger areas, information on forest cover characteristics can only be obtained by remote sensing such as visually to full-automatically deriving forest structure parameters from spectral or elevation earth observation (EO) data acquired with unmanned (UAV) or manned aircraft- or satellite-borne sensors (e.g., [37]; see also chapter [38] of this book).

A common method of EO-data collection on local to regional scales is the visual interpretation of aerial images, which is increasingly combined with vegetation or canopy height models (e.g., [39]) obtained from high-resolution digital elevation (surface) models retrieved from Structure from Motion SfM/IM photogrammetry or LiDAR. As manual measurements and polygon mapping are time consuming, subjective, and susceptible to topology errors, automated procedures using machine learning techniques are increasingly available, which show promising results (e.g., [40]). However, synoptic assessments of forest conditions in relation to their current or future protective effects require data from different sensors (e.g., [41]; see also chapters [42, 43] of this book), and often additional information from visual interpretations and terrestrial mappings (expert knowledge). The reliability of assessing (object) protective effects of forests based on EO data depends on their temporal match with the current state of the forest cover and between point/return densities of different sensors, their spatial and spectral resolution, and quality as well as limitations in representing forest characteristics by such data. Therefore, procedures to assess the protective effects of forests against natural hazards should be adapted *a priori* to the capabilities of EO data.

6. Conclusions

Usually, national geodata infrastructures are not organized, updated, and supervised centrally, resulting in inhomogeneous data availability, data models, and qualities, which are not yet optimized in terms of interoperability and for mapping protective functions and effects of forests. Therefore, providing adequate geodata for risk assessments by different sources and data providers is a multidisciplinary challenge and may be associated with high editing efforts [13]. However, the potential of basic and thematic geodata to be applied in various analyses is increasing at a considerable rate, for example, the focus of geodata infrastructure strategies of public administrations in many European countries is shifting from large quantity to a higher quality [44].

Ultimately, the applicability and/or acquisition of hazard, asset, or forest geodata and needed editing and modeling efforts depend strongly on the purpose and spatial scale of mapping protective functions and effects of the forest. For example, if the goal is to map the ecosystem service "protection of people and assets against natural hazards" on an Alpine (cross-national) scale, less accurate and detailed spatial information may be required and geodata from global and open-source

mapping services such as OpenStreetMap can be applied, for example, in [14]. The same is true for defining protection targets and object classes acknowledging existing public interests in protecting different asset types. For example, in the Interreg Alpine Space project GreenRisk4ALPs (ASP 635) [45], we applied whenever possible (provided the input data were available) a simplified classification scheme that fits our goal of comparing modeling outcomes between Alpine Space countries and to get a first overview of potentially endangered objects in a region that can be followed by a more detailed risk assessment [11] (see also chapter [10] of this book). However, such global data and simplifications may not be appropriate for producing legally binding national maps or maps that must reflect a country's forest law or be useable for prioritization of measures and subsidies such as the maps of forests with a protective function in Switzerland [4] and Austria [7].

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by the Interreg Alpine Space program, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy.

Author details

Frank Perzl* and Michaela Teich
Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

*Address all correspondence to: frank.perzl@bfw.gv.at

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

[2] Accastello C, Teich M, Cocuccioni S. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[3] Giamboni M, Wehrli A. Improving the management of protection forests in Switzerland. The project SilvaProtect-CH. In: Interpraevent 2008 – Conference Proceedings. Klagenfurt; Vol. 2. 2008. pp. 469-480

[4] Losey S, Wehrli A. Schutzwald in der Schweiz. Vom Projekt SilvaProtect-CH zum harmonisierten Schutzwald. Bern: Bundesamt für Umwelt; 2013. 29 p. + Annexes.

[5] Perzl F, Huber A. GRAVIPROFOR. Verbesserung der Erfassung der Schutzwaldkulisse für die forstliche Raumplanung. Synthese und Zusammenfassung: Ziele, Grundlagen und Ergebnisse der Modellierung von Waldflächen mit Lawinen- und Steinschlag-Objektschutzfunktion. Technische Hilfe im Rahmen des österreichischen Programms LE 07-13. Projektbericht V1. Innsbruck: Bundesforschungszentrum für Wald (BFW); 2014. p. 92. Available from: https://gruenerbericht.at/cm4/jdownload/download/28-studien/1644-78-schutzwaldkulisse

[6] Huber A, Kofler A, Fischer JT, Kleemayr K. Projektbericht DAKUMO. Innsbruck: Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW); 2017. p. 74

[7] Perzl F, Rössel M, Kleemayr K. PROFUNmap – Verbesserung der Darstellung der Österreichischen Wälder mit Objektschutzfunktion. Integration von Geodaten mit Aussagen über die Schutzfunktion des Waldes. Projektbericht V3 2019 im Auftrag des BMLRT. Innsbruck: Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW), Institut für Naturgefahren; 2019. Map accessible at: https://www.schutzwald.at/karten.html

[8] Perzl F, Rössel M, Lauss E, Neuhauser M. Mapping of protective functions of forests in Austria against shallow landslides. In: Conference Proceedings 14th Congress INTERPRAEVENT 2021; May 31st to June 2nd 2021; Virtual Congress; Norway; 2021. p. 240-248

[9] D'Amboise CJL, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[10] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise CJL, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[11] Teich M, Accastello C, Poratelli F, Cocuccioni S, Renner K, Rabanser M,

Pecan P, Kobal M. D.T2.4.2 Identification of potentially endangered assets and functional assessment of protection measures in the PARs. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 2 ACTINA)

[12] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[13] Van Westen CJ. Remote sensing and GIS for natural hazards assessment and disaster risk management. In: Shroder J, Bishop MP, editors. Treatise on Geomorphology. Vol. 3, Remote Sensing and GIScience in Geomorphology. San Diego, CA: Academic Press; 2013. pp. 259-298

[14] Dupire S, Toe D, Barré JB, Bourrier F, Berger F. Harmonized mapping of forests with a protection function against rockfalls over European Alpine countries. Applied Geography. 2020;**120**:102221

[15] Paprotny D, Kreibich H, Morales-Nápoles O, Terefenko P, Schröter K. Estimating exposure of residential assets to natural hazards in Europe using open data. Natural Hazards and Earth System Sciences. 2020;**20**:323-343. DOI: 10.5194/nhess-20-323-2020

[16] Lee S, Choi J, Woo I. The effect of spatial resolution on the accuracy of landslide susceptibility mapping: A case study in Boun, Korea. Geosciences Journal. 2004;**8**(1):51-60

[17] Steger S, Mair V, Kofler C, Pittore M, Zebisch M, Schneiderbauer S. Correlation does not imply geomorphic causation in data-driven landslide susceptibility modelling – Benefits of exploring landslide data collection effects. Science of the Total Environment. 2021;**776**:145935

[18] Guzzetti, F. Landslide hazard and risk assessment. Concepts, methods and tools for the detection and mapping of landslides, for landslide susceptibility zonation and hazard assessment, and for landslide risk evaluation [thesis]. Bonn: Rheinische Friederich-Wilhelms-Universität; 2006

[19] Ferrari F, Ciacomini A, Thoeni K. Qualitative rockfall hazard assessment: A comprehensive review of current practises. Rock Mechanics and Rock Engineering. 2016;**49**(7): 2865-2922. DOI: 10.1007/s00603-016-0918-z

[20] UN-ISDR. Terminology of Disaster Risk Reduction. Geneva, Switzerland: United Nations, International Strategy for Disaster Reduction; 2004. Available from: http://unisdr.org/eng/library/lib-terminologyeng%20home.htm

[21] OEIWG. Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction (Geneva, 29-30 September 2015, 10-11 February 2016 and 15 & 18 November 2016); 2016. Available from: https://www.preventionweb.net/files/50683_oiewgreportadvanceuneditedversion.pdf

[22] Birkmann J. Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definitions. In: Birkmann J, editor. Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies. Tokyo: United Nations University Press; 2006. pp. 9-54

[23] Thomalla F, Downing T, Spanger-Siegfried E, Han G, Rockström J. Reducing hazard

vulnerability: Towards a common approach between disaster risk reduction and climate adaptation. Disasters. 2006;**30**(1):39-48

[24] Meyer V, Becker N, Markantonis V, Schwarze R, van den Bergh JCJM, Bouwer LM, et al. Review article: Assessing the costs of natural hazards – State of the art and knowledge gaps. Natural Hazards and Earth System Science. 2013;**13**:1351-1357. DOI: 10.5194/nhess-13-1351-2013

[25] Hess JT. Schutzziele im Umgang mit Naturrisiken in der Schweiz [thesis]. Zürich: vdf Hochschulverlag AG an der ETH Zürich; 2011. p. 262

[26] Forst G. Österreichisches Bundesgesetz vom 3. Juli 1975, mit dem das Forstwesen geregelt wird, BGBl. Nr. 440/1975; 1975

[27] Perzl F, Den Outer J, Rössel M. GRAVIPROFOR. Verbesserung der Erfassung der Schutzwaldkulisse für die forstliche Raumplanung. Methodik – Datengrundlagen für die Modellierung von Waldflächen mit Lawinen- und Steinschlag-Objektschutzfunktion. Technische Hilfe im Rahmen des österreichischen Programms LE 07-13. Projektbericht. Innsbruck: Bundesforschungszentrum für Wald (BFW); 2014. p. 175

[28] Rudolf-Miklau F, Promper C. Die ÖREK-Partnerschaft "Risikomanagement für gravitative Naturgefahren": Problemstellung und fachpolitische Ziele. In: ÖROK, editor. Risikomanagement für gravitative Naturgefahren in der Raumplanung. ÖROK: Wien; 2015. Schriftenreihe 193. pp. 33-42

[29] Kanonier A. Rechtsgrundlagen des Schutzes vor gravitativen Prozessen (Muren, Lawinen, Steinschlag, Rutschungen) im Bundesrecht sowie Raumordnungs- und Baurecht der Länder. In: ÖROK, editor. Risikomanagement für gravitative Naturgefahren in der Raumplanung. ÖROK: Wien; 2015. Schriftenreihe 193. pp. 90-147

[30] BUWAL. Risikoanalyse bei gravitativen Naturgefahren. Methode. Bern: BUWAL, Umwelt-Materialien Nr. 107/I; 1999. p. 115

[31] Ladier J, Rey F, Dreyfus P, editors. Guide des Sylvicultures de Montagne. Alpes du Sud françaises: OFN, Irstea, Centre PACA; 2012. p. 301

[32] Zischg A, Keiler M, Fuchs S, Meißl G. Konzepte zur flächendeckenden Risikoanalyse für Naturgefahren im regionalen Maßstab. In: Strobl J, Blaschke T, Griesebner G, editors. Geographische Informationsverarbeitung XIV. Beiträge zum AGIT-Symposium Salzburg 2002. Heidelberg: Wichmann; 2002. pp. 607-615

[33] Kotsev A, Minghini M, Tomas R, Cetl V, Lutz M. From spatial data infrastructures to data spaces – A technological perspective on the evolution of European SDIs. International Journal of Geo-Information. 2020;**9**:176. DOI: 10.3390/ijgi9030176

[34] Berger F, Beguš J, Garbarino M, Lingua L, Motta R, Perzl F, et al. National barriers identification and policy needs for improving forest ecosystem-based risk-management in the Alpine Space: D.T5.2.1 Report on 'Survey/comparison of national barriers for application of ecosystem-based natural hazard risk mitigation concept' – D.T5.1.1 Report on 'Policy needs for a sustainable strategy for ecosystem-based risk-management'; Grenoble, France: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 5 RIGOR)

[35] Lechner V, Markart G, Stöger A, Oven D, Pecan P, Žabota B, et al. D.T.1.4.3 Report on "High alpine afforestation – Survey and effectivity assessment"; Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[36] Perzl F, Kleemayr K. Report D.T1.3.2 Assessment of forest protection effects and functions for natural hazard processes. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[37] Ginzler C, Adams M, Hormes A, Lechner V. D.T1.5.2 Applying remote sensing techniques to identify and monitor forest disturbances. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2019. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[38] Lingua E, Marchi N, Bettella F, Costa M, Pirotti F, Piras M, et al. Natural disturbances and protection forests: at the cutting edge of remote sensing technologies for the rapid assessment of protective effects against rockfall. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99509

[39] Ginzler C, Hobi M. Das aktuelle Vegetationshöhenmodell der Schweiz: spezifische Anwendung im Waldbereich. Schweizerische Zeitung für Forstwesen. 2016;**167**(3):128-135. DOI: 10.3188/szf.2016.0128

[40] Schiefer F, Kattenborn T, Frick A, Frey J, Schall P, Koch B, et al. Mapping forest tree species in high resolution UAV-based RGB-imagery by means of convolutional neural networks. ISPRS Journal of Photogrammetry and Remote Sensing. 2020;**170**:205-215. DOI: 10.1016/j.isprsjprs.2020.10.015

[41] Stritih A, Bebi P, Grêt-Regamey A. Quantifying uncertainties in earth observation-based ecosystem service assessments. Environmental Modelling and Software. 2019;**111**:300-310. DOI: 10.1016/j.envsoft.2018.09.005

[42] Stritih A. Dealing with uncertainties in the assessment of the avalanche protective effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99515

[43] Bebi P, Bast A, Helzel KP, Schmucki G, Brozova N, Bühler Y. Avalanche protection forest: From process knowledge to interactive maps. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99514

[44] Barbero M, Lopez Potes M, Vancauwenberghe G, Vandenbroucke D, Nunes de Lima V, editors. The Role of Spatial Data Infrastructures in the Digital Government Transformation of Public Administrations. Luxembourg: Publications Office of the European Union; 2019. p. 155. DOI: 10.2760/324167

[45] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

Chapter 6

Natural Disturbances and Protection Forests: At the Cutting Edge of Remote Sensing Technologies for the Rapid Assessment of Protective Effects against Rockfall

Emanuele Lingua, Niccolò Marchi, Francesco Bettella, Maximiliano Costa, Francesco Pirotti, Marco Piras, Matteo Garbarino, Donato Morresi and Raffaella Marzano

Abstract

Protection forests can be severely affected by natural disturbances, whose consequences could greatly alter the fundamental ecosystem services they are providing. Assessing and monitoring the status of the protective effects, particularly within disturbed stands, is therefore of vital importance, with timing being a critical issue. Remote sensing technologies (e.g., satellite imagery, LiDAR, UAV) are widely available nowadays and can be effectively applied to quantify and monitor the protective effects of Alpine forests. This is especially important after abrupt changes in forest cover and structure following the occurrence of a disturbance event. In this contribution, we present a brief introduction on remote sensing technologies and their potential contribution to protection forest management, followed by two case studies. In particular, we focus on research areas within protection forests against rockfall affected by windthrow (i.e., the 2018 storm Vaia in the Eastern Italian Alps, where LiDAR and UAV data were used), and forest fires (i.e., the 2017 fall fires in the Western Italian Alps, involving Sentinel-2 image analyses).

Keywords: protection forests, remote sensing, natural disturbances, rockfall, forest fires

1. Introduction

In mountain areas, forests that directly protect human assets (i.e., houses, roads, touristic and sport facilities, etc.) against rockfall cover an area of more than 20,000 km^2 (www.alpine-space.eu/project/rockthealps/). These stands are defined as direct object protection forests (see chapter [1] of this book) and are providing a valuable ecosystem service to the Alpine communities. To perform an effective

protection, protection forests should have specific characteristics. These include stand density and average tree size, which could be effective against different natural hazards [2], particularly gravity-driven ones (see chapter [3] of this book). Indeed, forests can provide both an active protection, avoiding the occurrence of natural hazards (e.g., impeding avalanche release), and a passive one, mitigating their impacts (i.e., in the case of rockfall), depending on their position along the slope [4].

The ability to offer a protective effect is not a permanent characteristic of a stand. Throughout their development, forests can be subject to a variety of perturbations, potentially resulting in modifications of their structural attributes that could change their protective effect. Natural disturbances, i.e., discrete events in time that disrupt ecosystem, community, or population structure and change resources, substrate availability, or the physical environment [5], can severely impact protection forests. Avalanches, forest fires, windstorms and landslides are some of the most common disturbances in mountain forests in the Alps, whose effects can profoundly influence stand dynamics.

Natural disturbances are globally expected to increase in frequency, severity, and extent due to both climate change and land use change [6, 7]. These possible alterations in disturbance regimes could result in massive modifications of the structure and composition of protection forests, with potential negative implications on the ecosystem services they are currently providing [8, 9].

Adopting appropriate forest management allows maintaining the ideal protection profile of forest stands and sustaining their protective effect [10]. Silvicultural management can also contribute to mitigating the impact of some types of disturbances, particularly those that have a lower intensity. To guide forest management in this framework, it is necessary to identify protection forests, assess their protective effect and promptly detect any alteration in its efficacy. Available field data are generally not sufficient to properly evaluate the protective effect of forests over large areas, and the costs of specific surveys are usually not sustainable [11]. Furthermore, following the occurrence of a disturbance, an early assessment of the status of protection forests and their residual protective role is fundamental.

Remote sensing tools can provide sound solutions for detecting both abrupt and gradual changes in forest stands. These tools are a valid and well-established source of data for evaluating earth surface characteristics. Active sensors (e.g., laser scanner, radar) can provide useful 3D information on forest structures and are able to extract tree size and spatial arrangement [12], while passive sensors can be used to infer vegetation status and forest cover [13]. For example, active Synthetic Aperture Radar (SAR) sensors emit a polarized signal at wavelengths in the microwave range of the electromagnetic spectrum and record the backscattered intensity at different polarizations. Depending on the emitted wavelength, the local incidence angle and other factors, the backscatter behaves differently according to land-cover type, texture and even vegetation biomass. This allows detecting specific types of land-cover and changes that occur over time. The advantage of active technologies is that they are largely independent from lighting and atmospheric conditions.

In contrast, passive sensors collect light from the sun that is reflected from the Earth surface. Spectral signatures from surface objects are created by sampling reflected light at sensor-specific wavelengths. These spectral signatures can be analyzed through transforming the spectral components (e.g., vegetation indices) and via classification and regression methods, also using modern artificial intelligence approaches (e.g., neural networks, random forest).

Integrating data from active and passive sensors can provide complementary information related to forest attributes, ranging from biomass [14] to structural parameters and canopy characteristics [15]. The European Copernicus programme manages Sentinel 1 and Sentinel 2 missions that respectively provide active and

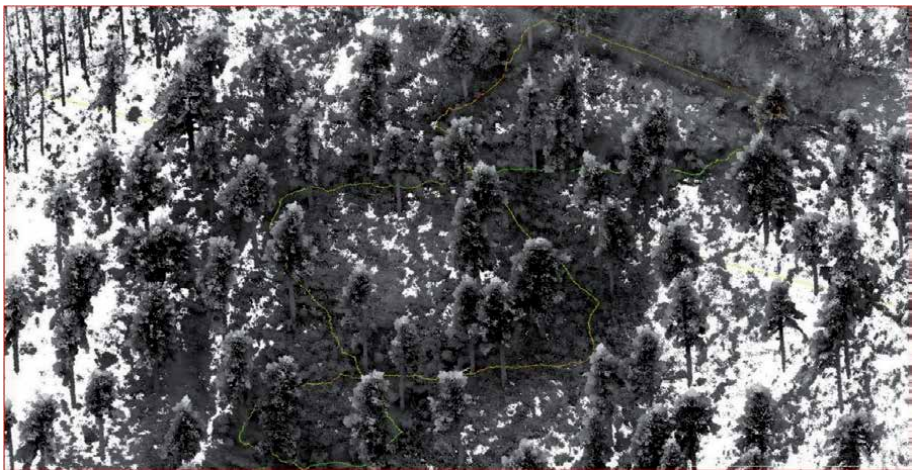


Figure 1.
Point cloud generated by a mobile mapping platform for rapid mobile scanning (Kaarta stencil 2) in the Mompantero site (Susa Valley, Piemonte, Italy) after the 2017 Susa fire.

passive remote sensing data at up to 10 m resolution. They were launched in 2014 and 2015, respectively, and have a revisit time of a few days. The Copernicus services offer unprecedented temporal and spatial coverage over forest stands, allowing an accurate assessment of the effects of disturbances and their impacts on forest ecosystem services.

At the forest stand scale, it is now possible to apply new technologies for fast data acquisition. Portable or handheld LiDAR is an innovative solution that can prove very effective since it allows to acquire data (i.e., point clouds) by simply walking in the forest (**Figure 1**). The sensor can be installed onto a hand-held system or can be carried in a backpack. This system works by emitting a laser beam, collecting the distance between the sensor and object, as well as beam angles and thus generating a point cloud. By coupling a digital camera, the point cloud generation can be enhanced since the color information helps the point matching. The registration of the point clouds is usually made adopting the Simultaneous Localization and Mapping (SLAM) approach, using several computer vision algorithms [16, 17].

Unmanned Aerial Vehicles (UAV) [18–20], both multirotor and fixed wings, can be employed to collect data, using different types of sensors. Nowadays, it is possible to install daylight, near infrared, multi/hyper-spectral, and thermal cameras, as well as a laser scanner on a drone. These autonomously flying systems allow collecting data very rapidly and with a very high spatial resolution. Photogrammetric processing of the UAV imagery allows generating orthophotos with different radiometric information and point clouds for digital surface and elevation models.

In the following, we describe two case studies where active sensors at the stand scale and remote sensing products from passive sensors were applied to assess the status of protection forests following high-severity forest disturbances.

2. Assessing the protective effects of forests after high-severity disturbances

The most frequent abiotic disturbances within European forests are windthrow and forest fires. In recent years unprecedented events affected mountain stands, posing serious threats to their ability to provide fundamental ecosystem services (e.g., protection against natural hazards) and creating a series of issues to be solved

by their post-disturbance management. Remote sensing applications were tested to assist in the different phases of emergency management.

2.1 The 2018 windthrow events in the Dolomites due to the the storm Vaia (Eastern Italian Alps)

At the end of October 2018, the storm Vaia affected the Central and Eastern Italian Alps, damaging more than 42,000 ha of forests with different levels of severity [21]. The windthrown forests were mostly located in steep terrain or in the valley bottom, where the wind was funneled. The majority of the stands on the slopes were protection forests. Salvage logging operations started right after the event and are still ongoing. However, in those areas where the potential for new avalanche releases in the absence of the forest cover was detected, it was decided to leave all the windthrown material on the ground until permanent or temporary technical protection structures are built. Research conducted in Switzerland after the storm Vivian in 1990 demonstrated that the presence of deadwood could have a positive effect in dissipating the energy of falling blocks [22, 23], by increasing the terrain roughness. However, an exhaustive quantification of this effect and its duration in relation to wood decay dynamics is still missing [24, 25]. Furthermore, leaving deadwood on-site can maintain a higher level of biodiversity [26] and enhance regeneration establishment. To incorporate the friction value provided by windthrown material into natural hazard simulation models, roughness estimation should be performed right after the events to assess the post-disturbance conditions. The spatialization of roughness data assessed through field surveys is quite complex. The spatial arrangement of deadwood elements on the ground affects rockfall in different ways: a continuous layer can for instance maximize rock energy dissipation, while tall clumps can result in a highly effective barrier for larger blocks. In the past this issue was solved by assigning the same value measured on a point location in the field to a homogeneous polygon (e.g., forest management unit, forest cover category). Recent remote sensing techniques allow performing a refined spatialization by providing spatially continuous data. Roughness information, relating to both standing and lying deadwood, can be obtained through LiDAR data. This approach has only recently been applied but has already proven to be effective in providing useful insights into the heterogeneity of the spatial arrangement of elements [27]. The availability of more spatially refined data on this feature improves simulation accuracy.

In the municipality of Colle S. Lucia (BL, Italy), in the framework of the RockTheAlps project (ASP462), the efficiency of a rockfall protection forest has been assessed in 2018, before the storm occurred. This was achieved by adopting a combined remote sensing and field data collection methodology (**Figure 2**). LiDAR data acquired in 2015 combined with a UAV data acquisition in July 2018 were used to extract single tree positions on the slopes.

The protective effect has been assessed using Rockyfor3D (v 5.2; [28]), running 1,000 simulations with a rock size corresponding to the 95th percentile of the rock deposits observed in the field (1.5 x 1.0 x 0.8 m, corresponding to 1.2 m^3). Stand data were validated within field plots where other parameters needed for the rockfall simulations were also recorded. Based on the software outputs, the Overall Rockfall Protection Index (ORPI; [29]) was computed for three different positions on the slope: the state road at the bottom, the municipality road to the Colcuc village in the middle, and a severely affected section (checkpoints 1, 2, and 3, respectively, in **Figure 3**). This index describes and quantifies the protective effect against rockfall by integrating the proportion of stopped rocks (frequency) and the total rock energy reduction due to forest cover (intensity) [29].

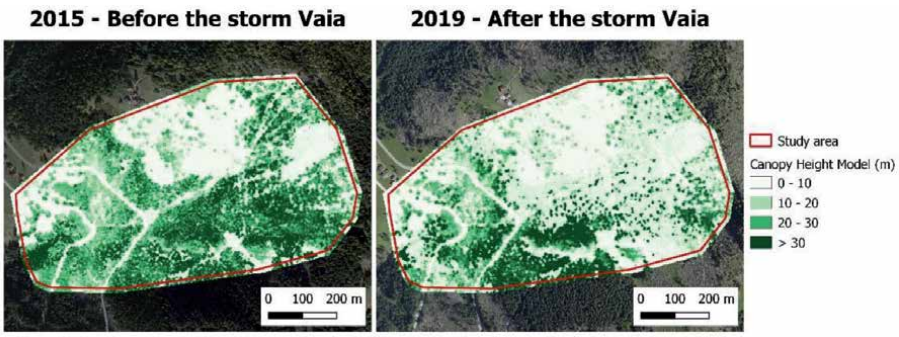


Figure 2.
Canopy height models (CHMs) derived from LiDAR data before (left; 2015) and after (right; 2019) the storm Vaia in the Colcuc case study (Colle S. Lucia, BL, Italy).

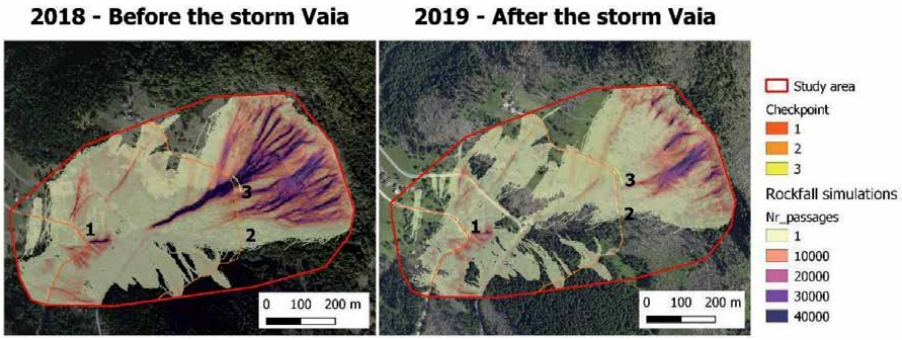


Figure 3.
Rockfall simulation with Rockyfor3D in two scenarios: before (left; 2018) and after (right; 2019) the storm Vaia in the Colcuc case study (Colle S. Lucia, BL, Italy). Maps show the cumulative number of rock passages meaning the number of rocks going through a cell based on 1,000 simulations (i.e., number of rocks released per source cells). Checkpoints are specific locations on the ground (the state road at the bottom, the municipality road to the Colcuc village in the middle, and a severely affected section: checkpoints 1, 2, and 3, respectively), where the ORPI [29] was calculated.

Later that year, the storm Vaia hit the site, leaving a large amount of timber on the ground. In July 2019, new LiDAR data and aerial imagery were acquired, providing up-to-date information on the forest status after the event. A new set of simulations was then performed using the forest cover values resulting from the windthrow and new roughness values for the windthrown area, to take into account the obstacles provided by logs and uprooted stumps. This information has been directly extracted from the LiDAR scans adopting an approach that makes use of quantiles of point distribution on a height-normalized point cloud filtered for the first returns [30].

All the other input parameters have been maintained (i.e., rock characteristics, number of simulations, etc.) to consider the same rockfall scenario and compare results before and after the disturbance. Post-disturbance simulations highlighted a peculiar situation since the protective effect, at least in the short term, was even improved along the slope after Vaia. In each analyzed checkpoint, the ORPI value actually increased (**Figure 4**), in most cases leading to a promotion to the upper class of protective effect (e.g., from low to medium or medium to high; for details on class thresholds see [29]), meaning that the presence of lying deadwood exerted a positive effect in increasing the protection against rockfall. The protective effect should however be assessed through time, monitoring the decay dynamics, the reduction in height above ground of downed logs, and the displacement of logs due

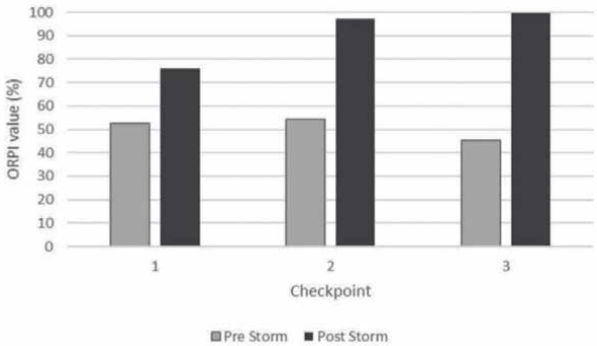


Figure 4.
The overall protection (expressed by ORPI) against rockfall provided by the forest in the Colcuc case study (Colle S. Lucia, BL, Italy) above the three checkpoints before and right after the storm Vaia (see ***Figure 2*** *for checkpoint locations).*

to downslope movements [31] and snow pressure. Remote sensing techniques such as LiDAR or UAV will continue to provide useful quantitative information about these dynamics.

2.2 The 2017 large forest fires in the Piedmont region (Western Italian Alps)

The severe and prolonged summer drought, which occurred in South-Central Europe in 2017 [32] was a major predisposing factor for the simultaneous ignition and spread of several forest fires in the Piedmont Region of Italy during the second half of October. These fires affected nearly 10,000 ha, including more than 7,200 ha of forest stands. Given the importance of fire severity in determining post-fire recovery dynamics, its assessment was considered a key issue to guide post-disturbance management and particularly to identify priority areas where to first intervene. The extensive areas affected by the fires made the application of remote sensing techniques highly useful and different severity indices, commonly applied in other regions of the world, were tested at these sites.

Fire severity maps were produced for the 10 largest forest fires (extent > 50 ha) by adopting the approach formerly developed within the Fire Effects Monitoring and Inventory System [33], which is aimed at integrating optical satellite data and field data (**Figure 5**). A multitemporal analysis based on multispectral imagery acquired by Sentinel-2 was employed to map spectral changes induced by fire in the near infrared and the shortwave infrared wavelengths using indices that compare pre- and post-fire conditions based on the Normalized Burn Ratio (NBR): the differenced NBR [33], the Relative difference NBR [34], and the Relativized Burn Ratio [35]. Field data collected using the Composite Burn Index protocol (**Figure 6**) were employed to obtain independent severity ratings, to be used to calibrate and validate remote sensing results, relating detected radiometric change to actual fire effects on the ground (**Figure 7**) [33]. The Composite Burn Index is obtained within plots (in our case 20 m circular plots) by ocularly evaluating the degree of change induced by fire in five vegetative strata, from the substrates to the dominant trees. Different attributes per stratum are rated on a burn severity scale, ranging from 0.0 (no burn effect) to 3.0 (highest burn effect). Stratum, understory, overstory, and overall composite ratings are then obtained by adding up scores within each hierarchical level and dividing by the number of rated factors. The overall index represents the magnitude of fire effects combined across all strata. In particular, the relationship between the overall Composite Burn Index score assessed in 251 plots

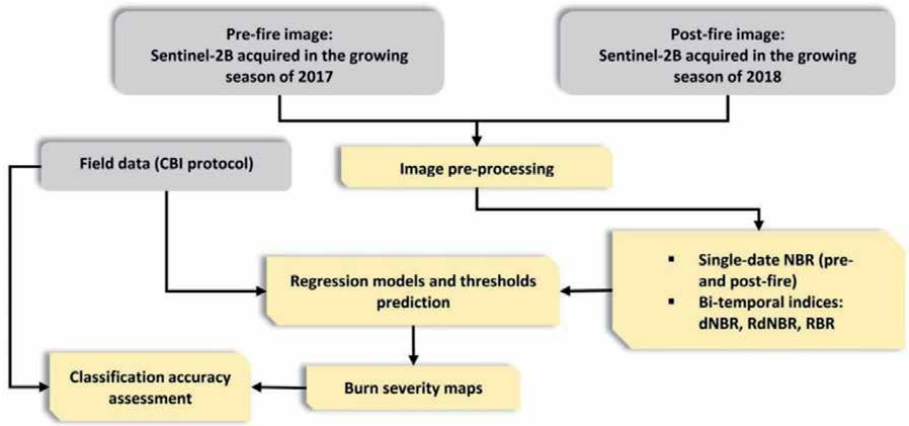


Figure 5.
Developed workflow to retrieve burn severity maps from remote sensing data based on remote sensing indices (Normalized Burn Ratio, NBR; differenced Normalized Burn Ratio, dNBR; Relative difference Normalized Burn Ratio, RdNBR; Relativized Burn Ratio, RBR) and field data (Composite Burn Index, CBI).

Figure 6.
*Patches burned at different severity in protection forest stands dominated by Scots pine (*Pinus sylvestris *L.) and European larch (*Larix decidua *Mill.), and corresponding Composite Burn Index (CBI) values. CBI quantifies the degree of change induced by fire thorough ocular evaluation of different attributes in five vegetative strata within field plots, along a burn severity scale, ranging from 0.0 (no burn effect) to 3.0 (highest burn effect). The overall CBI value for a plot is obtained by averaging attribute scores for all strata and used to describe fire severity. This index can then be related to the Normalized Burn Ratio (NBR) index (and other bi-temporal indices based on the NBR index), obtained through remote sensing data.*

and each bi-temporal index was evaluated through nonlinear regression models, which subsequently provided a threshold for classifying bi-temporal indices into burn severity categories.

The adopted methodology provided satisfying overall classification accuracies of severity maps, ranging from 77.7% to 79.3% depending on the bi-temporal index. Stands dominated by conifers, i.e., Scots pine (*Pinus sylvestris* L.) and European larch (*Larix decidua* Mill.), were burned by stand replacing crown fires, killing both the canopy trees and the understory (i.e. regeneration, shrubs), deeply affecting the soil organic layers and potentially compromising the protective effect for a long period of time. In contrast, broadleaf-dominated stands (e.g., European chestnut [*Castanea sativa* Mill.] and European beech [*Fagus sylvatica* L.]) were mainly burned by low and moderate severity fires [36], that affected only the understory layers, without major changes in the potential protective effect of the forest.

Overlapping the severity maps with the layers of protection forests against rockfall and the historical avalanche sites, priority areas were identified and mapped. Those stands characterized by high fire severity (namely those experiencing stand replacing crown fires) and a relevant protective function, whose protective effect

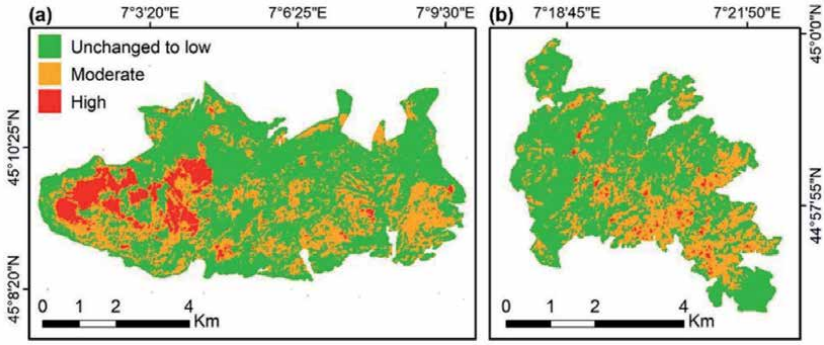


Figure 7.
Burn severity maps derived from the Relative difference Normalized Burn Ratio (RdNBR) index for (a) the Susa fire and (b) the Cumiana fire (Piemonte, Italy).

had thus potentially been highly compromised, were selected to perform interventions devoted to the rapid recovery of the protective effect, adopting ecoengineering techniques (building wooden structures with burned logs) and afforestation.

3. Conclusions

The availability to collect timely information on the status of protection forests is of fundamental importance for their management, particularly in the aftermath of high-severity disturbances, both in the response and recovery phases. Currently several freely available data sources are accessible to forest and land managers, as well as new tools and software (**Table 1**), to increase the amount of and improve information required to support a sustainable forest management in the framework of global change challenges. Rapid mapping through remote sensing technologies operating over large areas allows monitoring and updating on-demand knowledge about the protective effect of a stand, providing key data to guide the decision-making process. Characterizing disturbance severity and relating its short- and long-term effects to the stand residual protective effect can have a direct applicability in forest management to spatially define intervention necessities and priorities.

The described methodologies and related technologies are currently operational and require medium level skills in using GIS and remote sensing tools. Concerning LiDAR, some pre-processed data (e.g., canopy height models) are more and more available for end-users, but directly managing the point clouds still remains a task restricted to more skilled experts. Given the rapid progress in the development of new remote sensing technologies and tools for describing, measuring and monitoring forest stands, the forest sector as a whole should invest in training and continuing education in this field to keep its members updated to be competitive in rapidly evolving scenarios.

Category	Details	Website
Multispectral satellite data at medium spatial resolution	Landsat missions (Landsat 4–5 TM; Landsat 7 ETM+; Landsat 8 OLI/TIRS)	https://earthexplorer.usgs.gov/
	Sentinel-2 mission (Sentinel-2A and 2B)	https://scihub.copernicus.eu/

Category	Details	Website
Open-source software for remote sensing data analysis	FORCE: Framework for Operational Radiometric Correction for Environmental monitoring	https://github.com/davidfrantz/force
	R "raster" package	https://cran.r-project.org/web/packages/raster/index.html
	R "terra" package	https://github.com/rspatial/terra
	R "RStoolbox" package	http://bleutner.github.io/RStoolbox/
	Orfeo Toolbox	https://www.orfeo-toolbox.org/
	SAGA GIS	http://www.saga-gis.org/
	FUSION/LDV	http://forsys.cfr.washington.edu/fusion/fusionlatest.html
	R "Forest Tools" package	https://github.com/andrew-plowright/ForestTools
Free-of-charge cloud-computing platforms for remote sensing data analysis	Google Earth Engine	https://earthengine.google.com/
	Copernicus Research and User Support	https://rus-copernicus.eu/portal/the-rus-service/

Table 1.
Examples of freely available data, open-source software, and free-of-charge cloud-computing platforms for remote sensing data analysis (the list in the table is non-exhaustive).

Acknowledgements

The presented research was funded by the Interreg Alpine Space project "RockTheAlps" (ASP462), by Dept. TESAF, University of Padova in the frame of the project "Vaia FRONT" (CAVA_SID19_02), by the Veneto Region in the frame of the project Vaia-Land (OCDPC 558/2018), and by the Piemonte Region in the frame of the "Piano straordinario di interventi di ripristino in seguito agli incendi dell'autunno 2017" (DGR 18 Aprile 2019, n. 29-8813).

Conflict of interest

The authors declare no conflict of interest.

Author details

Emanuele Lingua[1*], Niccolò Marchi[1], Francesco Bettella[1], Maximiliano Costa[1], Francesco Pirotti[1], Marco Piras[2], Matteo Garbarino[3], Donato Morresi[3] and Raffaella Marzano[3]

1 Department of TESAF, University of Padova, Legnaro (PD), Italy

2 Department of DIATI, Politecnico di Torino, Torino (TO), Italy

3 Department of DISAFA, University of Torino, Grugliasco (TO), Italy

*Address all correspondence to: emanuele.lingua@unipd.it

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

[2] Frehner M, Wasser B, Schwitter R. Sustainability and success monitoring in protection forests – Guidelines for silvicultural interventions in forests with protective functions. Umwelt-Vollzug. 2007;**27**:29

[3] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[4] Berger F, Rey F. Mountain protection forests against natural hazards and risks: New French developments by integrating forests in risk zoning. Nat. Hazards. 2004;**33**:395-404. DOI: 10.1023/B:NHAZ.0000048468.67886.e5

[5] White PS, Pickett STA. Natural disturbance and patch dynamics, an introduction. In: Pickett STA, White PS, editors. The Ecology of Natural Disturbance and Patch Dynamics. New York: Academic Press; 1985. pp. 3-13

[6] Dale VH, Joyce LA, McNulty S, Neilson RP, Ayres MP, Flannigan MD, Hanson PJ, Irland LC, Lugo AE, Peterson CJ, Simberloff D, Swanson FJ, Stocks BJ, Wotton BM. Climate change and forest disturbances. Bioscience. 2001;**51**:723-734. DOI: 10.1641/0006-3568(2001)051[0723,CCAFD]2.0.CO;2

[7] Forzieri G, Girardello M, Ceccherini G, Spinoni J, Feyen L. Emergent vulnerability to climate-driven disturbances in European forests. Nat. Commun. 2021:1-12. DOI: 10.1038/s41467-021-21399-7

[8] Lingua E, Bettella F, Pividori M, Marzano R, Garbarino M, Piras M, Kobal M, Berger F. The protective role of forests to reduce rockfall risks and impacts in the Alps under a climate change perspective. In: Leal Filho W, Nagy GJ, Borga M, Chavez Muñoz PD, Magnuszwesk A, editors. Climate Change, Hazards and Adaptation Options: Handling the Impacts of a Changing Climate. Cham, Switzerland: Springer; 2020. pp. 333-347. DOI: 10.1007/978-3-030-37425-9_18

[9] Mina M, Bugmann H, Cordonnier T, Irauschek F, Klopcic M, Pardos M, Cailleret M. Future ecosystem services from European mountain forests under climate change. J. Appl. Ecol. 2017;**54**:389-401. DOI: 10.1111/1365-2664.12772

[10] Dorren LKA, Berger F, Imeson AC, Maier B, Rey F. Integrity, stability and management of protection forests in the European Alps. For. Ecol. Manage. 2004;**195**:165-176. DOI: 10.1016/j.foreco.2004.02.057

[11] Scheidl C, Heiser M, Vospernik S, Lauss E, Perzl F, Kofler A, Kleemayr K, Bettella F, Lingua E, Garbarino M, Skudnik M, Trappmann D, Berger F. Assessing the protective role of alpine forests against rockfall at regional scale. Eur. J. For. Res. 2020:139. DOI: 10.1007/s10342-020-01299-z

[12] Eysn L, Hollaus M, Lindberg E, Berger F, Monnet JM, Dalponte M, Kobal M, Pellegrini M, Lingua E, Mongus D, Pfeifer N. A benchmark of lidar-based single tree detection methods using heterogeneous forest

data from the Alpine Space. Forests. 2015;**6**:1721-1747. DOI: 10.3390/f6051721

[13] Piragnolo M, Pirotti F, Zanrosso C, Lingua E, Grigolato S. Responding to large-scale forest damage in an alpine environment with remote sensing, machine learning, and web-GIS. Remote Sensing. 2021:1541. DOI: 10.3390/rs13081541

[14] Vaglio GL, Pirotti F, Callegari M, Chen Q, Cuozzo G, Lingua E, Notarnicola C, Papale D. Potential of ALOS2 and NDVI to estimate forest above-ground biomass, and comparison with lidar-derived estimates. Remote Sens. 2017;**9**:18. DOI: 10.3390/rs9010018

[15] Zald HSJ, Wulder MA, White JC, Hilker T, Hermosilla T, Hobart GW, Coops NC. Integrating Landsat pixel composites and change metrics with lidar plots to predictively map forest structure and aboveground biomass in Saskatchewan, Canada. Remote Sens. Environ. 2016;**176**:188-201. DOI: 10.1016/j.rse.2016.01.015

[16] Fan Y, Feng Z, Mannan A, Khan TU, Shen C, Saeed S. Estimating tree position, diameter at breast height, and tree height in real-time using a mobile phone with RGB-D SLAM. Remote Sens. 2018:10. DOI: 10.3390/rs10111845

[17] Pierzchała M, Giguère P, Astrup R. Mapping forests using an unmanned ground vehicle with 3D LiDAR and graph-SLAM. Comput. Electron. Agric. 2018;**145**:217-225. DOI: 10.1016/j.compag.2017.12.034

[18] Aicardi I, Garbarino M, Lingua A, Lingua E, Marzano R, Piras M. Monitoring post-fire forest recovery using multi-temporal digital surface models generated from. EARSeL eProceedings. 2016. DOI: 10.12760/01-2016-1-01

[19] Adão T, Hruška J, Pádua L, Bessa J, Peres E, Morais R, Sousa JJ. Hyperspectral imaging: A review on UAV-based sensors, data processing and applications for agriculture and forestry. Remote Sens. 2017:9. DOI: 10.3390/rs9111110

[20] Torresan C, Berton A, Carotenuto F, Di Gennaro SF, Gioli B, Matese A, Miglietta F, Vagnoli C, Zaldei A, Wallace L. Forestry applications of UAVs in Europe: A review. Int. J. Remote Sens. 2017;**38**:2427-2447. DOI: 10.1080/01431161.2016.1252477

[21] Chirici G, Giannetti F, Travaglini D, Nocentini S, Francini S, D'Amico G, Calvo E, Fasolini D, Broll M, Maistrelli F, Tonner J, Pietrogiovanna M, Oberlechner K, Andriolo A, Comino R, Faidiga A, Pasutto I, Carraro G, Zen S, Contarin F, Alfonsi L, Wolynski A, Zanin M, Gagliano C, Tonolli S, Zoanetti R, Tonetti R, Cavalli R, Lingua E, Pirotti F, Grigolato S, Bellingeri D, Zini E, Gianelle D, Dalponte M, Pompei E, Stefani A, Motta R, Morresi D, Garbarino M, Alberti G, Valdevit F, Tomelleri E, Torresani M, Tonon G, Marchi M, Corona P, Marchetti M. Forest damage inventory after the "Vaia" storm in Italy. For. – Riv. di Selvic. Ed Ecol. For. 2019;**16**:3-9. DOI: 10.3832/efor3070-016

[22] Schönenberger W, Noack A, Thee P. Effect of timber removal from windthrow slopes on the risk of snow avalanches and rockfall. For. Ecol. Manage. 2005;**213**:197-208. DOI: 10.1016/j.foreco.2005.03.062

[23] Wohlgemuth T, Schwitter R, Bebi P, Sutter F, Brang P. Post-windthrow management in protection forests of the Swiss Alps. Eur. J. For. Res. 2017;**136**:1029-1040. DOI: 10.1007/s10342-017-1031-x

[24] Rammig A, Fahse L, Bugmann H, Bebi P. Forest regeneration after disturbance: A modelling study for the Swiss Alps. For. Ecol. Manage.

2006;**222**:123-136. DOI: 10.1016/j.foreco.2005.10.042

[25] Frey W, Thee P. Avalanche protection of windthrow areas: A ten year comparison of cleared and uncleared starting zones. For. Snow Landsc. Res. 2002;**77**:89-107

[26] Thorn S, Chao A, Georgiev KB, Müller J, Bässler C, Campbell JL, Castro J, Chen YH, Choi CY, Cobb TP, Donato DC, Durska E, Macdonald E, Feldhaar H, Fontaine JB, Fornwalt PJ, Hernández RMH, Hutto RL, Koivula M, Lee EJ, Lindenmayer D, Mikusiński G, Obrist MK, Perlík M, Rost J, Waldron K, Wermelinger B, Weiß I, Żmihorski M, Leverkus AB. Estimating retention benchmarks for salvage logging to protect biodiversity. Nat. Commun. 2020:11

[27] Marchi N, Pirotti F, Lingua E. Airborne and terrestrial laser scanning data for the assessment of standing and lying deadwood: Current situation and new perspectives. Remote Sens. 2018;**10**:1356. DOI: 10.3390/rs10091356

[28] Dorren LKA. Rockyfor3D (v5.2) revealed – Transparent description of the complete 3D rockfall model; ecorisQ pa; 2015. 32 p

[29] Dupire S, Bourrier F, Monnet JM, Bigot S, Borgniet L, Berger F, Curt T. Novel quantitative indicators to characterize the protective effect of mountain forests against rockfall. Ecol. Indic. 2016;**67**:98-107. DOI: 10.1016/j.ecolind.2016.02.023

[30] Costa M, Marchi N, Bettella F, Bolzon P, Berger F, Lingua E. Biological legacies and rockfall: The protective effect of a windthrown forest. Forests. 2021;**12**(9):1141. DOI: 10.3390/f12091141

[31] Picco L, Scalari C, Iroumé A, Mazzorana B, Andreoli A. Large wood load fluctuations in an Andean basin. Earth Surf. Process. Landforms. 2020. DOI:10.1002/esp.5030

[32] Rita A, Camarero JJ, Nolè A, Borghetti M, Brunetti M, Pergola N, Serio C, Vicente-Serrano SM, Tramutoli V, Ripullone F. The impact of drought spells on forests depends on site conditions: The case of 2017 summer heat wave in southern Europe. Glob. Chang. Biol. 2020;**26**: 851-863. DOI: 10.1111/gcb.14825

[33] Key CH, Benson NC. Landscape Assessment (LA) Sampling and Analysis Methods. USDA For. Serv. – Gen. Tech. Rep. RMRS-GTR. 2006

[34] Miller JD, Thode AE. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta normalized burn ratio (dNBR). Remote Sens. Environ. 2007;**109**:66-80. DOI: 10.1016/j.rse.2006.12.006

[35] Parks SA, Dillon GK, Miller C. A new metric for quantifying burn severity: The relativized burn ratio. Remote Sens. 2014;**6**:1827-1844. DOI: 10.3390/rs6031827

[36] Morresi D, Marzano R, Lingua E, Motta R, Garbarino M. Mapping burn severity in the western Italian Alps through phenologically coherent reflectance composites derived from Sentinel-2 imagery. Remote Sens. Environ. 2022;**269**:112800. DOI: 10.1016/j.rse.2021.112800

Chapter 7

Modeling Protective Forests for Gravitational Natural Hazards and How It Relates to Risk-Based Decision Support Tools

Christopher James Laplante D'Amboise, Michaela Teich, Anne Hormes, Stefan Steger and Frédéric Berger

Abstract

Simulation tools and their integrated models are widely used to estimate potential starting, transit and runout zones of gravitational natural hazards such as rockfall, snow avalanches and landslides (i.e., gravitational mass flows [GMFs]). Forests growing in areas susceptible to GMFs can influence their release and propagation probabilities (i.e., frequency and magnitude of an event) as well as their intensity. If and how well depends on the GMF type, the topography of the terrain and the forest's structure. In this chapter, we introduce basic concepts of computer models and state-of-the-art methods for modeling forest interactions with rockfall, snow avalanches and landslides. Furthermore, an example of a protective forest routine embedded in the runout angle-based GMF simulation tool Flow-Py will be presented together with its parameterization for forest-GMF interactions. We applied Flow-Py and two custom extensions to model where forests protect people and assets against GMFs (the protective function) and how forests reduce their frequency, magnitude and/or intensity (the protective effect). The goal of this chapter is to describe protective forest models, so that practitioners and decision makers can better utilize them and their results as decision support tools for risk-based protective forest and ecosystem-based integrated risk management of natural hazards.

Keywords: simulation tools, statistical and physical models, protective forest, rockfall, snow avalanches, landslides

1. Introduction

Simulation tools and their integrated models are widely used by the scientific community and practitioners for their predicting power, which is where science and practice overlap. One major advantage of simulation tools is their potential to highlight what is known about a system and where knowledge gaps exist. Every model is a simplification of reality and practitioners can use the output of models as a decision support tool (see chapter [1] of this book). By simplifying a natural system, it is necessary to make assumptions, which goes hand in hand with

reducing complexity and loss of detail. To best benefit from using simulation tools, practitioners should therefore be familiar with the basics of the underlying models to understand their limitations.

In this chapter, we discuss how to incorporate forests into gravitational mass flow (GMF; [2]) models to gain an understanding of where forests protect people and assets (their protective function) and to estimate how forests reduce the frequency, magnitude and intensity of gravitational natural hazard (their protective effect; see chapters [3, 4] for definitions and details on forest-GMF interactions). We first introduce basic concepts of computer models regarding protective forests and then summarize some of the state-of-the-art methods used for modeling forest interactions with rockfall, snow avalanches and landslides in their starting zone as well as transit and runout zones. Lastly, an example of a protective forest routine embedded into Flow-Py, a GMF simulation tool based on a runout angle (also referred to as the travel or α-angle) model [2, 5], is presented together with the justifications for the parameterization and implementation. This example highlights the development process of simulation tools and allows the user a deeper look into the assumptions that are necessary for modeling protective forests.

The model development process can be thought of as a 4-part cycle as shown in **Figure 1**. The cycle starts with obtaining a greater process understanding via laboratory experiments, field measurements, remote sensing data acquisition or existing observations. The next step of the cycle is to incorporate that new knowledge into an existing model or newly developed model. The third step is a model validation where the model results are compared to observations. The last step is a model evaluation where the validation results are used to highlight improvements that have been made during the cycle and, more importantly, to reveal remaining knowledge gaps. These knowledge gaps are opportunities for new research to obtain a deeper process understanding and the cycle repeats.

In general, models can be grouped in several categories. For simplicity, we group GMF models by two main characteristics:

1. with regards to the size of the modeling domain which is linked to a model's (spatial) resolution, and

2. the general methods and techniques that were used to develop a model.

The domain sizes and model types that will be discussed are the regional (10s to 100s of km^2) and the hill slope or path scale (less than 10 km^2), and data-driven

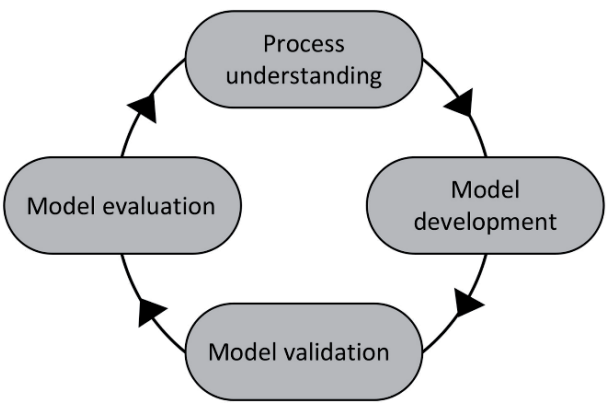


Figure 1.
The model development cycle.

statistical models (hereafter referred to as statistical models, e.g., the α-β model [6], Flow-R [7], or the topographic approach of [8]) and process-based physical models (hereafter referred to as physical models, e.g., RAMMS [9] or Rockyfor3D [10]).

We use the expression "statistical model" to summarize data-driven, data-based and machine learning approaches whose quantitative outcome originates directly from empirical data without needing a deeper understanding of the underlying processes. The equation that results is based on statistics and the parameters have no physical meaning but are inferred from real-world observations. The major strengths of statistical models are the simplistic parameterization and their flexibility in terms of input data requirements compared to physical models. However, statistical models can only answer questions they were designed for, which strongly depends on the input data used to develop and calibrate them. The major challenge for developing a reliable statistical model is, therefore, the collection of data on which to base the statistical relationships and parameterizations on.

In contrast, physical models break the main modeling question into the governing processes or smaller sub-processes that are expressed in equations. By compiling the sub-processes, information of the system is gained, and the modeling question can be addressed. Physical models usually involve more calculations and require larger computational resources than statistical models. However, the major advantage of physical models is that the variables, parameters, and some intermediate calculations (usually) have physical meanings providing additional information, e.g., the energy of the GMF or the depth of the flow. This strength of physical models is also one of their major drawbacks, because they require very accurate input data and parameterization. That is, physical models can have large parameter sets, whose values can be difficult to measure and are often impractical to obtain for many modeling efforts. Moreover, although physical models split the main modeling question into sub-processes, significant feedback between processes still exists and cannot be ignored, i.e., the results of one sub-process are fed into another process. In practice, the calibration of physical models is often based on empirical parameter adjustments that gives these models a statistical character. In the end, a model can only be as "good" as the data that is used for its development, which is true for any (statistical or physical) model development.

GMF and protective forest models have often elements of both statistical and physical models (e.g. [11, 12]). The sub-processes that are lacking a strong understanding or that demand an excessive amount of data, such as forest interactions with a GMF, are frequently represented with statistical models. GMF runout models identify the spatial extent or how far a hazard reaches down slope. To account for the vegetation effect in such a model, it requires the adjustment to the mechanisms for modeling the two main effects on gravitational natural hazards (see chapter [4] of this book):

1. the starting zone identification (release susceptibility or probability) in forested areas, and

2. the runout model (the movement of the GMF) in forested locations.

The mechanisms to adapt a GMF model to a protective forest model are different depending on the type of model (statistical or physical), the size of the modeling domain and the research question being investigated. In statistical models, the mechanisms to account for interactions between a GMF and forest have to be rooted in empirical data, while these mechanisms must adjust the equations of physical models. However, the size of the modeling domain often determines the type of model that is applied. For large areas or regional scale modeling, statistical models

are regularly used due to the lack of existing and detailed input data. On single paths or the hill slope scale precise input data and parameterizations can often be collected more easily. Compared to regional-scale studies, investigations at the hill slope scale provide finer details relevant to individual properties in terms of the resolution and accuracy of simulated outputs (see chapter [13] of this book). In contrast, detailed information is often less useful for studies at the regional scale, and input data and simulation results are often simplified and presented as summaries of higher resolution data (e.g., average values, standard deviations or trends). As a practitioner it is important to choose the appropriate model depending on the question at hand.

2. Protective forest models

Protective forest models can be applied to model (1) forests' protective functions, and/or (2) forests' protective effects. That is, they can be used to **identify** locations of forests with an (object) protective function (see chapter [3] of this book for definitions), and/or to **quantify** the degree to which these forests protect a location.

Protective forest models are used by different user groups to support decision making. For example, the road administration could use a protective forest model to investigate the degree of protection a forest provides in a single avalanche starting zone or avalanche flow path that endangers a section of a road. Or a local or state government could use protective forest models to investigate the extent of protective forest located in a region (e.g., municipality, state, or province) to determine a budget for managing these forests. These examples require very different amounts of information and different mechanisms that must be implemented into the GMF model, so that it can be applied as a protective forest model. In this subsection the main mechanisms currently used to include protective forest into different types of GMF models are introduced.

2.1 Identification of protective forests' function

To address the question where object protective forest is located, a union between the spatial distribution of the forest and the spatial distribution of the GMF areas (consisting of starting, transit and runout zones) that endanger assets must be established. Therefore, the applied GMF runout model must be able to discriminate between parts of the GMF that endanger infrastructure and parts that do not, because not all parts of the transit zone and/or runout zone will necessarily reach infrastructure for a given starting zone. This adaption to GMF runout models is relatively straight forward. The union between the spatial distribution of forest and the sub-set of GMF areas that endanger infrastructure is done in a post-processing step. The resulting maps highlight forests that have a direct object protective function, which has been mapped, for example, in Switzerland (project: SilvaProtect-CH [14, 15]) and in Austria (projects: PROFUNmap for data integration [16]; GRAVIMOD II for shallow-seated landslides [17, 18]; DAKUMO for snow avalanches [19]; GRAVIMOD I for rockfall and snow avalanches [20, 21]).

2.2 Quantification of protective forests' effect

Two interactions between forests and GMFs must be considered to answer how much a forest reduces the frequency, magnitude and/or intensity of a GMF (see section 1). That is, the initial release of mass can be influenced by forest and the

forest can also interact with the movement in the GMF's transit and runout zones dissipating energy by mass reduction or increasing friction, which differs depending on the GMF type.

The process for releasing a GMF is highly dependent on the material type and composition. Therefore, each GMF type requires different models for identifying its starting zones and/or quantifying associated release and propagation probabilities. Deeper process understanding of how the forest interacts with the movement and release mechanics is available for some types of GMFs, while for others the process understanding is weak (see chapter [4] of this book). A lack of process understanding will result in less precise model parameterizations for identifying starting zones and simulating forest-GMF interactions. Therefore, hazard-specific parameterizations and mechanisms are needed for the different GMF types such as rockfall, snow avalanches or landslides.

3. State-of-the-art forest-GMF interaction modeling approaches

3.1 Rockfall

Two main categories of rockfall models exist: 1) models that identify and characterize the potential starting (i.e., release or disposition) zones of boulders, and 2) models that simulate rockfall trajectories. That is, the effects of forest must be considered separately for the starting zone, and transit and runout zones, since forest might even increase rockfall activity in release areas due to wedge effects of the roots, and snow or wind effects on stem movements [22]. In the transit and runout zones, forest can shorten the runout lengths of boulders if the forest on the slope has a minimum length and no large gaps. For example, a minimum forested slope length of 250 m with openings below 40 m in length is one target [23] to potentially provide protection against rockfall. Currently, no rockfall model exists that combines disposition and trajectory modeling [24].

3.1.1 Rockfall release models

The impacts of trees in starting zones are mainly destabilizing due to the blasting and leverage effects of root systems and/or windthrow, which have not been considered in release models. The choice of modeling technique to identify rockfall starting zones depends on data availability and the desired resolution of the output. Physical rockfall release models consider the internal friction of bedrock, bedrock types, slope inclination, foliation and fractures [25]. The input data requirements to physically model the rockfall release mechanisms limit the application of this type of models to one or few starting zones on a hill slope scale. In contrast, statistical rockfall starting zone models have been developed using digital elevation models (DEMs), which are often the only reliable data source for regional-scale modeling. This type of models applies a threshold based on the slope calculated from a DEM and may consider some local geology [26]. The slope threshold can be applied to DEMs of different resolution by adjusting it accordingly [27].

3.1.2 Statistical rockfall propagation models

Released blocks move mainly by sliding, rolling, jumping or bouncing downslope; however, knowing the exact type of movement is not necessary for statistical rockfall models, which use a runout-angle approach to predict rockfall runout lengths [28]. Two angles are used for rockfall modeling: first, the classical

runout angle (also travel or α-angle), which is the angle from the top of the starting zone to the furthest runout of a block. This runout angle assumes that the starting zone (release or source area) is known. The second angle is the shadow angle, which is the angle of the line that is drawn from the bottom of a cliff face (or the lowest possible point of a rockfall release) to the furthest reach of the block runout [22]. The shadow angle describes the maximum travel distance of blocks by intersecting the topography with an energy line starting at the base of the rock face. Empirical studies on α-angles of rockfall trajectories where boulders can still bounce, roll or slide suggest a range between 51.2° and 28.5° [29–31]. A regression approach was used to specify α-angles for rockfall modeling by means of observed α-angles with an optimal solution of 32.9° [29], indicating that values between 30° and 35° provide useful α-angles to model large rockfall distances.

Individual trees can dissipate the energy of a falling rock by the impact of the boulder, deformation of the stem, rotation or translation of the root, or rebound of the boulder [32, 33]. Therefore, in addition to the length of the forested slope, the protective effect of a forest stand depends strongly on its structural properties, mainly average stem diameter, stem density and/or basal area (see chapter [4] of this book), and has been incorporated into both statistical and physical rockfall trajectory models. That is, forests with a high basal area and high stem density have been identified as a particularly effective measure against rockfall by reducing the kinetic energy and velocity of falling and bouncing blocks in the transit zone [34], which translates to an average increase of the runout angle by 6° [35, 36]. For coherent modeling results, calibrating statistical rockfall models with observations of past events is key; however, physical rockfall models that account for the energy dissipating effect of forests are also being used when such data is not available.

3.1.3 Rockfall trajectory models at the slope scale and integration of forest effects

Physical rockfall trajectory models calculate the runout length and trajectories of blocks and may consider the block's shape and type of movement as well as its interactions with different underlying surfaces (depending on roughness and soil cover) and the vegetation. Many physical rockfall models provide statistical distributions of the block jump height, velocity and kinetic energy at each point along a slope; however, only few also distinguish the block movement types. Current research is dedicated to also integrating block fragmentation during the fall process, which has not yet been implemented in rockfall models [37, 38].

Physical rockfall trajectory models have initially been developed in a two-dimensional framework. Similar to statistical models, forest-block interactions are implemented by a kinetic energy dissipation of a block in forested terrain, which is here translated by an equivalent friction coefficient [39]. Two-dimensional physical rockfall trajectory models are often employed in simulation experiments for parameterizing statistical rockfall models to quantify the effects a forest has on the dispersion of possible block trajectories. However, these models are not able to represent the variability in the spatial distribution of trees, tree species and stem diameters, and how they affect rockfall trajectories.

Spatially explicit simulations of forest effects on rockfall require three-dimensional models that account for the effects of individual trees on kinetic energy dissipation, lateral rebound and impact [40]. Therefore, three-dimensional trajectory models have been developed to simulate block dispersion depending on the topography of the terrain rather than just on a set of several two-dimensional trajectories [25, 41–43]; however, only few consider the protective effect of forest, e.g., Rockyfor3D by a reduction in kinetic energy dependent on stem diameter and the percentage of coniferous trees [44]. In RAMMS::ROCKFALL, non-smooth

mechanics are coupled with hard contact laws in the framework of a discrete element model; the plugin to simulate the effect of forest on rockfall trajectories will be released in fall of 2021 [45].

3.2 Snow avalanches

The primary effect of forest on slab avalanche is to reduce the probability of release by stabilizing the snowpack on the ground [46] (see also chapter [4] of this book). A secondary effect of forest is its capability to stop or significantly decelerate small-to-medium avalanches starting within forests or close to the upper timberline [47]. However, breakage, uprooting and overturning of trees also reduce runout lengths of medium-to-large avalanches starting above the timberline [48–51]. Both protective effects are influenced by forest structure in terms of canopy cover, stem density, species composition and size and distribution of forest gaps [52, 53]. To model these two effects usually requires different approaches and even different models.

The models used to identify an avalanche starting zone or to quantify the probability of an avalanche release in forests are primarily statistically based and can be applied to regional or hill slope scales [54, 55]. Models that quantify the forest effect on avalanche dynamics are mainly physical models for regional or hill slope scales [56]; however, the processes that describe forest-avalanche interactions can be expressed physically or statistically depending on the resolution of the avalanche dynamics model. Simpler statistical models are used more often on regional scales [57], while physical models are often limited by the required detail of the input data and are more applicable on the hill slope scale [58].

3.2.1 Snow avalanche starting zone and release models

The most basic release area models locate potential avalanche starting zones with statistical relations to terrain features [59–61]. In these models, forest is often oversimplified with no consideration of its type or structure. More sophisticated models, which usually require additional information on the snow climate, terrain roughness and/or vegetation type, can also quantify the avalanche release probability [62, 63]. The integration of forest in these models is necessary to quantify the forest effect in dependence on its structure, so that it can be integrated into risk assessments [64].

3.2.2 Statistical snow avalanche-forest interaction models

Statistical avalanche models are widely used to predict maximum runout lengths of extreme avalanches. These models are developed from topographic parameters of paths and observed runout lengths of representative avalanche events. The two mainly applied statistical models are the α–β model [6], and the runout ratio model [65], which uses a runout ratio or density probability function to fit a distribution to observed runouts. However, modeling forest-avalanche interactions with statistical models is challenging since (1) the existing approaches are designed to predict extreme avalanches where forest has a very limited effect on runout [47], and (2) reliable avalanche observations in forested terrain, which are needed for model parameterization and calibration, are rare (see also chapter [66] of this book). For example a terrain and runout ratio analyses for 45 forest-penetrating avalanches, which showed that all but one avalanches stopped up-slope of or at the β-point (the point at which the slope first becomes 10°) [49]. A plot of runout ratio probabilities was derived that can be used in the field to determine the likelihood of an avalanche travelling through forest to a given point on a slope.

In section 4, we present another example of a protective forest routine that was embedded in the GMF simulation tool Flow-Py [5], but is also applied in the online "Protective Forest Assessment Tool – FAT" [67, 68] – a risk-based decision support tool to estimate the value forest has for protecting buildings and infrastructure against GMFs and to compare it to technical and avoidance measures (see also chapter [1] of this book).

3.2.3 Physical snow avalanche dynamics-forest interaction models

Early approaches to model forest-avalanche interactions apply an increase in friction in forested areas to a Voellmy-type relation accounting for the decelerating effect of forest on the avalanche flow and thus a reduction in runout length [69–71]. Voellmy-type models split the total friction into a velocity-independent Coulomb friction term and a velocity-dependent "viscous" or "turbulent" friction [72]. The Coulomb friction is thought to summarize snow properties, whereas the velocity-dependent turbulent friction term expresses the topography and roughness of an avalanche flow path [73, 74]. To model the braking effect of forests on avalanches the turbulent drag of the basal friction is increased in forested areas compared to open unforested terrain [50, 55]. This increase in friction is supposedly caused by a combination of different forest-avalanche interactions such as breaking, overturning, uprooting or entrainment, which are thought to act mostly on the velocity-dependent turbulent friction [48]. However, this interpretation of the Voellmy friction terms is not ideal because it is based on expert judgment rather than on measurements [12]. Recently, a small-scale experiments of granular flows traveling through regularly spaced 'trees' was used to show that the overall deceleration rate can be predicted by applying a stem density-dependent effective basal friction coefficient [75]. The friction approach has been tested for large-scale fast-moving avalanches where the braking effects are small and occur over longer runout lengths [51, 76]; however, this method may not be valid for small-to-medium avalanches [77]. That is, snow detrainment which is the main process of forest-avalanche interactions in small-to-medium avalanches is not well represented with a frictional relationship and the local braking effect of forests on avalanche flow is difficult to model at the grid scale [56].

Based on field observations, Feistl et al. [56] developed an additional one-parameter function (detrainment function) to include forest-avalanche interactions in physical avalanche dynamics models. This function accounts for the snow that is deposited behind trees, groups of trees or remnant stumps by a combination of impact, rubbing dissipation, deflection, cohesion and jamming. The stopped mass is extracted from the avalanche volume and the corresponding momentum is removed from the total momentum of the moving snow leading to a reduction in runout length. The braking effect of forests on avalanche flow and, therefore, the mass to be removed from the avalanche volume is summarized in one parameter (the forest detrainment coefficient K) representing different forest structures [77].

3.3 Landslides

A multitude of possibilities exist to build spatial models for landslides, which are considered crucial for implementing efficient risk reduction strategies and for managing landslide risk [78–80]. Spatial landslide models are regularly applied to provide estimates on landslide-prone terrain, slope (in)stability or landslide hazard and are employed at different scales to obtain insights into the predisposing, preparatory or triggering factors of slope instability [81–83].

Spatial landslide models are generally based on qualitative (expert judgment/heuristic) or quantitative (statistically or physically based) approaches [78, 84]. The results of heuristic procedures can be considered subjective as they are primarily based on expert-driven weighting schemes. Instead, statistical and physical models provide numerical outputs and are extensively applied within current scientific studies. The wealth of currently available landslide modeling tools has certainly facilitated the spatial analysis of landslide processes (e.g., [7, 85–89]). However, despite the recent technical advancements, the explanatory power and applicability of a quantitative spatial landslide model still relies on a non-trivial balance between the quality of the available input data, the model complexity and the envisaged spatial coverage [78, 90, 91]. The following two subsections focus particularly on quantitative spatial landslide models for starting zones of shallow slope (in)stabilities and the implementation of forest's protective effects.

3.3.1 Statistical models for landslide release: regional scale

Statistical landslide models are usually based on a classification algorithm or are regression-based models that link landslide inventory data (e.g., landslide presence/absence information, counts on landslides) to a variety of environmental variables that are supposed to represent the static or dynamic causes of slope instability. The resulting relationships can then be transferred to each spatial unit of a study site (e.g., raster cell or catchment) to derive a static landslide susceptibility map or spatio-temporal landslide predictions [92, 93]. Statistical models are mainly applied for larger areas, as they are not reliant on a specific set of subsurface parameters that are hard to measure (e.g., soil properties), and because their predictive power increases with the number of observations [94, 95]. Several studies have shown that statistical models can provide insights into the contribution of different forest types, land cover changes and timber harvesting on landslide occurrence [81, 96, 97]; however, recent research conducted within the framework of the project GreenRisk4ALPs [98] also highlighted that an interpretation of statistical models must be done with great care [92], since widespread errors in the underlying input data may lead to distortions in the modeling results and a wrong inference on the causes of slope stability. For instance, a model based on land cover variables and landslide data that is incomplete in forested terrain is likely to underestimate the true stabilizing effect of the forest cover [99].

3.3.2 Physical models for landslide release: catchment scale

Spatial physical slope stability models are based on physical laws and formally allow to analyze causes and effects. Such models are frequently entitled the most advanced approaches to spatially assess slope instability [90]. Physical slope stability models calculate the ratio between stabilizing and destabilizing forces (i.e., factor of safety or probability of failure) for a planar sliding plane [100, 101] or non-planar shear surface [89], while the integration of dynamic components (e.g. hydrological modules) allows to trace the stability state over time. In theory, the (de)stabilizing effects of trees and/or forest cover on slope stability can be considered within such physical models by accounting for hydrological processes (e.g., evapotranspiration, canopy interception) and mechanical forces (e.g., cohesion, surcharge) [82, 102–105].

The high potential of physical models to elaborate causes of slope instability is seldomly questioned while recent technical advancements even allow to run these models efficiently for larger study areas [85]. In practice and especially when

evaluating the effects of vegetation on slope stability, the actual explanatory power of such analyses is restricted by a limited availability of geotechnical data and an appropriate spatio-temporal description of surface and subsurface biomass-related parameters (e.g., root system description, surcharge, evaporation) [82, 95, 106]. For instance, a detailed elaboration of the mechanical effects of roots (i.e., root reinforcement) requires additional area-wide information on potential slip surface depths, because anchoring becomes particularly relevant as soon as the roots penetrate the sliding plane. At the same time, sliding surfaces might not be equally distributed in space and be co-determined by prevalent soil depths and topography (e.g., slope angles). Further spatial information on species distribution, tree age and soil properties might be necessary to approximate root distribution (penetration depth) while geotechnical soil parameters are also known to influence the cohesion forces of a plant. Ultimately, this example also highlights that sophisticated physical models are a simplification of reality and challenging to parameterize, even for smaller and data-rich study sites [78, 84].

4. Protective forest modeling with the Flow-Py simulation tool

The Flow-Py simulation tool contains a GMF runout model for regional scales that allows users to customize GMF simulations by adjusting the parameterization or developing extensions to adapt the calculations, input data and outputs of the model [2, 5]. Flow-Py integrates a statistical model where the runout is solved by splitting the modeling question into two sub-questions, which are addressed in the two modeling routines:

1. The stopping routine: is a stopping criterion met?

2. The routing routine: if not, to where does the flux of the GMF (a portion of the mass flow) gets distributed?

The solver operates on a DEM by calculating the flux from one raster cell to the next until a stopping criterion is met. The cell-by-cell calculation results in the runout (magnitude) and intensity of the GMF without the need to predefine a flow path.

GMFs can flow very differently depending on the material of the mass [107]. Flow-Py overcomes this challenge by adapting the parameterization to fit the type of GMF being modeled using only four parameters: (1) runout angle, (2) divergence exponent, (3) flux cutoff, and (4) maximum kinetic energy height. The runout angel needs to be derived from observations and describes the average reach of the GMF measured from the top of the starting zone to the end of the furthest runout (**Figure 2**). The divergence exponent adjusts the concentration and spreading of flux across the terrain. The flux cutoff is a limit to describe the amount of flux needed to further propagate the GMF. Lastly, the maximum kinetic energy height limits the kinetic energy of the GMF, which is essentially a limit of the maximum velocity. Two criteria stop the flux, if (1) the simulated GMF runout reaches further than the predefined runout angle, and/or (2) the amount of mass, which is spreading across a slope, reaches a critical value that is required for further propagation. The routing routine calculates to which cell(s) the flux is distributed and uses the DEM to favor directions with steeper downward slopes, as well as persistence, which is similar to momentum but derived by statistical means and does not consider the GMF's mass (for further information and details see [2]).

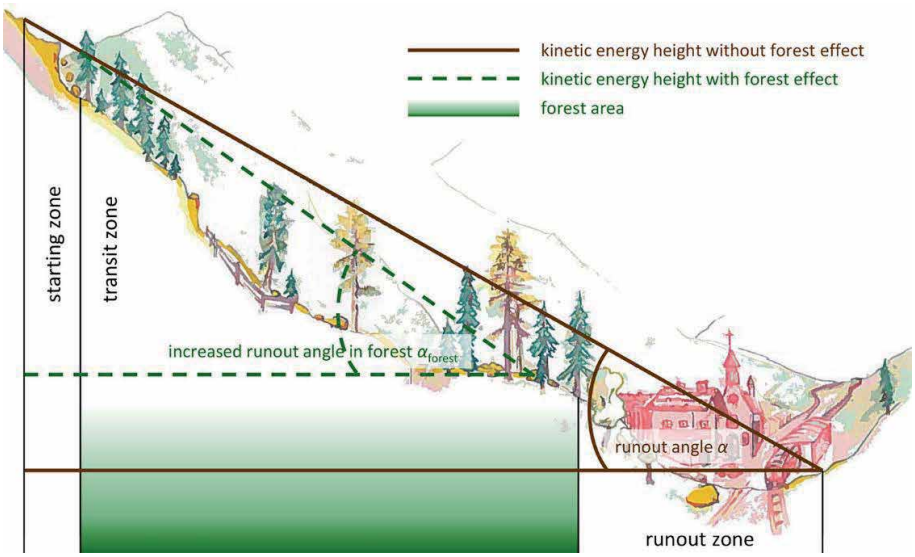


Figure 2.
The concept behind the forest extension. The solid brown lines indicate the runout length with α being the runout angle for a specific GMF. The dashed lines show the runout length with the forest being considered and α_{forest}, the runout angle in forested areas. Artwork: Karl Kleemayr.

To address specific questions regarding protective forest, we developed two custom extensions for Flow-Py to:

1. Identify locations of forests with an object protective function (back-tracking extension), and

2. Quantify their protective effect (forest extension).

From a modeling perspective these are two very different questions that generally require specific and significant adaptations of GMF runout models.

4.1 Identifying the location of forests with a protective function

The custom extension called "back-tracking" extension was implemented to adapt Flow-Py from a pure runout model to one that highlights the terrain associated with endangering infrastructures. Therefore, an additional input raster with the spatial distribution of infrastructure in the modeling domain is needed. Furthermore, minor changes must be implemented in the Flow-Py computer code, such that the path that the GMF traveled to reach the infrastructure is stored in computer memory.

4.2 Quantifying the protective effects of forests

To model the interactions between the movement of a GMF and forest, a custom "forest" extension was implemented in Flow-Py. The forest extension accounts for the increase in energy dissipation (or friction) in the parts of the GMF path that are located in forest by adjusting the runout angle to a steeper angle (**Figure 2**). The amount of change in the runout angle is dependent on the forested slope's length, the forest's structure and the kinetic energy height (relatable to velocity) of the GMF. That is, the forest extension adapts Flow-Py's runout-angle stopping criterion to account for the forest's ability to dissipate energy from GMFs.

To characterize the effect of different forest structures on the GMF movement, the forest extension uses the so-called forest structure index (FSI), which summarizes how developed a forest is with regards to its optimal protective effect and ranges between 0 (no protection) and 1 (optimal protection). The FSI needs to be provided as input for the Flow-Py simulation in form of a FSI forest raster. Because Flow-Py uses a statistical model, the parameterizations of forest-GMF interaction should ideally be based on observations quantifying the forest's protective effect. In absence of data on how forests interact with different GMFs, the parametrization was developed in this first model development cycle based on a literature review and can be further refined with future observations.

We developed and applied Flow-Py in the Interreg Alpine Space project GreenRisk4ALPs [98] to model forest's protective functions and effects on different GMFs. In the next subsections, the parameterizations established to model forest effects on rockfall, snow avalanches and shallow landslides using 10-m resolution raster (DEM and forest raster) will be presented. Since Flow-Py requires an already prepared starting zone raster as input, forest effects on avalanche and rockfall release were not explicitly considered. In terms of rockfall, we assumed that forest in the starting zone does not affect rockfall release. A method to quantify the relevance of the potential forest effect on the release of landslides has been developed as a pre-processing routine, which is an adaption to the input data showing the areas that are associated with potential landslide starting zones.

4.2.1 Modeling forest effects on rockfall propagation with Flow-Py

The recommended slope angle of ≥ 45° was used to identify rockfall release zones [108, 109]. The Flow-Py parameterization used to describe large single block rockfall can be found in **Table 1**.

The average energy loss along a rockfall trajectory can be modeled by friction parameters and is linear along a slope due to bouncing, rolling and sliding of falling rocks [111]. This linear relationship and normally distributed block stopping points along sections of the curve are displayed in **Figure 3**. The maximum increase to the runout angle due to forest is 13° (when FSI = 1 and kinetic energy height ~ 0), which leads to a maximum runout angle of 45° (mean runout angle of 32° + 13°). However, if the forest structure is not optimal the increase to runout angle is scaled to the FSI value (13° × FSI). That is, as the kinetic energy height increases, the less the protective effect of the forest. To incorporate this into the model the runout angle is reduced linearly by the kinetic energy height until the rock has a velocity of 30 m s^{-1}, which is well above 20 m s^{-1} that have been found for forest to have an influence on rockfall propagation [112]. The optimal protective forest for rockfall is a mixed or broad-leaved forest (FSI = 1) with a high stem density while dense evergreen forest has a slightly reduced effect (FSI = 0.8). We assume that at a rockfall

Parameter	Value
runout angle	32°
divergence exponent	75
flux cutoff	0.03% of the initial flux (0.0003 m)
velocity limit	50 m s^{-1} (maximum kinetic energy height ~ 130 m)

Table 1.
Flow-Py parameterization used to model large single block rockfall. The resulting behavior of the simulation is a single flow in steeper terrain and minimal spreading when the terrain flattens. The velocity limit keeps the speed of the rockfall in a range that has been observed in nature [32, 110].

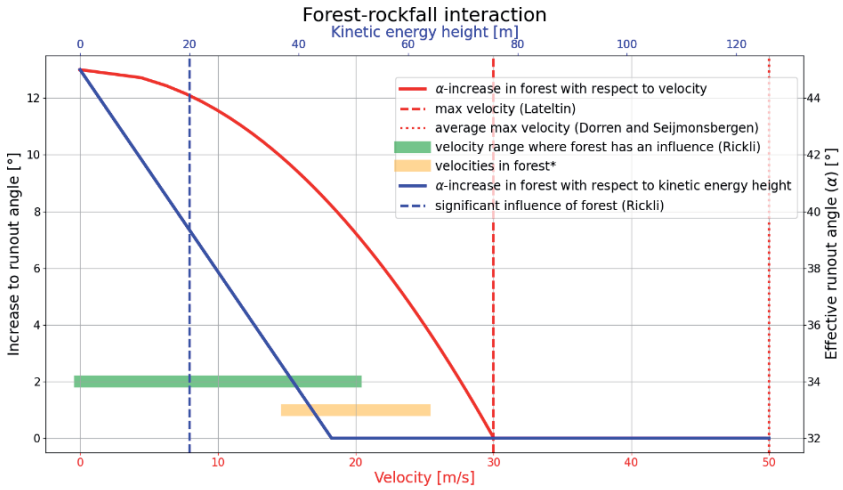


Figure 3.
*Relationship between rockfall velocity (lower x-axis, red line) and the amount of forest-rock interaction, which is expressed in an increase to the runout angle (left y-axis). The upper x-axis (blue line) shows the relationship between kinetic energy height and the amount of forest-rock interaction. The green and orange bars are velocity ranges where forest has been found to affect rockfall propagation (green [112]) or rockfall velocities measured in forests (orange, *[39, 108, 113–116]). The red dashed lines show measured rockfall velocities outside of forest [110, 117]. The blue dashed line shows that at 20 m kinetic energy height a forest can have a significant influence on the runout of a rockfall [112].*

velocity ≥ 30 m s^{-1} forest has no energy dissipating effect on a falling block (see **Figure 3** for justification).

4.2.2 Modeling forest effects on snow avalanches with Flow-Py

Avalanche starting zones were delineated based on a slope inclination ranging between 28° and 55°, which is most often applied to identify slab avalanche starting zones [20]. The parameterization used to describe large dry-snow slab avalanches with Flow-Py is given in **Table 2**. We applied a mean runout angle of 25°, which was determined from measurements of 89 documented large avalanche events in Austria [19]. The maximum kinetic energy height limit imposed keeps the speed of the avalanche in a range that has been observed in nature [118], and which can be thought of as describing the turbulent friction of the avalanche debris.

Similar to rockfall, we could not find publications addressing the relationship between avalanche kinetic energy height (or velocity) and the increase to the runout angle (energy dissipation) in forested terrain and, therefore, assumed a linear relationship (see **Figure 4** for justifications). The kinetic energy height

Parameter	Value
runout angle	25°
divergence exponent	8
flux cutoff	0.03% of the initial flux (0.0003 m)
velocity limit	70 m s^{-1} (maximum kinetic energy height ~ 250 m)

Table 2.
Flow-Py parameterization used to model large dry-snow slab avalanches. The resulting behavior of the simulation is a moderate spreading in steeper terrain and a more divergent flow in flat terrain.

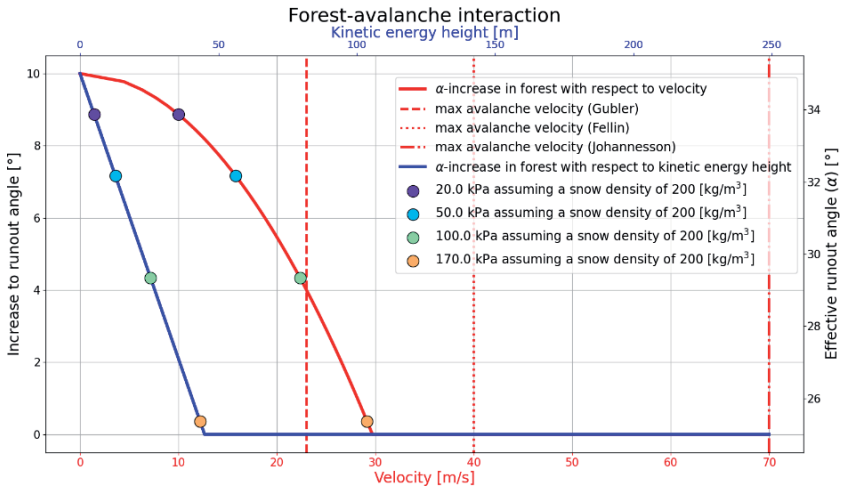


Figure 4.
Relationship between avalanche velocity (lower x-axis, red line), and the amount of forest-avalanche interaction, which is expressed in an increase to the runout angle (left y-axis). The upper x-axis (blue line) shows the relationship between kinetic energy height and the amount of forest-avalanche interaction. The dashed red lines show values of documented avalanche velocities [118–120]. Colored points are calculated velocities (and kinetic energy heights) based on the Swiss classification according to impact pressures and related damages [121].

is related to the square of the velocity which results in the relationship between the runout angle and velocity shown in red in **Figure 4**. The maximum increase to the runout angle in forest is 10° (when FSI = 1 and kinetic energy height ~ 0), which leads to a maximum runout angle of 35° (mean runout angle of 25° + 10°). However, if the forest structure is not optimal regarding avalanche protection the increase to the runout angle is scaled with the respective FSI value (10° × FSI). Furthermore, as the kinetic energy height increases the forest has less of a protective effect and, therefore, the runout angle is reduced linearly by the kinetic energy height until the avalanche has a velocity of 30 m s^{-1} (kinetic energy height ~ 105 m). This threshold is reasonable when compared to the Swiss classification according to avalanche impact pressures and potential damages [121], i.e., at 30 m s^{-1} an avalanche with a snow density of 200 kg m^{-3} would have an impact pressure of 170 kPa, which is a higher impact pressure than is needed to destroy large forest areas and uproot evergreen conifer trees. At a kinetic energy height of ~ 105 m (or velocity of 30 m s^{-1}) the forest is no longer capable of reducing the avalanches energy [51, 122].

An evergreen conifer forest with a high stem density and dense canopy cover (FSI = 1) can significantly reduce runout lengths of small-to-medium avalanches [47], where broad-leaved forest (FSI = 0.8) has a reduced effect as well as a forest with lower stem densities and less dense canopy cover, which needs to be reflected in the choice of FSI-values. The applied method of adjusting the runout angle not only accounts for increasing the energy dissipation in avalanche transit zones but also somewhat for forest effects in starting zones since the maximum runout angle increase in well-developed evergreen conifer forest is set to 10°, which leads to an effective runout angle of 35°. That is, applying an increase to the runout angle dependent on the FSI adjusts the starting zones in forests since an avalanche might not be released on forested slopes up to 35°, which is a conservative estimate for regional modeling and based on the assumption that small forest openings might still be present in forests growing in steep avalanche terrain [46, 52].

4.2.3 Modeling the relevance of potential forest effects on shallow landslides with Flow-Py

There are major differences between the protective forest model used for shallow landslides, and the one used for rockfall and snow avalanches. This is due to the lack of data and process understanding on how forest interacts with landslides (i.e., open hillslope debris flows) in the transit zone at the resolution and/or detail required for regional modeling (see chapter [3] of this book). We therefore assumed no forest effect in the transit and runout zones of landslides, but forest in the starting zones reduced the likelihood (probability) of landslide release. Flow-Py was then used to highlight locations on a slope and in the valley bottom that are being protected by reducing the landslide's release probability (the applied Flow-Py parameterization can be found in **Table 3**).

Landslide starting zone modeling was performed by building upon the principle 'the past is the key to the future'. A binary supervised classification algorithm was used to link past landslide locations and landslide-absence locations (topographically corrected random sample; > 50 m from past landslides) with a variety of topographical and thematic features (e.g., slope angle, topographic wetness index, relative topographic position, aspect, landform variables, and geology). The result is a raster that highlights potential landslide starting zones and breaks the areas down into likelihood categories based on how similar the areas are to past landslide release areas in the study region. This was done by a Generalized Additive Model that accounts for the previously observed non-linear relationships among landslide occurrence and the explanatory variables [81, 123]. The derived statistical model was applied to spatially predict the likelihood of class-membership of each raster cell that contains information on the environmental explanatory variables. This method of starting zone modeling is more sophisticated than that used for rockfall or snow avalanches; however, the applicability of this type of models is limited to the region of the input data and therefore is not a general model and not easily transferable to other locations.

The potential forest effect was considered at the level of the classified landslide release susceptibility (likelihood). Areas identified as favorable for landslide release (different classes) were grouped into forested terrain and non-forested terrain using a matrix-based approach. Areas susceptible to landsliding due to their topography and geology were considered more stable (without assigning a specific degree of stabilization) in case they were covered by forest compared to their non-forested counterparts. This builds upon the literature-supported assumption that stabilizing effects of trees usually outweigh destabilizing effects for shallow-seated landslide processes (e.g., [82, 96, 104, 124, 125]). Furthermore, we assumed that a forest located on a landslide-prone slope is more "relevant" compared to a forest on unsusceptible terrain (e.g., flat terrain or too steep terrain). For more details on how the forest effect on shallow landslide release was considered can be found in the GreenRisk4ALPs project report [126].

Parameter	Value
runout angle	22° [17]
divergence exponent	75 [18]
flux cutoff	0.03% of the initial flux (0.0003 m) [7]
maximum kinetic energy height	~ 12 m [7]

Table 3.
Flow-Py parameterization used to model large shallow-seated landslides. The resulting behavior is low spreading in steeper terrain and a more divergent flow when the terrain flattens.

4.3 Post-processing of Flow-Py simulation results for risk-based decision support

To locate protective forests or quantify their protective effects by reducing impacts of gravitational natural hazards on people and assets several post-processing steps of the Flow-Py simulation results are needed.

4.3.1 Forests with an object protective function

The workflow to identify forests with an object protective function is shown in **Figure 5** (see also subsection 4.1). The output of Flow-Py simulations with the back-tracking extension are spatially explicit subsets of the GMF starting, transit and runout zones that are associated with endangering infrastructure. A union between the back-tracking results and the spatial distribution of forested areas is then performed in a GIS resulting in a gridded dataset of forests with an object protective function, i.e., "Direct Object Protective Forest" for each hazard type. In chapter [1] of this book, we further explain these maps and discuss their use as decision support tool in risk-based protective forest and ecosystem-based risk management of natural hazards.

4.3.2 Forests' protective effects and regional impacts on gravitational natural hazards

The term protective effect describes the forest-GMF interaction, which we model with Flow-Py and its forest extension by increasing the runout angle in forested terrain. In contrast, we introduce the term forest impact(s) to describe how forest affects the spatial distribution or intensity of GMFs on a regional scale and their impacts on, e.g., infrastructure.

There are many types of forest impacts such as reductions in runout length, energy or mass of the GMF, or of its release probability, which can be quantified with different methods (see chapters [66, 127, 128] of this book). Within the GreenRisk4ALPs project, we developed the Impact Reduction Index (IRI), which shows the difference in average kinetic energy height between Flow-Py simulations with (employing the forest extension) and without forest effects. The post-processing workflow to calculate the IRI is outlined in **Figure 6**, and further examples and explanations of how the IRI can be applied for supporting decisions in protective forest and natural hazard risk management are provided in chapter [1] of this book.

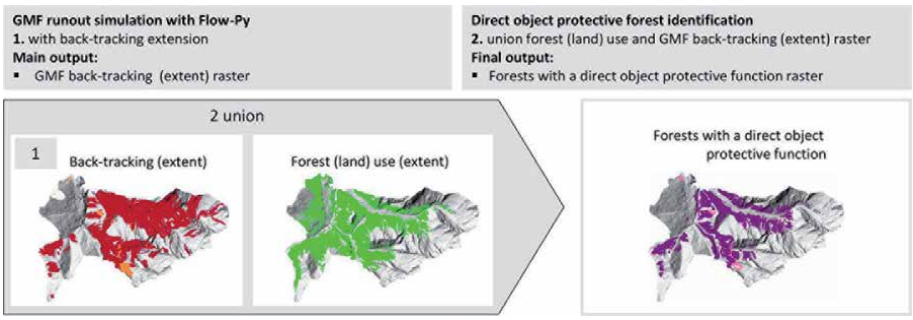


Figure 5.
Post-processing workflow to identify forests with an object protective function producing "Direct Object Protective Forest" maps.

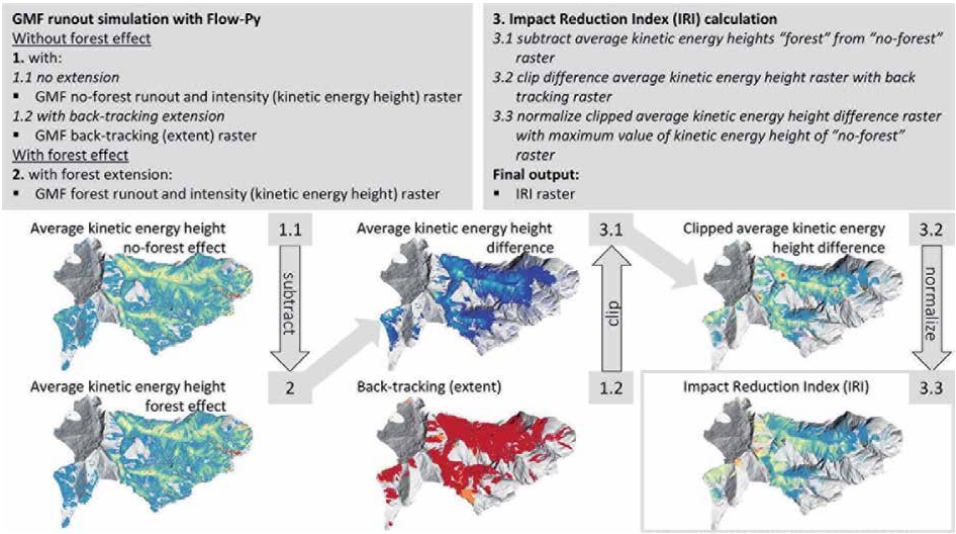


Figure 6.
Post-processing workflow to calculate the Impact Reduction Index (IRI). Adapted from [126].

It is important to note that several starting zones may route flux through the same forest area and, since the forest effect depends on the kinetic energy height (GMF velocity), the same forest area can have a high protective effect associated with one of these GMF starting zones but provide almost no protection for the others. To reflect this in the IRI, we normalized the difference in average kinetic energy height between Flow-Py simulations with and without forest effects with the maximum value of kinetic energy height of "no-forest" Flow-Py simulation results at a given location.

5. Conclusions

Models and simulation tools for gravitational natural hazards combine different bits of process understanding in a way that is useful for scientists and practitioners. The predictive power of protective forest models results from combining the state-of-the-art process understanding of GMFs with the state-of-the-art process understanding of forest-GMF interactions in one modeling approach. Knowledge about GMF processes and their interactions with forest can be derived by physical or statistical means; however, it is often a combination of both that is included in one model (e.g. [129]). By combining these model types scientist can quantify how well the current process understanding describes reality and practitioners can use GMF and protective forest models and their results as decision support tools. Examples of the results of modeling forests' protective functions and effects with Flow-Py that we described in this chapter, and which were obtained within the GreenRisk4ALPs project for rockfall, snow avalanches and landslides, as well as their application for decision support in natural hazard risk management are summarized in chapter [1] of this book. However, many of the presented parameterizations that were established in this first round of the model development cycle would benefit from further empirical parameter studies. The general lack of model parameterizations describing forest-GMF interactions is a major knowledge gap and should be addressed in future studies with the goal of obtaining a deeper process understanding that can be translated into enhanced parameterizations of, e.g., the four parameters that describe GMFs' behavior as well as the forest structure index (FSI) applied in Flow-Py.

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by Interreg Alpine Space, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy. We are grateful to the late Karl Kleemayr, who significantly contributed to the ideas behind the modeling of forest's protective effects with Flow-Py as well as to the development of the Impact Reduction Index (IRI).

Conflict of interest

The authors declare no conflict of interest.

Author details

Christopher James Laplante D'Amboise[1], Michaela Teich[1*], Anne Hormes[1], Stefan Steger[2] and Frédéric Berger[3]

1 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

2 Eurac Research, Institute for Earth Observation, Bolzano, BZ, Italy

3 National Research Institute for Agriculture, Food and Environment (INRAE), Université Grenoble Alpes, Grenoble, France

*Address all correspondence to: michaela.teich@bfw.gv.at

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise CJL, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[2] D'Amboise CJL, Neuhauser M, Teich M, Huber A, Kofler A, Perzl F, et al. Flow-Py v1.0: A customizable, open-source simulation tool to estimate runout and intensity of gravitational mass flows. Geosci Model Dev. 2022;**15**:2423-2439. DOI: 10.5194/gmd-15-2423-2022

[3] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

[4] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[5] Neuhauser M, D'Amboise CJL, Teich M, Kofler A, Huber A, Fromm R, et al. Flow-Py: routing and stopping of gravitational mass flows (Version 1.0). Zenodo; 2021. DOI: 10.5281/zenodo.5027275

[6] Lied K, Bakkehøi K. Empirical Calculations of Snow–Avalanche Run–out Distance Based on Topographic Parameters. J Glaciol. 1980;**26**(94):165-177. DOI: 10.3189/S0022143000010704

[7] Horton P, Jaboyedoff M, Rudaz B, Zimmermann M. Flow-R, a model for susceptibility mapping of debris flows and other gravitational hazards at a regional scale. Nat Hazards Earth Syst Sci. 2013;**13**(4):869-885. DOI: 10.5194/nhess-13-869-2013

[8] Keylock CJ, McClung DM, Magnússon MM. Avalanche risk mapping by simulation. J Glaciol. 1999;**45**(150):303-314. DOI: 10.3189/S0022143000001805

[9] Christen M, Kowalski J, Bartelt P. RAMMS: Numerical simulation of dense snow avalanches in three-dimensional terrain. Cold Reg Sci Technol. 2010;**63**(1-2):1-14. DOI: 10.1016/j.coldregions.2010.04.005

[10] Dorren LKA. Rockyfor3D (v5.2) revealed – Transparent description of the complete 3D rockfall model. ecorisQ paper (www.ecorisq.org). 2016. p. 33. Available from: www.ecorisq.org

[11] Barbolini M, Keylock CJ. A new method for avalanche hazard mapping using a combination of statistical and deterministic models. Nat Hazards Earth Syst Sci. 2002;**2**(3/4):239-245. DOI: 10.5194/nhess-2-239-2002

[12] Eckert N, Naaim M, Parent E. Long-term avalanche hazard assessment with a Bayesian depth-averaged propagation model. J Glaciol [Internet]. 2010;**56**(198):563-586. DOI: 10.3189/002214310793146331

[13] Perzl F, Teich M. Geodata requirements for mapping protective functions and effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99508

[14] Losey S, Wehrli A. Schutzwald in der Schweiz. Vom Projekt SilvaProtect-CH zum harmonisierten Schutzwald. Bern; 2013

[15] Giamboni M, Wehrli A. Improving the management of protection forests in Switzerland. The project SilvaProtect-CH. In: INTERPRAEVENT 2008 – Conference Proceedings, Vol 2. 2008. pp. 469-80

[16] Perzl F, Rössel M, Kleemayr K. PROFUNmap – Verbesserung der Darstellung der Österreichischen Wälder mit Objektschutzfunktion. Integration von Geodaten mit Aussagen über die Schutzfunktion des Waldes. Projektbericht V3 2019 im Auftrag des BMLRT. Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW). Institut für Naturgefahren, Innsbruck; 2019. Map accessible at: https://www.schutzwald.at/karten.html

[17] Perzl F, Rössel M, Lauss E, Neuhauser M. Mapping of protective function of forests in Austria against shallow landslides. In: Beyer Portner N, editor. 14th Congress INTERPRAEVENT 2021 May 31st to June 2nd 2021 Virtual Congress, Norway Conference Proceedings. Klagenfurt, Austria: International Research Society INTERPRAEVENT; 2021. p. 240-248. Available from: https://gyroconference.no/workspace/interpraevent/documents/IP_2021.pdf

[18] Perzl F, Rössel M, Lauss E. GRAVIMOD II. Erstellung von Grundlagen zur bundeseinheitlichen Ausweisung von Waldflächen mit Schutzfunktion vor Boden- und Felsrutschungen. Ergänzungsbericht: Validierung der Modellierung der Grunddisposition für spontane Hangrutschung. Projektbericht im Auftrag des Bundesministeriums für Landwirtschaft, Nachhaltigkeit und Tourismus (BMNT). Bericht Version B1 2019. BFW, Innsbruck; 2019

[19] Huber A, Kofler A, Fischer J-T, Kleemayr K. Projektbericht DAKUMO. Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW), Innsbruck; 2017

[20] Perzl F, Huber A. GRAVIPROFOR. Verbesserung der Erfassung der Schutzwaldkulisse für die forstliche Raumplanung. Synthese und Zusammenfassung: Ziele, Grundlagen und Ergebnisse der Modellierung von Waldflächen mit Lawinen- und Steinschlag-Objektschutzfunktion. Technische Hilfe im Rahmen des österreichischen Programms LE 07-13. Projektbericht V1. BFW, Innsbruck; 2014. Available from: https://gruenerbericht.at/cm4/jdownload/download/28-studien/1644-78-schutzwaldkulisse

[21] Huber A, Perzl F, Fromm R. Verbesserung der Beurteilung der Waldflächen mit direkter Objektschutzwirkung durch Modellierung von Massenbewegungsprozessen (GRAVIPROMOD). Projektbericht im Auftrag des BMLFUW. Bundesforschungszentrum für Wald (BFW), Innsbruck; 2015. Available from: https://gruenerbericht.at/cm4/jdownload/download/28-studien/1643-77-waldflaechen-objektschutzwirkung

[22] Jaboyedoff M, Dudt JP, Labiouse V. An attempt to refine rockfall hazard zoning based on the kinetic energy, frequency and fragmentation degree. Nat Hazards Earth Syst Sci. 2005;5(5):621-632. DOI: 10.5194/nhess-5-621-2005

[23] Lingua E, Bettella F, Pividori M, Marzano R, Garbarino M, Piras M, et al. The Protective Role of Forests to Reduce Rockfall Risks and Impacts in the Alps Under a Climate Change Perspective. In: Climate Change Management. Springer; 2020. pp. 333-347

[24] Poisel R. Felsstürze - Ablösemechanismen. Berichte der Geol Bundesanstalt. 2019;(125):49-58

[25] Volkwein A, Schellenberg K, Labiouse V, Agliardi F, Berger F, Bourrier F, et al. Rockfall characterisation and structural protection – a review. Nat Hazards Earth Syst Sci. 2011;**11**(9):2617-2651. DOI: 10.5194/nhess-11-2617-2011

[26] Loye A, Jaboyedoff M, Pedrazzini A. Identification of potential rockfall source areas at a regional scale using a DEM-based geomorphometric analysis. Nat Hazards Earth Syst Sci. 2009;**9**(5):1643-1653. DOI: 10.5194/nhess-9-1643-2009

[27] Dorren LKA, Domaas U, Kronholm K, Labiouse V. Methods for predicting rockfall trajectories and runout zones. In: Lambert S, editor. Rockfall engineering. London: John Wiley & Sons, Ltd; 2011. pp. 143-73

[28] Heim A. Bergsturz und Menschenleben. Zürich: Fretz & Wasmuth; 1932. 218 p

[29] Keylock C, Domaas U. Evaluation of Topographic Models of Rockfall Travel Distance for Use in Hazard Applications. Arctic, Antarct Alp Res. 1999;**31**(3): 312-320. DOI: 10.1080/15230430.1999.12003314

[30] Toppe R. Terrain models - A tool for natural hazard mapping. In: Avalanche formation, movement and effects (Proceedings of the Davos Symposium, September 1986). IAHS Publ. no. 162; 1987. p. 629-38. Available from: http://hydrologie.org/redbooks/a162/iahs_162_0629.pdf

[31] IRSTEA. Proposition d'une note technique à l'attention des Services Déconcentrés de l'Etat en charge des procédures PPRn. Méthodologie de l'élaboration du volet «aléa rocheux» d'un PPRn. 2014

[32] Dorren L, Berger F, Jonsson M, Krautblatter M, Mölk M, Stoffel M, et al. State of the art in rockfall – forest interactions. Schweizerische Zeitschrift für Forstwes. 2007;**158**(6):128-141. DOI: 10.3188/szf.2007.0128

[33] Berger F, Dorren LKA. Principles of the tool Rockfor.net for quantifying the rockfall hazard below a protection forest. Schweizerische Zeitschrift für Forstwes. 2007;**158**(6):157-165. DOI: 10.3188/szf.2007.0157

[34] Moos C, Dorren L, Stoffel M. Quantifying the effect of forests on frequency and intensity of rockfalls. Nat Hazards Earth Syst Sci. 2017;**17**(2):291-304. DOI: 10.5194/nhess-17-291-2017

[35] Quarteroni A. Modélisation statistique pour l'aide à la cartographie de l'aléa chute de blocs : Influence de la topographie du versant et du couvert forestier. AgroParisTech; 2017.

[36] Oswald V. Auswirkungen des Schutzwaldes auf Steinschlagmodellierungen in Vals: Sensitivitätsanalyse in Rockyfor3D und RAMMS::ROCKFALL. Leopold-Franzens-Universität Innsbruck; 2020

[37] Ruiz-Carulla R, Corominas J. Analysis of Rockfalls by Means of a Fractal Fragmentation Model. Rock Mech Rock Eng. 2020;**53**(3):1433-1455. DOI: 10.1007/s00603-019-01987-2

[38] Matas G, Lantada N, Corominas J, Gili J, Ruiz-Carulla R, Prades A. Simulation of Full-Scale Rockfall Tests with a Fragmentation Model. Geosciences. 2020;**10**(5):168. DOI: 10.3390/geosciences10050168

[39] Perret S, Dolf F, Kienholz H. Rockfalls into forests: Analysis and simulation of rockfall trajectories-considerations with respect to mountainous forests in Switzerland. Landslides. 2004;**1**(2). DOI: 10.1007/s10346-004-0014-4

[40] Dorren LKA, Berger F, Putters US. Real-size experiments and 3-D simulation of rockfall on forested and non-forested slopes. Nat Hazards Earth Syst Sci. 2006;**6**(1):145-153. DOI: 10.5194/nhess-6-145-2006

[41] Descoeudres F, Zimmermann T. Three-dimensional Dynamic Calculation of Rockfalls. In: 6th ISRM Congress, Montreal, Canada. 1987

[42] Guzzetti F, Crosta G, Detti R, Agliardi F. STONE: a computer program for the three-dimensional simulation of rock-falls. Comput Geosci. 2002;**28**(9):1079-1093. DOI: 10.1016/S0098-3004(02)00025-0

[43] Lan H, Derek Martin C, Lim CH. RockFall analyst: A GIS extension for three-dimensional and spatially distributed rockfall hazard modeling. Comput Geosci. 2007;**33**(2):262-279. DOI: 10.1016/j.cageo.2006.05.013

[44] Žabota B, Mikoš M, Kobal M. Rockfall Modelling in Forested Areas: The Role of Digital Terrain Model Grid Cell Size. Appl Sci. 2021;**11**(4):1461. DOI: 10.3390/app11041461

[45] Lu G, Caviezel A, Christen M, Bühler Y, Bartelt P. Modelling rockfall dynamics using (convex) non-smooth mechanics. In: Numerical Methods in Geotechnical Engineering IX. 1st ed. CRC Press; 2018. pp. 575-583

[46] Schneebeli M, Bebi P. Snow and Avalanche Control. Encycl For Sci. 2004:397-402

[47] Teich M, Bartelt P, Grět-Regamey A, Bebi P, Grêt-Regamey A, Bebi P. Snow Avalanches in Forested Terrain: Influence of Forest Parameters, Topography, and Avalanche Characteristics on Runout Distance. Arct Antarct Alp Res. 2012;**44**(4):509-519. DOI: 10.1657/1938-4246-44.4.509

[48] Bartelt P, Stöckli V. The influence of tree and branch fracture, overturning and debris entrainment on snow avalanche flow. Ann Glaciol. 2001;**32**:209-216. DOI: 10.3189/172756401781819544

[49] Anderson G, McClung D. Snow avalanche penetration into mature forest from timber-harvested terrain. Can Geotech J. 2012;**49**(4):477-484. DOI: 10.1139/t2012-018

[50] Takeuchi Y, Torita H, Nishimura K, Hirashima H. Study of large-scale dry slab avalanche and the extent of damage to a cedar forest in the Makunosawa valley, Myoko, Japan. Ann Glaciol. 2011;**52**(58):119-128

[51] Takeuchi Y, Nishimura K, Patra A. Observations and numerical simulations of the braking effect of forests on large-scale avalanches. Ann Glaciol. 2018**:**1-9. DOI: 10.1017/aog.2018.22

[52] Bebi P, Kulakowski D, Rixen C. Snow avalanche disturbances in forest ecosystems—State of research and implications for management. For Ecol Manage. 2009;**257**(9):1883-1892. DOI: 10.1016/j.foreco.2009.01.050

[53] Zurbriggen N, Nabel JEMS, Teich M, Bebi P, Lischke H. Explicit avalanche-forest feedback simulations improve the performance of a coupled avalanche-forest model. Ecol Complex. 2014;**17**(1):56-66. DOI: 10.1016/j.ecocom.2013.09.002

[54] Bühler Y, Von Rickenbach D, Stoffel A, Margreth S, Stoffel L, Christen M. Automated snow avalanche release area delineation-validation of existing algorithms and proposition of a new object-based approach for large-scale hazard indication mapping. Nat Hazards Earth Syst Sci. 2018;**18**(12):3235-3251. DOI: 10.5194/nhess-18-3235-2018

[55] Teich M, Bebi P. Evaluating the benefit of avalanche protection forest with GIS-based risk analyses-A case study in Switzerland. For Ecol Manage.

2009;**257**(9):1910-1919. DOI: 10.1016/j.foreco.2009.01.046

[56] Feistl T, Bebi P, Teich M, Bühler Y, Christen M, Thuro K, et al. Observations and modeling of the braking effect of forests on small and medium avalanches. J Glaciol. 2014;**60**(219):124-138. DOI: 10.3189/2014JoG13J055

[57] Feistl T. Vegetation effects on avalanche dynamics. Technische Universität München; 2015

[58] Brožová N, Fischer JT, Bühler Y, Bartelt P, Bebi P. Determining forest parameters for avalanche simulation using remote sensing data. Cold Reg Sci Technol. 2020;**172**:102976. DOI: 10.1016/j.coldregions.2019.102976

[59] Bühler Y, Kumar S, Veitinger J, Christen M, Stoffel A. Automated identification of potential snow avalanche release areas based on digital elevation models. Nat Hazards Earth Syst Sci. 2013;**13**(5):1321-1335. DOI: 10.5194/nhess-13-1321-2013

[60] Veitinger J, Stuart Purves R, Sovilla B. Potential slab avalanche release area identification from estimated winter terrain: A multi-scale, fuzzy logic approach. Nat Hazards Earth Syst Sci. 2016;**16**(10):2211-2225. DOI: 10.5194/nhess-16-2211-2016

[61] Maggioni M, Gruber U. The influence of topographic parameters on avalanche release dimension and frequency. Cold Reg Sci Technol. 2003;**37**(3):407-419. DOI: 10.1016/S0165-232X(03)00080-6

[62] Bebi P, Kienast F, Schönenberger W. Assessing structures in mountain forests as a basis for investigating the forests' dynamics and protective function. For Ecol Manage. 2001;**145**(1-2):3-14. DOI: 10.1016/S0378-1127(00)00570-3

[63] Gauer P. Avalanche probability: Slab release and the effect of forest cover. Proc Int Snow Sci Work 2018, Innbruck, Austria. 2018**:**76-83

[64] Stritih A, Bebi P, Grêt-Regamey A. Quantifying uncertainties in EO-based ecosystem service assessments. Environ Model Softw. 2019;**111**:300-310. DOI: 10.1016/J.ENVSOFT.2018.09.005

[65] McClung DM, Mears AI, Schaerer P. Extreme Avalanche Run-Out: Data from four Mountain Ranges. Ann Glaciol. 1989;**13**:180-184. DOI: 10.3189/S0260305500007850

[66] Stritih A. Dealing with uncertainties in the assessment of the avalanche protective effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99515

[67] D'Amboise CJL, Žabota B, Poratelli F, Pecan P, Plörer M, Accastello C, et al. A.T1.6 Construction of the innovative and new protective forest assessment tool (FAT). Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[68] Protective Forest Assessment Tool (FAT) [Internet]. Available from: https://gr4a.geocodis.com/

[69] Buser O, Frutiger H. Observed Maximum Run-Out Distance of Snow Avalanches and the Determination of the Friction Coefficients μ and ξ. J Glaciol. 1980;**26**(94):121-130. DOI: 10.3189/S0022143000010662

[70] Gubler H, Rychetnik J. Effects of forests near the timberline on avalanche formation. In: Bergmann H et al., editor. Snow, Hydrology and Forests in High Alpine Areas, Proceedings of the Vienna

Symposium, August 1991, IAHS Publications 205. Vienna, Austria; 1991. p. 19-37

[71] Salm B. Snow forces on forest plants. In: Mountain Forests and Avalanches IUFRO Working Party Snow and Avalanches Proceedings of the Davos Seminar September 1978: SFISAR. 1978. p. 157-81

[72] Voellmy A. Über die Zerstörungskraft von Lawinen. Schweizerische Bauzeitung. 1955;**73**(12):159-165. DOI: 10.5169/seals-61878

[73] Ancey C, Meunier M, Richard D. Inverse problem in avalanche dynamics models. Water Resour Res. 2003;**39**(4):1099. DOI: 10.1029/2002WR001749

[74] Salm B, Burkard A, Gubler HU. Berechnung von Fliesslawinen. Eine Anleitung für Praktiker mit Beispielen. Mitteilungen des Eidgenössischen Instituts für Schnee- und Lawinenforsch. 1990;(47):37

[75] Luong TH, Baker JL, Einav I. Spread-out and slow-down of granular flows through model forests. Granul Matter. 2020;**22**(1):1-10. DOI: 10.1007/s10035-019-0980-9

[76] Casteller A, Christen M, Villalba R, Martínez H, Stöckli V, Leiva JC, et al. Validating numerical simulations of snow avalanches using dendrochronology: the Cerro Ventana event in Northern Patagonia, Argentina. Nat Hazards Earth Syst Sci. 2008;**8**(3):433-443. DOI: 10.5194/nhess-8-433-2008

[77] Teich M, Fischer J-T, Feistl T, Bebi P, Christen M, Grêt-Regamey A. Computational snow avalanche simulation in forested terrain. Nat Hazards Earth Syst Sci. 2014;**14**(8): 2233-2248. DOI: 10.5194/nhess-14-2233-2014

[78] Corominas J, van Westen C, Frattini P, Cascini L, Malet J-P, Fotopoulou S, et al. Recommendations for the quantitative analysis of landslide risk. Bull Eng Geol Environ. 2014;**73**:209-263. DOI: 10.1007/s10064-013-0538-8

[79] Fell R, Corominas J, Bonnard C, Cascini L, Leroi E, Savage WZ. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. Eng Geol. 2008;**102**(3-4):85-98. DOI: 10.1016/j.enggeo.2008.03.022

[80] Glade T, Anderson M, Crozier MJ. Landslide hazard and risk: Issues, Concepts and Approach. Chichester: John Wiley & Sons, Ltd; 2005

[81] Goetz JN, Guthrie RH, Brenning A. Forest harvesting is associated with increased landslide activity during an extreme rainstorm on Vancouver Island, Canada. Nat Hazards Earth Syst Sci. 2015;**15**(6):1311-1330. DOI: 10.5194/nhess-15-1311-2015

[82] Schmaltz EM, Van Beek LPH, Bogaard TA, Kraushaar S, Steger S, Glade T. Strategies to improve the explanatory power of a dynamic slope stability model by enhancing land cover parameterisation and model complexity. Earth Surf Process Landforms. 2019;**44**(6):1259-1273. DOI: 10.1002/esp.4570

[83] Vorpahl P, Elsenbeer H, Märker M, Schröder B. How can statistical models help to determine driving factors of landslides? Ecol Modell. 2012;**239**:27-39. DOI: 10.1016/j.ecolmodel.2011.12.007

[84] van Westen CJ, Castellanos E, Kuriakose SL. Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview. Eng Geol. 2008;**102**(3-4):112-131. DOI: 10.1016/j.enggeo.2008.03.010

[85] Alvioli M, Baum RL. Parallelization of the TRIGRS model for

rainfall-induced landslides using the message passing interface. Environ Model Softw. 2016;**81**:122-135. DOI: 10.1016/j.envsoft.2016.04.002

[86] Wichmann V. The Gravitational Process Path (GPP) model (v1.0) - A GIS-based simulation framework for gravitational processes. Geosci Model Dev. 2017;**10**(9):3309-3327. DOI: 10.5194/gmd-10-3309-2017

[87] Mergili M, Fischer J-T, Krenn J, Pudasaini SP. r.avaflow v1, an advanced open-source computational framework for the propagation and interaction of two-phase mass flows. Geosci Model Dev. 2017;**10**(2):553-569. DOI: 10.5194/gmd-10-553-2017

[88] Mergili M, Krenn J, Chu H-J. r.randomwalk v1, a multi-functional conceptual tool for mass movement routing. Geosci Model Dev. 2015;**8**(12):4027-4043. DOI: 10.5194/gmd-8-4027-2015

[89] Mergili M, Marchesini I, Alvioli M, Metz M, Schneider-Muntau B, Rossi M, et al. A strategy for GIS-based 3-D slope stability modelling over large areas. Geosci Model Dev. 2014;7(6):2969-2982. DOI: 10.5194/gmd-7-2969-2014

[90] Cascini L. Applicability of landslide susceptibility and hazard zoning at different scales. Eng Geol. 2008;**102**(3-4):164-177. DOI: 10.1016/j.enggeo.2008.03.016

[91] Van Rompaey AJJ, Govers G. Data quality and model complexity for regional scale soil erosion prediction. Int J Geogr Inf Sci. 2002;**16**(7):663-680. DOI: 10.1080/13658810210148561

[92] Steger S, Mair V, Kofler C, Pittore M, Zebisch M, Schneiderbauer S. Sci Total Environ. 2021;**776**:145935. DOI: 10.1016/j.scitotenv.2021.145935

[93] Lombardo L, Opitz T, Ardizzone F, Guzzetti F, Huser R. Space-time landslide predictive modelling. Earth-Science Rev. 2020;**209**:103318. DOI: 10.1016/j.earscirev.2020.103318

[94] Heckmann T, Gegg K, Gegg A, Becht M. Sample size matters: investigating the effect of sample size on a logistic regression susceptibility model for debris flows. Nat Hazards Earth Syst Sci. 2014;**14**(2):259-278. DOI: 10.5194/nhess-14-259-2014

[95] de Lima Neves Seefelder C, Koide S, Mergili M. Does parameterization influence the performance of slope stability model results? A case study in Rio de Janeiro, Brazil. Landslides. 2017;**14**(4):1389-1401. DOI: 10.1007/s10346-016-0783-6

[96] Schmaltz EM, Steger S, Glade T. The influence of forest cover on landslide occurrence explored with spatio-temporal information. Geomorphology. 2017;**290**:250-264. DOI: 10.1016/j.geomorph.2017.04.024

[97] Reichenbach P, Busca C, Mondini AC, Rossi M. The Influence of Land Use Change on Landslide Susceptibility Zonation: The Briga Catchment Test Site (Messina, Italy). Environ Manage. 2014;**54**(6):1372-1384. DOI: 10.1007/s00267-014-0357-0

[98] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

[99] Steger S, Brenning A, Bell R, Glade T. The influence of systematically incomplete shallow landslide inventories on statistical susceptibility models and suggestions for improvements. Landslides. 2017;**14**(5):1767-1781. DOI: 10.1007/s10346-017-0820-0

[100] Montgomery DR, Dietrich WE. A physically based model for the topographic control on shallow landsliding. Water Resour Res.

1994;**30**(4):1153-1171. DOI: 10.1029/93WR02979

[101] Baum RL, Savage WZ, Godt JW. TRIGRS – A Fortran Program for Transient Rainfall Infiltration and Grid Based Regional Slope Stability Analysis, Open file report 02-424. Denver, CO; 2002

[102] Schwarz M, Cohen D, Or D. Spatial characterization of root reinforcement at stand scale: Theory and case study. Geomorphology. 2012;**171-172**:190-200. DOI: 10.1016/j.geomorph.2012.05.020

[103] Van Beek LPH, Van Asch TW. Regional Assessment of the Effects of Land-Use Change on Landslide Hazard By Means of Physically Based Modelling. Nat Hazards. 2004;**31**(1):289-304. DOI: 10.1023/B:NHAZ.0000020267.39691.39

[104] Sidle RC, Ochiai H. Landslides: processes, prediction, and land use. Water Reso 18. Washington, DC: American Geophysical Union; 2006. DOI: 10.1029/WM018

[105] Moos C, Bebi P, Graf F, Mattli J, Rickli C, Schwarz M. How does forest structure affect root reinforcement and susceptibility to shallow landslides? Earth Surf Process Landforms. 2016;**41**(7):951-960. DOI: 10.1002/esp.3887

[106] Kuriakose SL, van Beek LPH, van Westen CJ. Parameterizing a physically based shallow landslide model in a data poor region. Earth Surf Process Landforms. 2009;**34**(6):867-881. DOI: 10.1002/esp.1794

[107] Pudasaini SP, Mergili M. A Multi-Phase Mass Flow Model. J Geophys Res Earth Surf. 2019;**124**(12):2920-2942. DOI: 10.1029/2019JF005204

[108] Gsteiger P. Steinschlagschutzwald. Ein Beitrag zur Abgrenzung, Beurteilung und Bewirtschaftung. Schweizerische Zeitschrift für Forstwes. 1993;**144**(2):115-132

[109] Mölk M, Rieder B. Rockfall hazard zones in Austria. Experience, problems and solutions in the development of a standardised procedure. Geomech Tunn. 2017;**10**(1):24-33. DOI: 10.1002/geot.201600065

[110] Dorren LK., Seijmonsbergen AC. Comparison of three GIS-based models for predicting rockfall runout zones at a regional scale. Geomorphology. 2003;**56**(1-2):49-64. DOI: 10.1016/S0169-555X(03)00045-X

[111] Jaboyedoff M, Pedrazzini A. The usefulness of the reach angle concept for hazard zoning using statistical approach. In: EGU General Assembly Conference Abstracts. Vienna, Austria; 2010. p. 5409. Available from: https://ui.adsabs.harvard.edu/abs/2010EGUGA..12.5409J/abstract

[112] Rickli C, Graf F, Gerber W, Frei M, Böll A. Der Wald und seine Bedeutung bei Naturgefahren geologischen Ursprungs. Forum für Wissen. 2004:27-34

[113] Jahn J. Deforestation and Rockfall. In: Internationales Symposium INTERPRAEVENT 1988 - Graz Tagugspublikation, Band 1. 1988. pp. 185-98

[114] Zinggeler A. Steinschlagsimulation in Gebirgswäldern: Modellierung der relevanten Teilprozesse. 1990

[115] Doche O. Etude expérimentale de chutes de blocs en forêt. 1997

[116] Dorren LK., Maier B, Putters US, Seijmonsbergen AC. Combining field and modelling techniques to assess rockfall dynamics on a protection forest hillslope in the European Alps. Geomorphology. 2004;**57**(3-4):151-167. DOI: 10.1016/S0169-555X(03)00100-4

[117] Lateltin O, Beer C, Raetzo H, Caron C. Landslides in Flysch terranes of Switzerland: Causal factors and climate change. Eclogae Geol Helv. 1997;**90**(3):401-406

[118] Johannesson T, Gauer P, Issler D, Lied K. The design of avalanche protection dams: recent practical and theoretical developments. Project Reports EUR23339. Brussels: European Communities; 2009

[119] Gubler HU. Measurements and modelling of snow avalanche speeds. IAHS Publ. 1987;(162):405-420

[120] Fellin W. Einführung in Eis-, Schnee- und Lawinenmechanik. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg; 2013. DOI: 10.1007/978-3-642-25962-3

[121] Rapin F. A new scale for avalanche intensity. In: Proceedings of the International Snow Science Workshop (2002, Pentincton, BC). 2002. p. 103-10. Available from: https://arc.lib.montana.edu/snow-science/objects/issw-2002-090-096.pdf

[122] Feistl T, Bebi P, Christen M, Margreth S, Diefenbach L, Bartelt P. Forest damage and snow avalanche flow regime. Nat Hazards Earth Syst Sci. 2015;**15**(6):1275-1288. DOI: 10.5194/nhess-15-1275-2015

[123] Petschko H, Brenning A, Bell R, Goetz J, Glade T. Assessing the quality of landslide susceptibility maps – case study Lower Austria. Nat Hazards Earth Syst Sci. 2014;**14**(1):95-118. DOI: 10.5194/nhess-14-95-2014

[124] Crozier MJ. Landslides: causes, consequences & environment. London: Taylor & Francis; 1989

[125] Bathurst JC, Bovolo CI, Cisneros F. Modelling the effect of forest cover on shallow landslides at the river basin scale. Ecol Eng. 2010;**36**(3):317-327. DOI: 10.1016/j.ecoleng.2009.05.001

[126] Cocuccioni S, Renner K, Steger S, D'Amboise C, Hormes A, Plörer M, et al. D.T3.2.1 Report on "Preparation for risk analysis and strategy workshops". Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[127] Bebi P, Bast A, Helzel KP, Schmucki G, Brožová N, Bühler Y. Avalanche protection forest: from process knowledge to interactive maps. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99514

[128] Moos C, Dorren LKA. Cost-benefit analysis as a basis for risk-based rockfall protection forest management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99513

[129] Zgheib T. Trajectories of avalanche risk resulting from socio-environmental changes in the high valleys of the French Alps. Université Grenoble Alpes; 2021. Available from: https://tel.archives-ouvertes.fr/tel-03231395/document

Chapter 8

Influence of Canopy Disturbances on Runoff and Landslide Disposition after Heavy Rainfall Events

Christian Scheidl, Micha Heiser, Sebastian Kamper, Thomas Thaler, Werner Rammer, Rupert Seidl, Klaus Klebinder, Veronika Lechner, Fabian Nagl, Bernhard Kohl and Gerhard Markart

Abstract

As protective forests have a major control function on runoff and erosion, they directly affect the risk from hydrogeomorphic processes such as sediment transport processes or debris flows. In this context, future scenarios of climate-related canopy disturbances and their influence on the protective effect remain, however, an unsolved problem. With the individual-based forest landscape and disturbance model iLand, an ensemble of forest landscape simulations was carried out and the effects of future changes in natural disturbance regimes were evaluated. To determine peak runoff, hydrological simulations have been conducted, using the conceptual hydrological model ZEMOKOST as well as the deterministic model GEOtop. Effects of forest disturbances on hillslope stability were investigated, based on a modified Coulomb landslide model. Our results suggest no influence of the disturbance regime on the runoff. The climate-related increase in the frequency of disturbances is not reflected in increased runoff during the period under consideration. Contrary, slope stability analyses indicate that the availability of shallow landslides in steep forested torrent catchments might be decreased by the occurrence of disturbances – especially for a warm and dry climate projection. Canopy disturbances seem to accelerate the adaptation of tree species to future climate conditions, which is likely to be accompanied by a change in root systems away from flat roots that currently predominate in torrential catchments. In terms of managing the protective effect of forests against shallow landslides, such natural disturbances can thus be considered as positive interventions in the existing forest ecosystem by promoting natural succession.

Keywords: canopy disturbance, runoff, hillslope stability, torrential catchment, protective forest

1. Introduction

Quantitative risk assessment of natural hazards serves nowadays as the basis for a targeted risk management, respectively allows a risk-based classification and communication of the considered hazardous event in society [1, 2] (see also chapter [3] of this book). One of the most important and pervasive problems in this context concerns the investigation of time-scale properties and complex relationships between process activity, social development (exposure, protection measures, land use, etc.) and climate change. The correct understanding of the correlation structures governing observational time series might provide useful information on the dynamical features of natural hazard processes and on the dynamical mechanisms involved [4].

Steep headwater catchments typically provide the setting for such natural hazardous events because they are, besides being a drainage area for precipitation (see chapter [5] of this book), also sediment source zones of river systems, delivering significant volumes of sediment to the valley floor in highly dissected and coupled landscapes. As stated by Gomi and Sidle [6], headwater catchments differ from down-stream reaches by their close coupling to hillslope processes, more temporal and spatial variation, and their need for different means of protection from land use. Especially processes, which are capable to relocate a considerable quantity of sediments, like bedload transport processes, debris floods or debris flows, often have tragic consequences on human settlements and infrastructures. Thus, for such hydrogeomorphic hazards the probability of occurrence and magnitude is beside the occurrence of critical rainfall events essentially a function of runoff and erosion which is, however, directly coupled to the protective effects of forested landscapes. In connection with frequently occurring natural hazard processes, protective forests, even if they currently only fulfill indirect protective effects, represent an essential factor in the risk reduction of natural hazard processes over long periods of time – on large potential natural hazard disposition areas. Today, about 30% of the forest area in Austria is assigned a protective function to avoid serious natural hazards, and according to the interim evaluation of the Austrian Forest Inventory, this share is increasing [7]. However, the same inventory data show that only half of such classified protective forests have a stable structure. The reasons for this are a significant aging of the Austrian protective forest stands due to a lack of natural regeneration and a lack of resistance to natural disturbances. This concerns climate-related forest disturbances such as forest fires, wind, and insect outbreaks, which will likely increase in the coming decades. Here, climate change can alter the frequency, intensity, duration and timing of such natural disturbances [8, 9]. Based on data of more than 10,000 torrent catchment areas in Austria [10], showed that natural disturbances increased the probability of torrential events in the last 32 years. With the expected increase of the global average surface temperature of 3–5°C by 2100, compared to the first decade of the 20th century, the spatial and temporal impact of climate change on forests represents an additional threat to the desired protective forest structures and thus to natural hazard management.

The aim of this research was to investigate the effects of climate-induced natural disturbance regimes (bark beetle or storm damage) on hydrogeological processes in forested alpine torrent catchments. Combining methods from forestry, hydrology and geotechnical engineering, an integral approach was chosen to analyze possible effects of natural disturbances on hydrogeomorphic hazards in the perspective of future protective forest developments. This work was carried out in the course of the project "PROTECTED" funded by the Austrian Climate Research Program. The chapter presents hydrological findings as well as a brief summary of geotechnical findings as described in [11].

2. Runoff and landslide simulations in forested headwater catchments affected by canopy disturbances

To analyze the impact of future change, an ensemble of forest landscape simulations has been conducted in two steep headwater catchments located in the Stubai valley, Tyrol, Austria. With the "Innerer Lehnertalbach" (IL) and the "Äußere Lehnertalbach" (AL) two typical torrential catchments with high relief energy (Melton ratio for IL = 1.3; Melton ratio for AL = 1.2, cf. [12]) have been chosen. Both catchments are situated in ecoregion 1.2 (Subkontinentale Innenalpen-West), dominated by metamorphic lithologies (mainly Gneiss). They are a typical example of mountain forest ecosystems of the central Alps, dominated by Norway spruce (*Picea abies* (L.) Karst.), European larch (*Larix decidua* L.) and Swiss stone pine (*Pinus cembra* L.). An overview of the catchment area characteristics is shown in **Table 1**.

2.1 Climate and precipitation scenarios

In order to cover the widest possible range of future climate scenarios, four different climate forecasts have been selected, based on three global models from the Irish Center for High-End Computing (ichec), the Pierre Simon Laplace Institute (ipsl) and the MetOffice Hadley Center (mohc). All three global models (ichec, ipsl, mohc) have been operated with the RCP 8.5 scenario – assuming a very high gain of energy (8.5 W/m^2) caused by future climate change. The global model ichec, however, was additionally operated with a moderate, RCP 4.5, climate perspective (4.5 W/m^2). The temperature and precipitation differences of the Eur-11 dataset for the period 2071–2100 compared to 1981–2010 are shown in **Figure 1**. All mean air temperatures increase in comparison to 1981–2010. Of the climate predictions used, only mohc8.5 shows negative precipitation trends. In addition to the climate forecast scenarios, forest landscape simulations are further driven by assuming no climate change and a future climate development aligned with historic climate data. This climate scenario is denoted as historic and results for the period from 1961 to 2015 from combined 1x1 km INCA and SPARTACUS, grid data of the Central Institute for Meteorology and Geodynamics (ZAMG) and observation series of ZAMG weather stations, as well as locally installed monitoring stations.

For each of the climate forecast scenarios, forest landscape development was simulated for 200 years with the individual-based forest landscape and disturbance model (iLand) [13]. Disturbance events have been stochastically considered based on 20 replicates, while we considered the non-disturbance landscape to be based on one replicate. Further, all iLand simulations were additionally conducted with and without considering forest management activities. Thus, in total 210 landscape simulations have been performed.

Parameters	"Innerer Lehnertalbach"	"Äußerer Lehnertalbach"
Area [km^2]	4.8	1.3
Min. elevation [m a.s.l]	1,043	1,037
Max. elevation [m a.s.l]	2,094	2,480
Mean slope gradient [°]	34	36
Forest cover [%]	83	36

Table 1.
Catchment area characteristics of the "Innere-" and "Äußere Lehnertalbach".

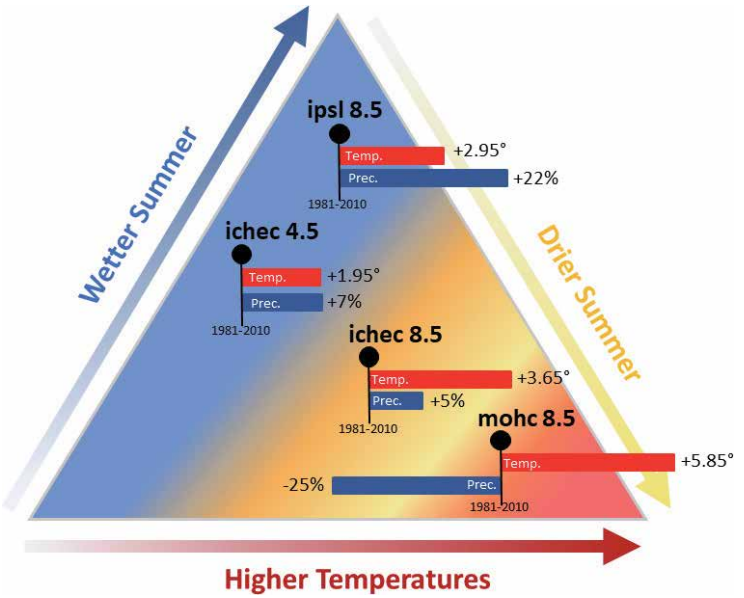


Figure 1.
Used climate forecasts based on the EUR-11 dataset as average temperature and precipitation difference of the period 2071–2100 compared to 1981–2010 (summer).

Duration [min]	Precipitation intensities [mm/h]	
	"Innerer Lehnertalbach"	"Äußerer Lehnertalbach"
60	88.85	94.65
240	130.10	138.39
720	178.56	180.26

Table 2.
eHYD design precipitation values based on a 100-year recurrence interval for the selected catchments.

Three precipitation events of varying duration (60 min, 240 min and 720 min) with a recurrence interval of 100 years have been defined, covering a wide range of information about the hydrological response of disturbances in forests. The design precipitation events result from the area-averaged, maximized precipitation (MaxModN, eHYD) of grid points close to the selected torrential catchments. Design precipitation probabilities of MaxMod are based on a simulation model calibrated with measured data and accounting for the topography. MaxModN gives precipitation values that are usually higher than those observed (**Table 2**).

2.2 Runoff simulations

The runoff simulations in the study area were performed with two, conceptually different, hydrological modeling approaches.

For the selected torrential catchments, like for nearly 96% of all torrential catchments in Austria, no information about past rainfall-runoff events exists. This is mainly because of the lack of continuous discharge measurements devices (water gauges). For this reason, runoff simulations have been performed with the precipitation/runoff (P/R) model ZEMOKOST [14] – an easy to apply event-based concept-model, specially developed for the application in small to medium-sized (< 100 km^2) ungauged torrential catchments. The semi distributed model is based

on a two-layer concept with a surface and a subsurface runoff module. ZEMOKOST needs the portions of surface runoff classes (RC_{const}) and surface roughness (c) classes for each sub-catchment (see chapter [5] of this book). The main parameters, runoff coefficient (RC_{const}) and surface roughness (c), have been investigated, following the code of practice developed by [15]. Actual site characteristics (vegetation, soil) were mapped in the field to ensure realistic assessment of runoff characteristics. In this context, vegetation in ZEMOKOST is primarily considered on the basis of its hydrologic vegetation characteristics, i.e., forest vegetation and dwarf shrub cover versus woody free vegetation. ZEMOKOST was then calibrated and checked for plausibility for the test-catchments using the existing precipitation and discharge time series and data from historic events.

Runoff simulations have additionally been carried out with the physically based, grid-distributed hydrological program GEOtop 2.1. Such models account beside surface flow also for subsurface (or inter) flow and groundwater related effects, important phenomena when simulating soil erosion activity. In GEOtop, land use is made up of vegetation classes consisting of a non-arable and differently forested groups. The individual groups do not represent any particular tree species, but result from units of similar vegetation height, leaf area, canopy coverage and root depth, directly determined by iLand simulations. Surface runoff in the channel and along the hillslopes are determined by Manning's empirical hydraulic approach. Since the runoff regime in forests is determined primarily by forest soil conditions, the interaction with the lithosphere is of high importance, described by soil physical parameters. In addition to the topographical data, pedological data add differences in depth, so-called horizons. Each type of soil consists of different soil horizons. Each soil horizon is characterized by its physical properties (soil texture data). The storage and conductivity of the individual horizons is given by the water content at wilting point, field capacity and saturation, as well as the conductivity at saturation and determined by means of pedotransfer functions proposed by [16] on their sand and clay content. The conductivity in the unsaturated soil matrix is calculated by van Genuchten values (α, n). Those values can be determined according to [17] by classifying the soil texture according to United States Department of Agriculture (USDA).

Finally, GEOtop runoff results have been validated with the runoff results proposed by ZEMOKOST, where it has been found that the drainage roughness has a significant impact. **Figure 2** shows a calibration example of the "Äußere Lehnertalbach" for GEOtop simulations based on a sensitivity analyses of varying hydraulic roughness parameters (40 simulations), compared to ZEMOKOST simulations for a 100-year precipitation event of the duration levels 60, 240 and 720 min. The solid line corresponds to the calibrated GEOtop simulation.

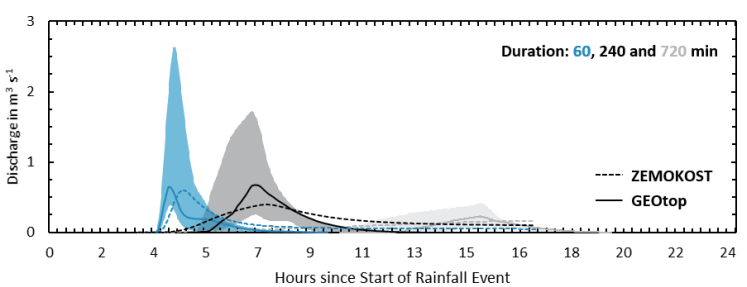


Figure 2.
Validation of GEOtop based on ZEMOKOST simulations for a 100-year precipitation event of the duration levels 60, 240 and 720 min at the "Äußere Lehnertalbach". While the shaded area contains all simulated hydrographs, the solid line represents the hydrograph of the calibrated model.

For future runoff predictions of peak discharges, simulated with both hydrological models, varying land use conditions were provided by the pre-conducted number of iLand simulations of the selected catchments – resulting in multiple runoff simulation scenarios.

For future ZEMOKOST simulations the parameters RC_{const} and c are calculated from iLand outputs. In order to derive RC_{const}, pedohydrological reaction units were mapped in the field. Six different units have been characterized. Considering the iLand outputs canopy cover, ground cover and soil water content, RC_{const} is given as an output for the different reaction units. Each c value is assigned a range of iLand output values per parameter on basis of [15]. For an iLand output parameter set the best fit c value is selected.

GEOtop simulations have been based on the biosphere mapped via land use parameters. The land use is formed by vegetation classes, consisting of non-vegetated and differently forested groups. The individual groups do not represent a specific tree species, but result from units of similar vegetation height, soil roughness, leaf area, canopy cover and root depth, which were determined via iLand.

2.3 Slope stability simulations

Simulations of the effect of forest disturbances on hillslope erosion processes are based on the results from the distributed runoff simulations of GEOtop in combination with an extended version of the Mohr-Coulomb soil stability model. The stability of each soil column – 1 m in depth with an area of 100 m^2 – i.e. each cell in the study area, was subsequently estimated for each layer l for simulation i at time t according to Eq. (1).

$$FS_i(l,t) = \frac{B + \left(A - \sum_{k=1}^{l} h(k) * m_i(k,t)\right) * \frac{tan\,(\phi(l))}{tan\,(\beta)}}{A} \tag{1}$$

where $FS_i(l,t)$ is the factor of safety for a specific soil column in the study area under simulation i for its layer l, with values below 1 indicating that the soil column is instable at the depth of layer l and time t. $h(k)$ is the depth of layer k, $m_i(k,t)$ the saturation of layer k at time t, as given by Eq. (3), $\phi(l)$ is the internal angle of friction of layer l in rad and β is the slope angle of the soil column in rad. In Eq. (1), A equals to the normal stress resulting from the soil and plant weight reduced by the pore water pressure and was derived by means of Eq. (2).

$$A = \gamma_w^{-1} * \left(q_i + \sum_{k=1}^{l} h(k) * [m_i(k,t) * (\gamma_{sat}(k) - \gamma(k)) + \gamma(k)]\right) \tag{2}$$

where γ_w is the specific weight of water in kNm^{-3}, q_i is the additional pressure due to the weight of the vegetation in Pa, $h(k)$ is the depth of layer k in m, $m_i(k,t)$ is the saturation of layer k for simulation i given by Eq. (3):

$$m_i(k,t) = \frac{\theta_i(k,t)}{\theta_{sat}(k)} \tag{3}$$

where $\theta_i(k,t)$ is the soil water content of layer k at the time t for simulation i and $\theta(k)$ is the saturated water content of layer k, $\gamma_{sat}(k)$ is the specific weight of the saturated soil of layer k in kNm^{-3}, $\gamma(k)$ and is the specific weight of the dry soil of layer k in kNm^{-3}.

The cohesion component of the resisting forces was estimated according to Eq. (4).

$$B = \frac{2 * (C_s(l) + C_{r,i}(l))}{\gamma_w \sin(2\beta)} \tag{4}$$

where $C_s(l)$ is the soil cohesion of layer l in Pa, $C_{r,i}(l)$ is the root cohesion of layer l for simulation i in Pa, γ_w is the specific weight of water in kNm^{-3} and β is the slope angle of the soil column in rad.

A detailed description of the geotechnical parameterization as well as the parametrization of root cohesion and vegetation weight can be found in [11].

3. Future possible tendencies of canopy disturbances show no significant influence on runoff after heavy rainfall events

The variability of the peak discharge, resulting from the presence of natural disturbances within the forested area, is given by the relative peak discharge change $\Delta Q_j(t,d)$ for each climate scenario j, with specific precipitation duration d and time frame t. Accounting for disturbance effects per applied climate scenario, $\Delta Q_{j,i}(t,d)$ is estimated based on the ratio between the peak discharge of the i-th replicant of the climate change scenario j considering disturbance effects $Q^1_{j,i}(t,d)$, with the

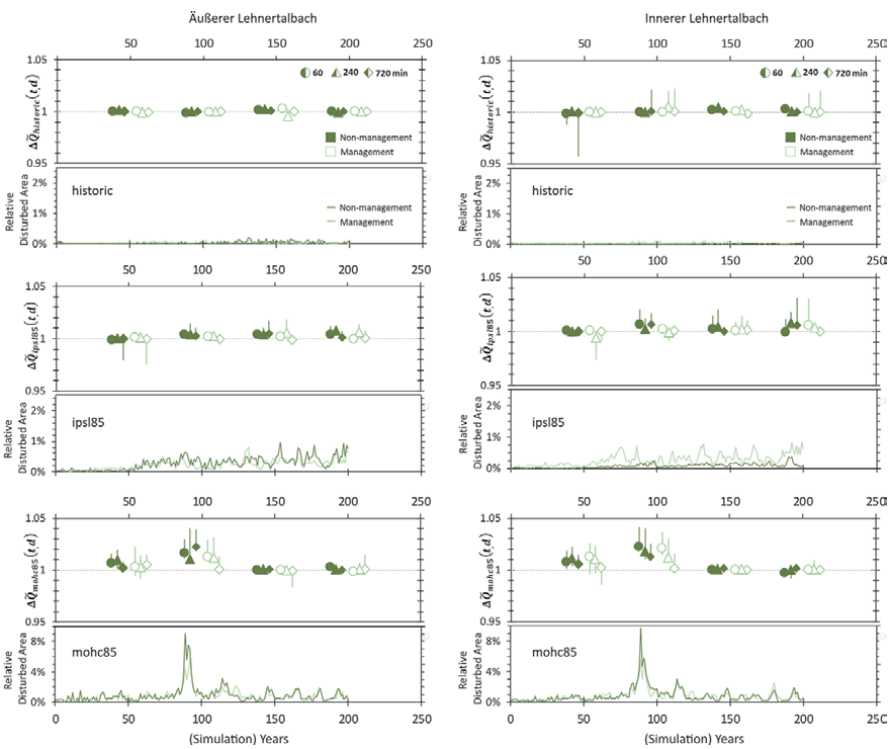


Figure 3.
In each figure, the upper panel shows the change in peak discharge relative to the peak discharge without disturbances stratified by management and no management for 50, 100, 150 and 200 years after simulation begin. All discharge values are based on the pooled model results (ZEMOKOST and GEOtop). The symbol is located at the median, while the lower and upper end of the bar represent the 25th and 75th percentile estimated from 20 repetitions. The lower panel shows the disturbed area relative to the total area occupied by forest for each year.

peak discharge of the climate change scenario j without considering disturbance effects $Q_j^0(t,d)$, for each precipitation duration and time slice.

$$\Delta Q_{j,i}(t,d) = \frac{Q^1_{j,i}(t,d)}{Q^0_j(t,d)} \tag{5}$$

From the 20 relative peak discharge change observations per climate scenarios, precipitation duration and time slices, the median $\Delta\tilde{Q}_j(t,d)$ is derived, and the 95% confidence interval is estimated based on 2,500 bootstrap samples. To account for epistemic uncertainty, $\Delta Q_{j,i}(t,d)$ values are based on the pooled model results (ZEMOKOST and GEOtop).

Figure 3 shows the relative peak discharge change for 50, 100, 150 and 200 years after simulation begin – stratified by the selected torrential catchments, historical based –, wettest (ipsl85) –, and driest (mohc85) climate scenarios as well as management and no management.

The results (**Figure 3**) do not permit any significant influence of natural disturbances on the runoff behavior in torrent catchment areas. Neither could a significant change in soil water content be observed for any of the future climate scenarios and disturbance induced simulated landscapes (c.f. **Figure 4**). However, positive trends describing an increase in runoff due to an increase in the disturbed forest area cannot be completely ruled out visually, i.e.: times with a high number of disturbances (supposing a critical size of disturbed area) apparently also cause an increase in runoff behavior during heavy precipitation events.

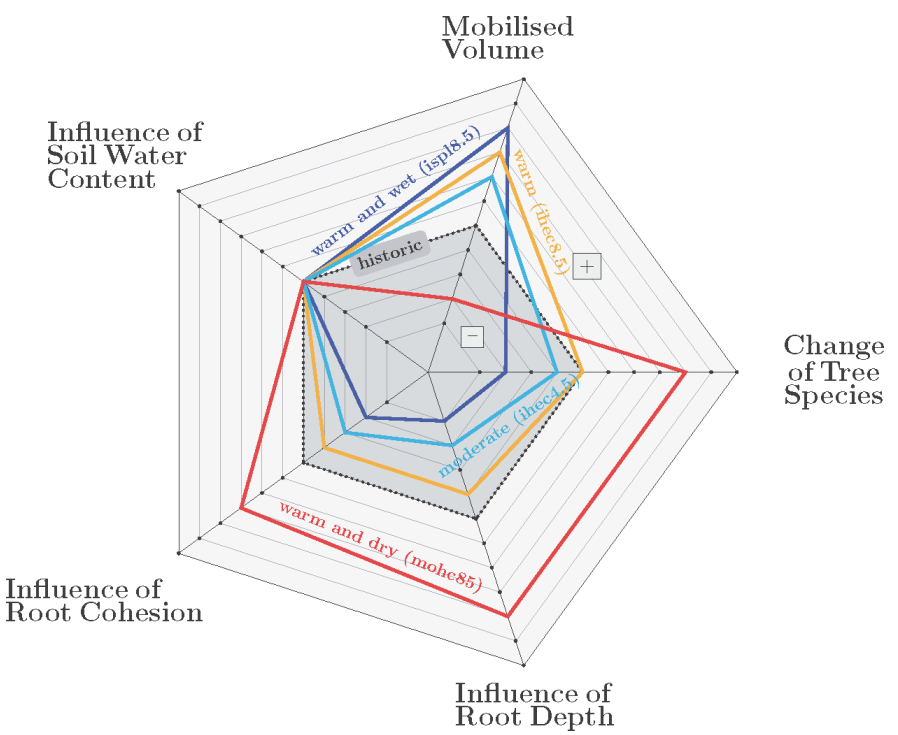


Figure 4.
The influence on climate change scenarios on modeled slope stability criteria and the corresponding mobilized volume. Canopy disturbances influence the development of tree species and thus the existing apparent cohesion through the root system.

4. Climate change and climate-driven development of canopy disturbances are directly related to the disposition of landslides

The results given refer to the mobilized volume, which is calculated for each cell and all climate scenarios individually as the cell-area times the unstable soil depth. The latter is defined as the height from the surface, of the considered cell, to the first soil layer whose factor of safety (FS_i, eq.1) is simulated below one. A detailed presentation and discussion of all results can be found in [11]. However, this chapter provides a brief summary of the main findings that summarize the influence of natural disturbances on slope stability criteria (amount of mobilized volume) by i) the influence of soil water content, ii) the influence of root cohesion, iii) the influence of rooting depth, and iv) the change in tree species (**Figure 4**). While under historical conditions the mobilized volume is constant over time, the mobilized volume increases for the moderate (ihec4.5) and warm (ihec8.5) to the warm and wet (ispl8.5) climate scenarios (**Figure 4**). A considerable decrease of the mobilized volume was, however, found for the warm and dry climate scenario (mohc8.5). Beside these trends the mobilized volume is for all climate scenarios and time periods constantly less for forest stands influenced by canopy disturbances. These conclusions are also preserved if the duration is changed from 240 minutes to 60 or 720 minutes, with the only difference that for the 60-minute scenario less volume and for the 720-minute scenario more volume is mobilized compared to the 240-minute scenario.

The lower landslide disposition for the warm and dry climate scenario (mohc8.5) may initially be contra-intuitive but can be explained by a closer look at the structural change of the forest stands. Regardless of the climate scenario or the time period, the share of heart and taproot systems is higher for forest stands with natural disturbances. While for the climate scenarios ihec4.5, ihec8.5 and ispl8.5 the share of trees with sinker root system increases over time, the share of trees with sinker root system decreases in the mohc8.5 scenario. This leads to an increase in slope stability due to a higher rooting depth and increased root cohesion. The results suggest that on steep slopes, stability due to disturbances can occur through a more rapid change in natural succession – especially when a change in climate leads to a change in tree species with a higher root cohesion capacity.

5. Conclusion

Forest disturbances which have a possible influence on natural hazard processes are understood to refer primarily to large-scale disturbances, i.e. disturbances which cause large-scale deforestation. After such large-scale disturbances, technical protection structures are very often installed as immediate measures to compensate for the loss of forest's protective effects. Frequently recurring disturbances are often much smaller in relation to "catastrophic" large-scale disturbances and thus less in the awareness of natural hazard experts, but very much in the attention of forest experts. The canopy disturbance intensities modeled in this study affected less than 20% of the forested area of the considered catchments – somehow a critical size of disturbances regarding change in runoff regimes [18–20]. Although the runoff simulations do not permit clear quantifiable statements, it must be noted that such critical size of the natural disturbance is more likely to be reached in steep and small torrent basins especially in causing a change in runoff behavior. However, future research questions will most certainly address quantifying the size of a critical disturbance area, i.e., determining the area above which a significant impact on the hydrologic regime in steep torrent catchments would be evident. The influence of

critical disturbances on slope stability showed, in a first moment, contra intuitive results, especially for the smallest and most densely forested investigation area. Here we have noticed an increase in slope stability with an increase in the disturbed area, significantly for the climate scenario with high temperatures in combination with lower precipitation (mohc 8.5). As trees exert a kind of cohesion on the soil layer due to their roots, the formation of the root system plays an important role regarding slope stability. However, the shape of the root system depends mainly on the tree species and the age. Both are subject to significant changes due to the influence of climate and the occurrence of natural disturbances and thus influence stability on steep forested slopes. In the Alpine Region, the treatment of protective forests faces more than ever the challenges of sustainable and proactive management. While it is still too early to define general management strategies to maintain or improve the protective effect of forests in relation to runoff formation in the context of disturbances, it can be stated that scenarios of future climate projections suggest the targeted promotion of tree species with deep-root or heart-root systems as necessary, especially on landslide-prone sites.

Acknowledgements

The study was funded by the Austrian Climate Research Program PROTECTED (KR16AC0K13167). R.S. and W.R. further acknowledge support through the Austrian Science Fund (FWF) through START grant Y895-B25. We thank K. Albrich for help with data preparation for the simulations with iLand.

Conflict of interest

The authors declare no conflict of interest.

Author details

Christian Scheidl[1*], Micha Heiser[1], Sebastian Kamper[1], Thomas Thaler[1], Werner Rammer[2], Rupert Seidl[2], Klaus Klebinder[3], Veronika Lechner[3], Fabian Nagl[3], Bernhard Kohl[3] and Gerhard Markart[3]

1 Institute of Mountain Risk Engineering, University of Natural Resources and Life Sciences, Vienna, Austria

2 Ecosystem Dynamics and Forest Management, TUM School of Life Sciences, Technical University of Munich, Germany

3 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

*Address all correspondence to: christian.scheidl@boku.ac.at

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Fuchs S, Keiler M, Zischg A. A spatiotemporal multi-hazard exposure assessment based on property data. Natural Hazards and Earth System Sciences. 2015;**15**(9):2127–2142. DOI: 10.5194/nhess-15-2127-2015

[2] Smith K, Petley DN. Environmental hazards: Assessing Risk and Reducing Disaster. 5th ed. Routledge Milton Park, Abingdon, Oxon; New York, NY; 2009. 414 p

[3] Accastello C, Teich M, Cocuccioni S. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[4] Telesca L. Time-clustering of natural hazards. Nat Hazards. 2007; **40**(3):593–601. DOI: 10.1007/s11069-006-9023-z

[5] Markart G, Teich M, Scheidl C, Kohl B. Flood protection by forests in Alpine watersheds – Lessons learned from Austrian case studies. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99507

[6] Gomi T, Sidle RC. Bed load transport in managed steep-gradient headwater streams of southeastern Alaska. Water Resources Research. 2003;**39**(12):1336. DOI: 10.1029/2003WR002440

[7] Gschwantner T, Russ W, Freudenschuss A, Zaunbauer F, Schadauer K, Koukal T, et al. Zwischenauswertung der Waldinventur 2016/18. 2019. p. 40. (BFW. Praxisinformation). Report No.: 50.

[8] Dale VH, Joyce LA, McNulty S, Neilson RP, Ayres MP, Flannigan MD, et al. Climate change and forest disturbances: Climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. BioScience. 2001;**51**(9):723–734. DOI: 10.1641/0006-3568(2001)051[0723:CCAFD]2.0.CO;2

[9] Seidl R, Thom D, Kautz M, Martin-Benito D, Peltoniemi M, Vacchiano G, et al. Forest disturbances under climate change. Nature Clim Change. 2017;**7**: 395–402. DOI: 10.1038/nclimate3303

[10] Sebald J, Senf C, Heiser M, Scheidl C, Pflugmacher D, Seidl R. The effects of forest cover and disturbance on torrential hazards: Large-scale evidence from the Eastern Alps. Environ Res Lett. 2019;**14**(11):114032. DOI: 10.1088/1748-9326/ab4937

[11] Scheidl C, Heiser M, Kamper S, Thaler T, Klebinder K, Nagl F, et al. The influence of climate change and canopy disturbances on landslide susceptibility in headwater catchments. Science of the Total Environment. 2020;**742**:140588. DOI: 10.1016/j.scitotenv.2020.140588

[12] Heiser M, Scheidl C, Eisl J, Spangl B, Hübl J. Process type identification in torrential catchments in the eastern Alps. Geomorphology. 2015;**232**:239–247. DOI: 10.1016/j.geomorph.2015.01.007

[13] Seidl R, Rammer W, Scheller RM, Spies TA. An individual-based process model to simulate landscape-scale forest ecosystem dynamics. Ecological Modelling. 2012;**231**:87–100. DOI: 10.1016/j.ecolmodel.2012.02.015

[14] Kohl B. Das Niederschlags–/Abflussmodell ZEMOKOST: Entwicklung eines praktikablen Modells

zur Ermittlung von Hochwasserabflüssen in Wildbacheinzugsgebieten unter Einbeziehung verbesserter Felddaten [PhD Thesis]. na; 2011

[15] Markart G, Kohl B, Sotier B, Klebinder K, Schauer T, Bunza G, et al. A Simple Code of Practice for the Assessment of Surface Runoff Coefficients for Alpine Soil-/Vegetation Units in Torrential Rain (Version 2.0). Report in the frame of the Interreg-SEE-project CC-WaterS (WP7–Water supply management measures, Act 7.1). 2011. Available from: https://www.researchgate.net/profile/Gerhard_Markart/publication/273761280_A_Simple_Code_of_Practice_for_the_Assessment_of_Surface_Runoff_Coefficients_for_Alpine_Soil-Vegetation_Units_in_Torrential_Rain_(Version_2.0)/links/550ae07c0cf265693cee3e89.pdf

[16] Saxton KE, Rawls WJ. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. Soil Sci Soc Am J. 2006;**70**(5):1569–1578. DOI: 10.2136/sssaj2005.0117

[17] Carsel RF, Parrish RS. Developing joint probability distributions of soil water retention characteristics. Water Resources Research. 1988;**24**(5):755–769. DOI: 10.1029/WR024i005p00755

[18] Hibbert AR. Forest Treatment Effects on Water Yield. Coweeta Hydrologic Laboratory, Southeastern Forest Experiment Station; 1965. 86 p

[19] Johnson R. The forest cycle and low river flows: A review of UK and international studies. Forest Ecology and Management. 1998;**109**(1): 1–7. DOI: 10.1016/S0378-1127(98)00231-X

[20] Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA. A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. Journal of Hydrology. 2005;**310**(1): 28–61. DOI: 10.1016/j.jhydrol.2004.12.010

Chapter 9

Risk-Based Decision Support for Protective Forest and Natural Hazard Management

Cristian Accastello, Francesca Poratelli, Kathrin Renner, Silvia Cocuccioni, Christopher James Laplante D'Amboise and Michaela Teich

Abstract

Protective forests are an effective Forest-based Solution (FbS) for Ecosystem-based Disaster Risk Reduction (Eco-DRR) and are part of an integrated risk management (IRM) of natural hazards. However, their utilization requires addressing conflicting interests as well as considering relevant spatial and temporal scales. Decision support systems (DSS) can improve the quality of such complex decision-making processes regarding the most suitable and accepted combinations of risk mitigation measures. We introduce four easy-to-apply DSS to foster an ecosystem-based and integrated management of natural hazard risks as well as to increase the acceptance of protective forests as FbS for Eco-DRR: (1) the Flow-Py simulation tool for gravitational mass flows that can be used to model forests with protective functions and to estimate their potential for reducing natural hazards' energy, (2) an exposure assessment model chain for quantifying forests' relevance for reducing natural hazard risks, (3) the Rapid Risk management Appraisal (RRA), a participatory method aiming to identify IRM strengths and points for improvement, and (4) the Protective Forest Assessment Tool (FAT), an online DSS for comparing different mitigation measures. These are only a few examples covering various aims and spatial and temporal scales. Science and practice need to collaborate to provide applied DSS for an IRM of natural hazards.

Keywords: natural hazard risk, decision support tools and systems, protective forest, integrated risk management, exposure assessment

1. Introduction

The variety of available natural hazard risk mitigation measures, such as land use planning, technical measures, biological measures, and organizational directives [1], necessitates decision-making in integrated risk management (IRM) processes to recognize and incorporate social, economic, and ecological sustainability criteria as well as conflicting interests and constraints (see chapter [2] of this book). Protective forests as an effective Forest-based Solution (FbS) for Disaster Risk Reduction (DRR) must have a key role within the portfolio of IRM measures (see chapter [3] of this book). However, managing protective forests and natural hazard risks requires including different spatial and temporal dimensions such as slope and regional scales

as well as short- and long-term changes in land use in the decision-making process to implement the most suitable combinations of risk mitigation measures.

Decision support tools and systems (DSS) are computer-based tools and/or techniques and methods that were developed to improve the quality of decision-making on complex issues. DSS are often applied in participatory processes by integrating decision-makers own insights with the information processing capabilities of computers [4]; however, they do not automate decisions by simply finding optimal solutions. The final decision is still left to the decision-maker [5]. For a DSS to be effective, it must present aspects of a complex system as well as the effects of changing the system in a user-friendly interface. Examples of well-established DSS are simulation models, expert opinions, and decision flowcharts. DSS are therefore also one of the most common ways to transfer knowledge from science into practice as a vehicle for communication, training, and experimentation [6]. They are often integrated within web platforms or GIS (geographic information systems), facilitating a dialogue and the exchange of information, and thus providing insights to decision-makers, which can support them in exploring, for example, potential outcomes of different policy options. Numerous DSS have been developed for forest management over the past 40 years [7, 8]. More recently, DSS have also been introduced in natural hazard risk management with the goal to communicate hazard and risk modeling results to the public, supported by improved visuals and graphical user interfaces (GUI) [6]. For example, Xu et al. [9] developed a geospatial web platform that considers combined risks of multiple water-related hazards using serious gaming techniques to involve a variety of decision-makers and to foster a holistic and collaborative planning process. Like natural hazard models (see chapter [10] of this book), the features and characteristics of risk models vary widely. For example, operating at different scales requires to adopt different approaches for data collection and model complexity as well as influences the representation and precision of the results, which determines the applicability and effectiveness of a tool itself. Based on a literature review, Newman et al. [6] proposed a classification for natural hazard risk reduction DSS based on their components and characteristics such as scoping, problem formulation, analysis framework, user engagement, and evaluation (**Figure 1**).

The application of risk-based approaches that are not only hazard-focused in decision-making processes regarding Ecosystem-based Disaster Risk Reduction (Eco-DRR) is increasing [11]. Risk-based approaches have been developed to estimate the economic value of mountain forests' protective functions and effects by reducing the risk from natural hazards that endanger people and assets, considering all three risk components, hazard, exposure, and vulnerability (see chapter [3] of this book). These studies were conducted at different spatial scales from local [12–15] to regional [16, 17] as well as national evaluations ([18]; see also chapters [19–21] of this book). Other studies integrated Eco-DRR in hazard and risk models into more complex online DSS, for example, Grandjean et al. [22] created a multi-risk tool for identifying management strategies to reduce potential impacts of global change by considering short- and long-term changes in land use, climate change scenarios, and alternative socio-economic development pathways. Bebi et al. [21] highlight how scenario-specific avalanche protective forest maps can be developed by collaborating with avalanche modelers and practitioners, and implemented into an interactive, web-based DSS providing combined information about natural hazards and effective avalanche protective forests. However, for ecosystem-based and integrated natural hazard risk management, few economic evaluation methods and/or DSS are currently available in practice to compare the effectiveness and/or cost-efficiency of protective forests with technical measures. One reason could be that the remaining considerable uncertainties in assessing the protective effects of forests against natural hazards are affecting the confidence in FbS in contrast to technical

SCOPING

Function and use e.g.
- explore risk problem
- evaluate mitigation options
- develop plans

Hazards
- geophysical
- meteorological
- hydrological
- climatological

End-users and operators
- scientific / technical
- public administrations
- media

Spatial and temporal information
- planning horizon and temporal representation
- geographic extent

PROBLEM FORMULATION

Risk reduction measures
- structural mitigation
- land-use planning
- administrative changes
- Eco-DRR
- education / communication

External drivers
- social
- technological
- economic
- environmental
- political

Decision indicators
- economic
- environmental
- social
- built environment

ANALYSIS FRAMEWORK

Model selection
- hazard modeling
- vulnerability modelling
  - ➢ dynamic / static
  - ➢ process / empirical

Screening through risk reduction options
- optimization
- post-analysis of options:
  - ➢ sensitivity / uncertainty analysis

Model integration
- source of model components
- type of integrated model

USER AND ORGANIZATIONAL INTERACTION WITH THE SYSTEM

Specification of indicators for criteria, and their derivation from model output
- means of aggregating risk:
  - ➢ across vulnerability types
  - ➢ across hazards
  - ➢ across time / space

Software architecture; GUI design and development
- graphical
- interactive
- stakeholder involvement in design
- software frameworks used

USE AND USER ENGAGEMENT

Development process
- participatory approach to development
- evidence of an iterative development process

Use process
- number of case studies
- scenarios developed
- workshops used
- training offered / provided

MONITORING AND EVALUATION

Monitoring and evaluation process
- evidence that DSS changed practice

→ evaluation categories:
- ➢ improved planning process
- ➢ improved risk-outcomes

Figure 1.
Classification system for reviewing natural hazard risk-reduction decision support tools and systems (DSS) proposed by and adapted from Newman et al. [6]. The listed examples are not exhaustive; for the complete list see [6].

measures (e.g., [23]; see also chapters [3, 20, 24] of this book.). These uncertainties could be addressed, for example, with Bayesian probability theory and Bayesian Networks [25]. However, there is a lack of openly available and easy-to-use tools to apply Bayesian Networks as a DSS for an IRM in practice, which also includes the essential spatial and temporal dimensions to implement the most suitable combinations of risk mitigation measures [26].

In this and two other chapters of this book [10, 27], we introduce four easy-to-apply DSS that were developed in the frame of the Interreg Alpine Space project GreenRisk4ALPs [28] to support and foster ecosystem-based and integrated

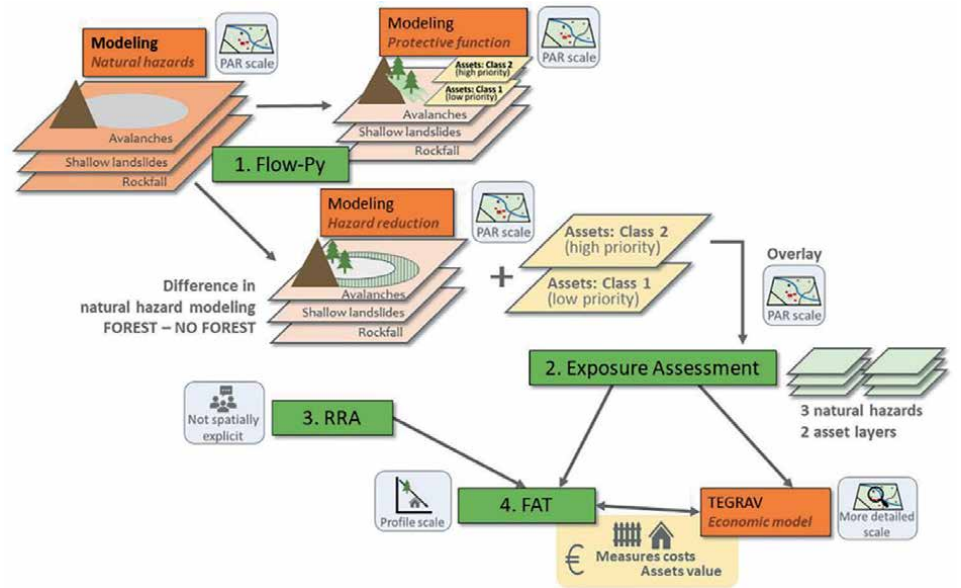


Figure 2.
Overview of the different components and analysis conducted in the GreenRisk4ALPs project for developing decision support tools and systems (DSS) for an integrated risk management (IRM) of natural hazards in the Alpine Space. Green rectangles = DSS, orange rectangles = model chains, yellow rectangles = generated input data. PAR = GreenRisk4ALPs Pilot Action Region [29]. FAT = Protective Forest Assessment Tool; RRA = Rapid Risk management Appraisal (see chapter [27] of this book); TEGRAV = TEchnical—GReen—AVoidance (see subsection 2.3).

management of natural hazard risks as well as to increase the acceptance of FbS for Eco-DRR (**Figure 2**):

1. the Flow-Py simulation tool for gravitational mass flows (GMF; [30, 31]) can be used to model forests with a direct object protective function and to estimate their potential for reducing natural hazards' energy (see also chapter [10] of this book),

2. an exposure assessment model chain to quantify potential forest relevance for reducing natural hazard risk to people and assets,

3. the Rapid Risk management Appraisal (RRA), a participatory tool aiming to identify strengths and points for improvement of IRM, supporting municipalities to increase their resilience to natural disasters (see chapter [27] of this book), and

4. the Protective Forest Assessment Tool (FAT), an open-access online DSS for profile-based comparisons of different mitigation measures to support local risk management strategies.

Considering the differences in DSS for natural hazard risk management (see **Figure 1**), these tools were developed following a complementary approach that allows for robust and comprehensive risk analysis at different scales. They are still addressing rather an expert audience than non-experts or the general public; however, an extended group of stakeholders and policy makers was involved in their development, evaluation, and testing within the GreenRisk4ALPs project.

2. GreenRisk4ALPs' risk-based decision support tools and systems (DSS)

2.1 Flow-Py: regional mapping and modeling of protective forests

Flow-Py is a simulation tool to model runout and intensity of gravitational mass flows (GMFs) based on a runout angle model (also referred to as travel or α-angle [32]) at regional scales [30, 31]. The required input data are a digital elevation model (DEM) and a release raster containing one or several starting cells. Together with two developed custom extensions, post-processing routines, and recommendations for the visualization of simulation results (see chapter [10] of this book), Flow-Py can be used as DSS to support protective forest and risk management-related decisions. To develop an easy-to-apply procedure we asked: Where does the presence of forest reduce the impact of GMFs on elements potentially at risks such as exposed buildings, transport, or recreational infrastructure?

The objectives to answer this question are:

1. to map the forest areas that may reduce the natural hazard risk for people and assets,

2. to model potential GMF runout and intensity reductions due to the presence of forest and to quantify forest effects in reducing risk by assessing the reduced impact each GMF has on different types of assets, and

3. to identify and visualize areas where the risk-reducing effect of forests is greatest within a region.

To test the DSS, five types of protective forest-related map products were developed for the three GMFs snow avalanches, rockfall, and shallow landslides, and applied in five of the six GreenRisk4ALPs Pilot Action Regions (PARs; [29]). The freely available and open-source Flow-Py code allows users to customize GMF simulations by adjusting the parameterization or developing extensions to adapt calculations, input data, and model outputs as well as to apply their own post-processing routines and visualizations based on their specific questions and problems. **Figures 3–7** show example maps of the PAR "Wipptal South" in South Tyrol, Northern Italy, and the snow avalanche hazard that were created from Flow-Py simulation results, providing relevant information to support decision-making in protective forest and natural hazard management.

The map shown in **Figure 3** was created based on Flow-Py simulations with the "back-tracking" custom extension. This extension changes Flow-Py from a pure runout model to one that can identify terrain associated with endangering assets by storing the path that a GMF traveled to reach an infrastructure in computer memory (see also [33]). To apply the back-tracking extension an input raster including the location of infrastructure in the modeling domain is therefore required. The simulation output is a spatially explicit subset of the GMF release areas, transit, and runout zones that were modeled to endanger infrastructure, which can be united with the spatial distribution of forested areas (for details see chapter [10] of this book). The resulting map highlights the location of forests with a direct object protective function (for definitions see chapter [3] of this book). In other words, it shows those forested areas located between physical assets and a hazard's release area. The map provides information at a regional scale about the approximate geographic extent of protective forests and how they are distributed in the landscape. Similar maps have been produced in Switzerland [34, 35] and Austria [36, 37]; however, such protective forest maps are not available for all Alpine Space countries.

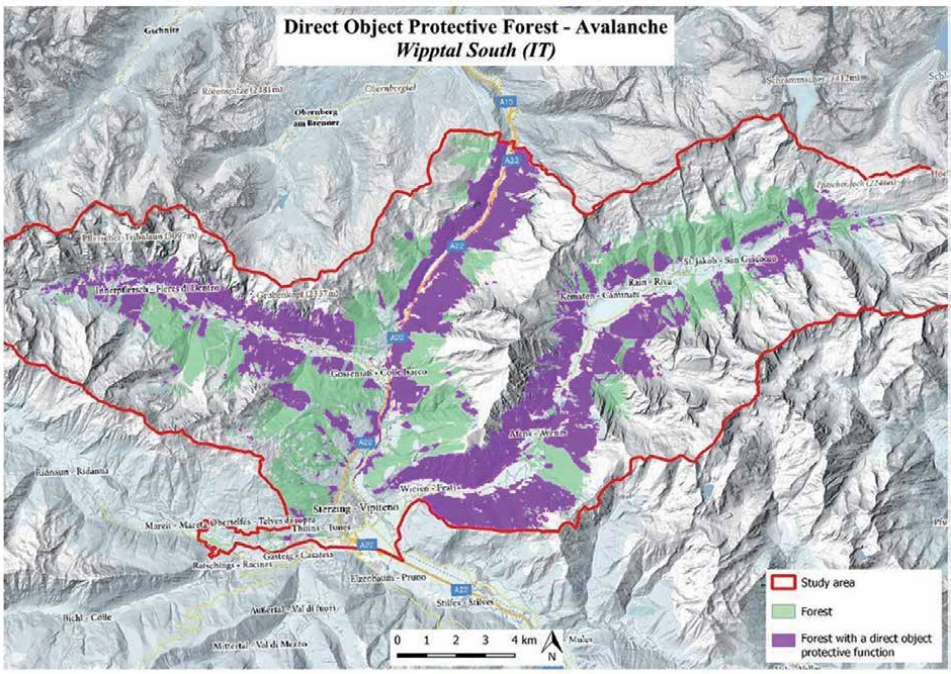


Figure 3.
Example for a direct object protective forest map based on Flow-Py simulations. Purple shaded areas were modeled as forests with a direct object protective function, which can protect people and assets from large and very large dry snow slab avalanches. Green shaded are forested areas that are not considered protective forests against snow avalanches.

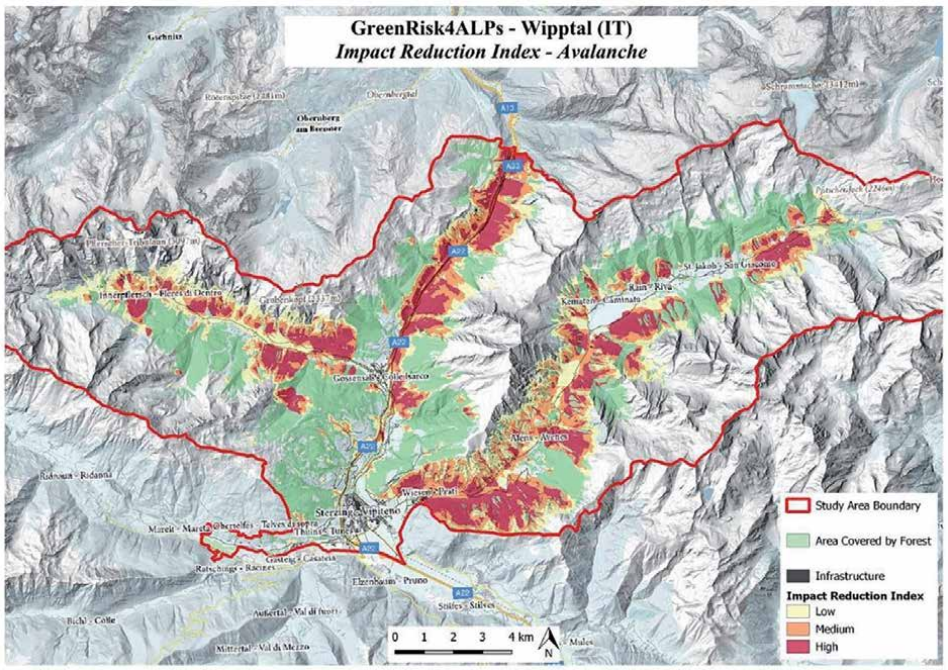


Figure 4.
Example for a map quantifying the magnitude of snow avalanches' kinetic energy potentially reduced by forest based on Flow-Py simulations. Yellow to red colors show the difference in the kinetic energy from simulations with and without the effect of the forest. The Impact Reduction Index (IRI) is only shown for areas where elements are potentially at risk.

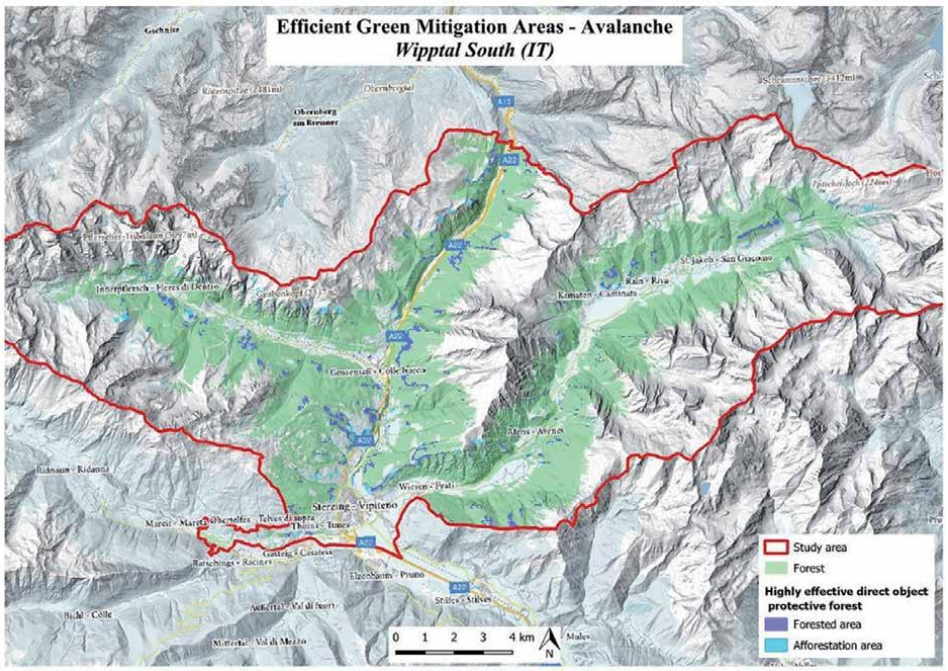


Figure 5.
Example for a map delineating locations of potentially highly effective protective forests against snow avalanches based on Flow-Py simulations. Dark blue are forested locations that were identified as highly effective for reducing the kinetic energy by forests of large and very large dry snow slab avalanches. Light blue are non-forested locations that were identified as highly effective for reducing snow avalanche's kinetic energy by forest; it was not considered whether it is possible to grow forests at these locations in terms of, e.g., land use, soil, or climatic conditions (except altitude and slope).

The Impact Reduction Index (IRI) shown in **Figure 4** quantifies the magnitude of the potential hazard's energy reduction by forests, which depends on forest structure and tree species composition by comparing the difference in kinetic energy in simulations with and without forest effects. The IRI was calculated based on Flow-Py simulations with the "forest" custom extension and a developed post-processing workflow (see chapter [10] of this book for details). That is, this map shows which areas are benefiting most from the surrounding protective forests in terms of reduced GMF's kinetic energy. To account for the increase in energy dissipation (or friction) in the parts of a GMF path that are located in a forest, the forest extension adjusts the runout angle to a steeper angle dependent on the length of the forested slope, the forest structure and the kinetic energy of the GMF. For this, an additional Forest Structure Index (FSI) input raster ranging between 0 and 1, which summarizes how developed a forest is regarding its optimal protective effect is needed. For example, the optimal protective forest for snow avalanches is an evergreen conifer forest with a high stem density and dense canopy cover (FSI = 1), which can hinder avalanche formation and significantly reduce runout lengths of small-to-medium avalanches ([38]; see chapter [24] of this book). A broad-leaved forest has a reduced effect (FSI = 0.8) as well as a forest with lower stem densities and less dense canopy cover, which needs to be reflected in the choice of the FSI values. However, the parameterizations of forest-GMF interactions to model the forest's potential to reduce the kinetic energy of natural hazards with Flow-Py and the forest extension as well as FSI-values were developed and estimated based on a literature review but can and should be further refined with observations.

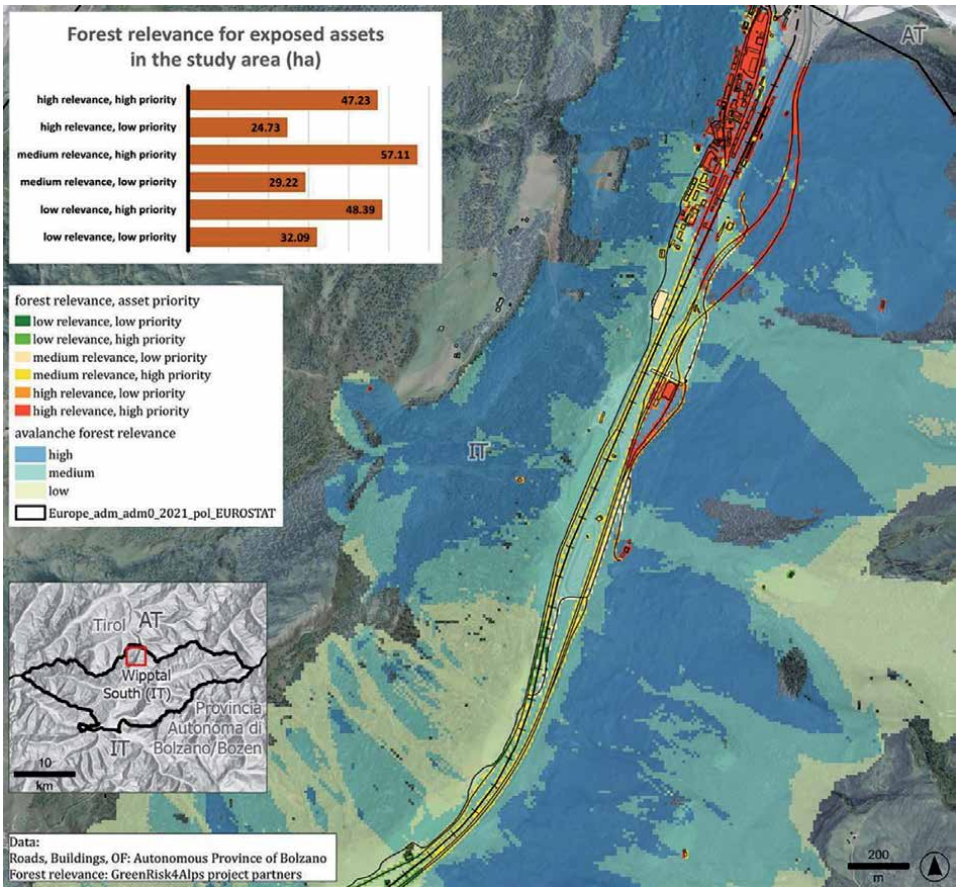


Figure 6.
Forest relevance in reducing the impact of snow avalanches is classified into three levels in the far north of the GreenRisk4ALPs Pilot Action Region (PAR) Wipptal South (IT), and forest relevance levels are combined with the building and infrastructure priority classes. The bar chart indicates for the entire PAR the square meters of assets for which the forest has relevance in reducing the potential risk from snow avalanches. Building and transport infrastructure footprints are shown with black outlines.

Figure 5 shows areas where forests are assumed to be highly effective in reducing GMF runout and intensity based on maximum thresholds in the kinetic energy of a GMF calculated with the Flow-Py simulation tool. To be considered as highly effective (or having the potential to be), the location must lie between a release area of a GMF and elements potentially at risk. The maximum kinetic energy threshold, which indicates where forests can reduce GMF runout and intensity considerably, is dependent on the GMF type and dictated by the different forest-GMF interactions. For example, a threshold of ~105 m in kinetic energy (velocity of ~30 m s^{-1}) was applied for snow avalanches above which a forest is no longer capable of reducing the avalanches' energy considerably since trees can be easily uprooted [39, 40]. In contrast, a threshold of ~75 m in kinetic energy was assumed for rockfall, which also translates to a velocity of ~30 m s^{-1}, above which forest is considered to have no energy dissipating effect on a falling block [41]. Other criteria used to identify such locations are the same for all GMF types since they characterize the forest growing conditions by simple terrain characteristics. For example, we assumed that an effective protective forest cannot grow above 2000 m in elevation and on slopes steeper than 45°. However, these criteria and thresholds can be adjusted easily and added to dependent on specific questions and/or, for example, land use, growing region, soil, and climatic conditions.

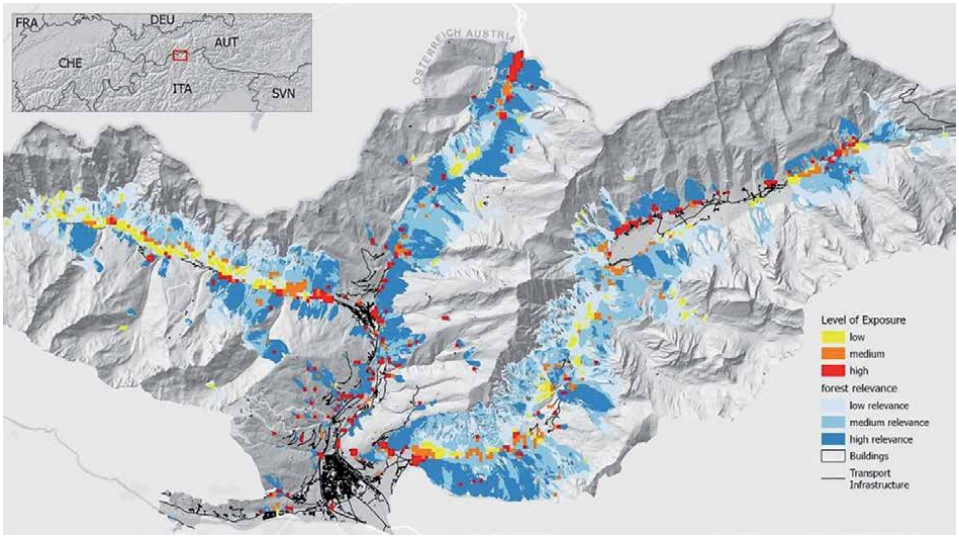


Figure 7.
Hotspots where protective forests are particularly relevant for reducing risk for the GreenRisk4ALPs Pilot Action Region (PAR) Wipptal South (IT). Building hotspots are shown for three levels of forest relevance to reduce the risk of snow avalanches.

2.2 Exposure assessment: relevance of forests in reducing natural hazard risk

Exposure is, together with hazard and vulnerability, one of the three components determining the risk (see chapter [2] of this book). As defined by the Intergovernmental Panel for Climate Change (IPCC), exposure refers to "the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected" [42].

The aim of the exposure assessment was to spatially identify those forest areas that have significant relevance in reducing the impact of GMFs on assets. We considered buildings, transport, and recreational infrastructure as exposed assets and classified each asset type into high and low priority (provided the required input data was available) following the recommendations of Perzl et al. [43] to acknowledge the commonly existing public interests in the protection of assets that are used frequently [44]. Perzl et al. [43] thoroughly discuss the challenge of a common classification scheme based on existing laws and regulations and applied a much more detailed classification of assets potentially at risk to model forests with a direct object protective function in Austria. However, the simplified scheme fits our purpose and goal to produce an overview of assets potentially at risk enabling to compare model outcomes of different PARs and countries that can be followed by a more detailed risk assessment. Accordingly, buildings used for residential, commercial, and industrial purposes were categorized as high priority and all other buildings (e.g., garages, stables, derelict buildings) were classified as a lower priority. Regarding transport infrastructure, highways, and primary and secondary roads were assigned a high priority whereas tertiary roads, for example, roads within settlements were categorized as a lower priority; forest roads were excluded from the analysis. Recreational infrastructure, such as cable cars, campgrounds, ski runs, golf courses, and sports grounds were considered assets of lower priority.

The spatial data needed for the exposure assessment were available in different formats representing different levels of detail (thematic and spatial) for five PARs of the GreenRisk4ALPs project. In the first step, the required features, buildings, transport, and recreational infrastructure, were extracted from the original data

sets. In a second step, the assets were attributed categories of importance as defined and according to their priority, that is, high priority = 2 and low priority = 1. All asset information was subsequently converted into 10-m resolution gridded data sets. To spatially identify those areas where the forest has significant relevance in reducing the impact of GMFs, the IRI data sets that were computed based on Flow-Py simulation results (for method and result description see subsection 2.1 and chapter [10] of this book) were translated into forest relevance levels and intersected with the classified asset information. Building and infrastructure classes combined with forest relevance levels were visualized on maps. This spatial overlay allowed to quantify for the entire study area the square meters of each combination of forest relevance and asset priority level (**Figure 6**).

The forest relevance maps were used to identify hotspots where protective forests are particularly relevant for reducing risk (**Figure 7**). To define these hotspots of forest relevance, we considered those building types and infrastructure of a higher priority and combined them with the high level of forest relevance. Aggregating those features to larger pixel sizes allows to increase their visibility in a map showing a region at a scale of approximately 1:135,000 and for a qualitative consultation and discussion with local stakeholders.

2.3 The Protective Forest Assessment Tool (FAT)

The Protective Forest Assessment Tool (FAT) is a DSS in form of an interactive web platform, which consists of a model chain provided with a dedicated and easily accessible web interface. It serves for assessing the protective effect of a forest along a natural hazard process path/profile by comparing it to alternative mitigation measures to determine the best risk reduction measures in terms of cost-benefit ratio [45]. The FAT model chain consists of a GMF model that is connected to the risk assessment and economic model TEGRAV (TEchnical – GReen – AVoidance; [46]; **Figure 8**). FAT is targeted at different stakeholder groups, for example, local/regional decision-makers, forest managers, safety and infrastructure managers, planning officers, and local/regional public authorities. The aim of the tool is to present an assessment of the effectiveness of protective forest and ecosystem-based risk management compared to other solutions such as technical measures or avoidance strategies.

The Protective Forest Assessment Tool is freely available through a web interface [45], which enables users to perform an ad hoc risk analysis by uploading and entering input data, running the model chain, and viewing the results in a user-friendly way. Most of the user's inputs are predefined via dropdown menus, and graphical results are apparent and intuitive (**Figures 9** and **10**). Furthermore, detailed instructions guide the user through the modeling process as needed via the info buttons on each page.

To maximize its applicability, FAT's GMF model is based on a simple empirical relationship, which requires minimal input data and parameterization. Three GMFs, snow avalanches, rockfall, and shallow landslides, are parameterized with a runout angle model [32], which calculates the runout and intensity of the natural hazard process. The GMF model considers two types of effects that forest exhibit: (1) the forest effect in the release area, and (2) the forest effect in the process path of the natural hazard by increasing the runout angle dependent on forest type (broad-leaved or coniferous forest) and forest structure. The forest effect in the process path applies to snow avalanches and rockfall, while forest effects in release areas are considered for snow avalanches and shallow landslides. The forest effect is parameterized with the FSI (see subsection 2.1), which is a relative measure characterizing the current structure of the forest in relation to the most robust and dense forest possible for the respective forest type and selected natural hazard (see **Figure 10**,

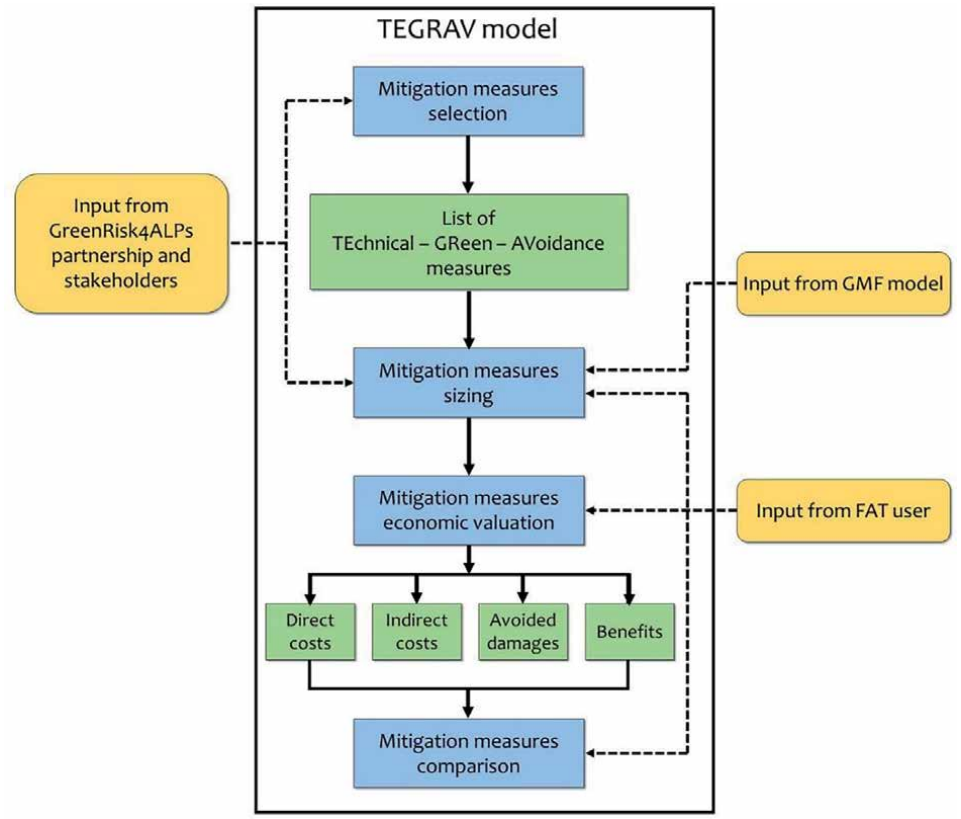


Figure 8.
TEGRAV (TEchnical – GReen – AVoidance) risk assessment and economic model workflow: modeling steps in blue, model outputs in green, external inputs in yellow. GMF = gravitational mass flow, FAT = Protective Forest Assessment Tool. Adapted from [47].

and chapter [10] of this book for details). Forest type and FSI as well as the forest's location along the process profile need to be defined by the FAT user. Based on this information, the runout angle associated with the chosen natural hazard is adjusted to a steeper angle, which can immediately stop or shorten the simulated runout. To quantify the forest's protective effect as the resulting difference in kinetic energy and thus simulated runout, the GMF model runs two times: 1) accounting for forest effects along the GMF profile, and 2) without considering forest.

Using the simulation results of the GMF model, the risk assessment and economic model TEGRAV performs a cost-benefit analysis of FbS (green measures), technical measures (grey measures), and land use avoidance (avoidance measures), allowing for their comparison [47, 48]. Risk assessment and cost-benefit analysis are carried out by integrating costs and effects of mitigation measures and damage potentials (i.e., the estimated values of assets that are potentially at risk; **Figure 8**). The TEGRAV model assesses the costs and benefits of each mitigation measure selected by the FAT user among an extensive list of possible solutions, which was established with the goal to cover the most frequent solutions currently used in the Alpine Space (**Figure 11**). Standard economic values were assigned to each technical and avoidance measure as well as to average afforestation costs based on the country or region in which they are implemented to obtain results in line with the geographic location of the natural hazard process path defined in FAT (see **Figure 9**). Costs for protective forest maintenance and rehabilitation need to be defined by the user based on their experience. These standard or regional values are then

Figure 9.
Protective Forest Assessment Tool (FAT) web interface. Upper panel: selection of the natural hazard process to be modeled. Additional information about the type and characteristics of each process is provided by moving the cursor to the respective process. Lower panel: the hazard process profile can be uploaded from a .txt file or drawn on a map. Info buttons guide the user through each step.

combined with the input data provided by the FAT user such as asset location and type, path width, maximum snow depth, or which assets should be protected to provide path-specific economic estimates (see **Figures 9** and **10**). For example, the costs for steel snow bridges depend on the maximum depth of the snowpack that they should stabilize. The sizes of rockfall nets and retention dams are estimated

Figure 10.
Protective Forest Assessment Tool (FAT) web interface. Upper panel: information about the existing forest, buildings, and roads to be protected need to be entered by the FAT user. Lower panel: green, technical, and avoidance mitigation measures can be selected via dropdown menus. Info buttons guide the user through each step.

based on the kinetic energy simulated with the GMF model at their chosen location, that is, nets and dams will be higher and more costly in the middle of the transit zone in contrast to lower and less expensive measures located in the runout zone. The cross-slope width of steel snow bridges, rockfall nets, and retention dams, which is also considered in cost calculations, are equal to the path width defined by the FAT user. The path-specific costs for afforestation and forest rehabilitation depend on its location in terms of elevation, length along the profile, and the

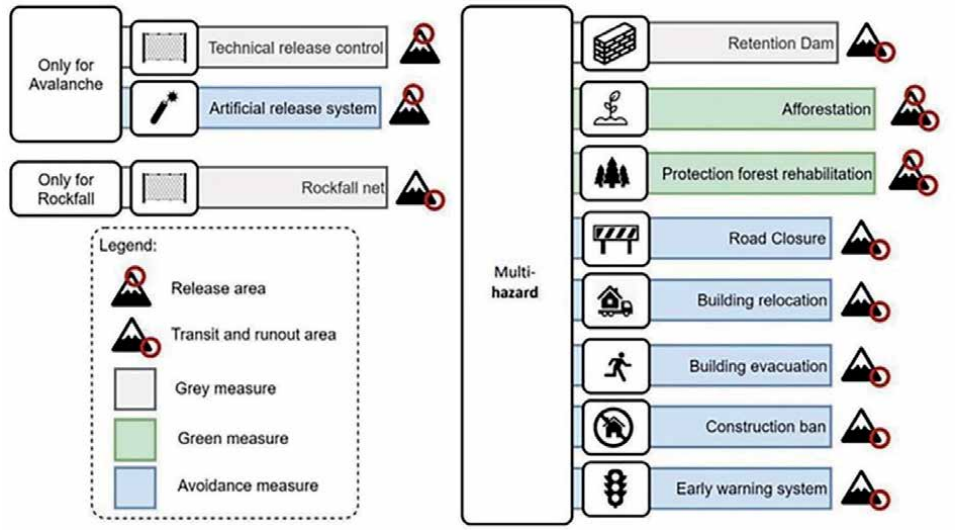


Figure 11.
Mitigation measures that are included in the TEGRAV (TEchnical – GReen – AVoidance) risk assessment and economic model and considered in the Protective Forest Assessment Tool (FAT), distinguished by hazard, area of implementation, and type. Adapted from [48].

defined path width. Since forest growth takes a considerable amount of time and dictates the development of protective effects, afforestation and forest rehabilitation measures are assessed at four (0, 25, 50, and 100 years) and three (0, 10, and 20 years) time steps, respectively. Therefore, a simplified forest growth model (based on [49]), which accounts for forest type and elevation is running in the background, estimating the forest's stage of development after a certain time, which affects the GMF runout. The costs for planting and/or maintenance are added up over time while the benefits as avoided damages will increase with the development of the forest.

Each mitigation measure included in FAT is assigned to one or more natural hazards in relation to its effectiveness. That is, in potential snow avalanche release areas, two types of measures are considered exclusively: technical release control such as snow nets or steel snow bridges and artificial release systems. For rockfall, only rockfall nets are considered in transit and runout zones. However, most measures can be applied for all natural hazards (multi-risk approach): retention dam for transit and runout zones; afforestation and protective forest rehabilitation for release, transit and runout zones; road closure, building relocation, building evacuation, and early warning system for transit and runout zones.

Based on the user's selection of mitigation measures, the model chain then calculates the remaining risk. That is, the GMF model performs simulations in the background with and without forest, adjusting the runout angle according to the protective forest type, FSI, and location along the process profile. TEGRAV then uses the simulation results to determine the damages that could be avoided thanks to the selected mitigation measures (benefits), that is, if a building or road is still reached by the simulated GMF and calculates the costs for the path-specific FbS, technical and avoidance measures.

The main output of FAT is an overview of economic metrics for each selected mitigation measure as well as for combinations of green and technical measures:

- Direct costs: originating from construction and/or implementation costs + maintenance costs + dismantling cost for the mitigation measure,

- Indirect costs: originating from constructing and/or implementing the mitigation measure, which presumably modifies an existing situation,

- Avoided damages: all damages to assets that could have happened without the mitigation measure, and

- Benefits: the sum saved or earned due to the construction and/or implementation of the mitigation measure.

The novelty of this DSS is the possibility to identify potential benefits of protective forest as a mitigation measure for natural hazard risk that can be implemented instead of or in combination with technical and avoidance measures. However, FAT's objective is neither to design real-life mitigation measures for exposed assets nor to achieve a quick, ready-to-use cost-benefit analysis for projected technical measures. The aim of FAT is to be used as DSS by displaying the potential of alternative solutions to the current practices. Forest-based Solutions and other Eco-DRR measures are often proved to be more efficient than grey measures, with little or no drawbacks from their implementation and they are, therefore, also an example of solutions that have a positive impact on livelihoods and ecosystems (see also chapter [3] of this book).

3. Conclusion

The tools and methods to support decisions in IRM of natural hazards considering protective forests that we presented in this chapter are only a few examples of different types of DSS that can cover various aims, and spatial and temporal scales, and address different user groups with specific questions and problems (see **Figure 1**). While the development of hazard and risk models has increased in number and improved in precision and effectiveness in the last years, additional effort to channel these DSS and their results into real-life risk management is still needed [50]. Indeed, several authors draw attention to the various lacks in bringing model results from science to policy and practice [51, 52], demanding the need for stronger stakeholder engagement and larger efforts to minimize uncertainties and to develop relevant indicators ([53–55]; see also chapter [56] of this book).

The next chapter of this book [27], therefore, focuses on the integration of stakeholders and decision-makers in an IRM of natural hazards. Following examples of communicating modeling results in the field of natural hazard risk management with a particular focus on mountain areas ([57, 58]; see also chapters [21, 59] of this book), the project GreenRisk4ALPs aimed to deliver openly available and easy-to-use DSS to practitioners and policy makers.

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by the Interreg Alpine Space programme, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of the European Regional policy.

Conflict of interest

The authors declare no conflict of interest.

Author details

Cristian Accastello[1,2], Francesca Poratelli[1], Kathrin Renner[3], Silvia Cocuccioni[3], Christopher James Laplante D'Amboise[4] and Michaela Teich[4*]

1 Department of Agriculture, Forest and Food Sciences (DISAFA), University of Turin, Grugliasco, TO, Italy

2 Consorzio Forestale Alta Valle Susa (CFAVS), Oulx, TO, Italy

3 Eurac Research, Institute for Earth Observation, Bolzano, BZ, Italy

4 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

*Address all correspondence to: michaela.teich@bfw.gv.at

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Federal Office for Civil Protection (FOCP). Integrated Risk Management. Its importance in protecting people and their livelihoods. Bern, Switzerland: FOCP; 2014. p. 20

[2] Accastello C, Cocuccioni S, Teich M. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[3] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

[4] Keen P, Scott-Morton M. Decision Support Systems: An Organizational Perspective. Reading, MA: Addison-Wesley Publishing; 1978

[5] Cooney TM. Software: Decision support systems. Journal of Forestry. 1986;**84**(1):13-14. DOI: 10.1093/jof/84.1.13

[6] Newman JP, Maier HR, Riddell GA, Zecchin AC, Daniell JE, Schaefer AM, et al. Review of literature on decision support systems for natural hazard risk reduction: Current status and future research directions. Environmental Modelling & Software. 2017;**96**:378-409. DOI: 10.1093/jof/84.1.13

[7] Kašpar J, Bettinger P, Vacik H, Marušák R, Garcia-Gonzalo J. Forests Special Issue "Decision Support Approaches in Adaptive Forest Management—Selected Papers from the IUFRO 125th Anniversary Congress". In: MDPI. 2017. Available from: https://www.mdpi.com/journal/forests/special_issues/IUFRO_2017_decision_manage#info

[8] Reynolds KM, Twery M, Lexer MJ, Vacik H, Ray D, Shao G, et al. Decision support systems in forest management. In: Handbook on Decision Support Systems 2. Berlin, Heidelberg: Springer Berlin Heidelberg; 2008. pp. 499-533

[9] Xu H, Windsor M, Muste M, Demir I. A web-based decision support system for collaborative mitigation of multiple water-related hazards using serious gaming. Journal of Environmental Management. 2020;**255**:109887. DOI: 10.1016/j.jenvman.2019.109887

[10] D'Amboise CJL, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[11] Sudmeier-Rieux K, Arce-Mojica T, Boehmer HJ, Doswald N, Emerton L, Friess DA, et al. Scientific evidence for ecosystem-based disaster risk reduction. Nature Sustainability. 2021;**4**(9):803-810. DOI: 10.1038/s41893-021-00732-4

[12] Moos C, Thomas M, Pauli B, Bergkamp G, Stoffel M, Dorren L. Economic valuation of ecosystem-based rockfall risk reduction considering disturbances and comparison to structural measures. Science of The Total Environment. 2019;**697**:134077. DOI: 10.1016/j.scitotenv.2019.134077

[13] Moos C, Fehlmann M, Trappmann D, Stoffel M, Dorren L. Integrating the mitigating effect of forests into quantitative rockfall risk

analysis—Two case studies in Switzerland. International Journal of Disaster Risk Reduction. 2018;**32**:55-74. DOI: 10.1016/j.ijdrr.2017.09.036

[14] Teich M, Bebi P. Evaluating the benefit of avalanche protection forest with GIS-based risk analyses—A case study in Switzerland. For Ecol. Manage. 2009;**257**(9):1910-1919. DOI: 10.1016/j.foreco.2009.01.046

[15] Accastello C, Bianchi E, Blanc S, Brun F. ASFORESEE: A harmonized model for economic evaluation of forest protection against rockfall. Forests. 2019;**10**(7):578. DOI: 10.3390/f10070578

[16] Stritih A, Bebi P, Grêt-Regamey A. Quantifying uncertainties in earth observation-based ecosystem service assessments. Environmental Modelling & Software. 2019;**111**:300-310. DOI: 10.1016/j.envsoft.2018.09.005

[17] Grêt-Regamey A, Bebi P, Bishop ID, Schmid WA. Linking GIS-based models to value ecosystem services in an alpine region. Journal of Environmental Management. 2008;**89**(3):197-208. DOI: 10.1016/j.jenvman.2007.05.019

[18] Getzner M, Gutheil-Knopp-Kirchwald G, Kreimer E, Kirchmeir H, Huber M. Gravitational natural hazards: Valuing the protective function of Alpine forests. Forest Policy and Economics. 2017;**80**:150-159. DOI: 10.1016/j.forpol.2017.03.015

[19] Moos C, Dorren L. Cost-benefit analysis as a basis for risk-based rockfall protection forest management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99513

[20] Stritih A. Dealing with uncertainties in the assessment of the avalanche protective effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99515

[21] Bebi P, Bast A, Helzel K, Schmucki G, Brozova N, Bühler Y. Avalanche protection forest: From process knowledge to interactive maps. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99514

[22] Grandjean G, Thomas L, Bernardie S, The SAMCO Team. A novel multi-risk assessment web-tool for evaluating future impacts of global change in mountainous areas. Climate. 2018;**6**(4):92. DOI: 10.3390/cli6040092

[23] Stritih A. Risk-based assessments of ecosystem services: Addressing uncertainty in mountain forest management. Zurich: ETH Zurich; 2021. p. 157. DOI: 10.3929/ethz-b-000493088

[24] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[25] Grêt-Regamey A, Straub D. Spatially explicit avalanche risk assessment linking Bayesian networks to a GIS. Natural Hazards and Earth System Sciences. 2006;**6**(6):911-926. DOI: 10.5194/nhess-6-911-2006

[26] Stritih A, Rabe SE, Robaina O, Grêt-Regamey A, Celio E. An online platform for spatial and iterative modelling with Bayesian networks.

Environmental Modelling and Software. 2020;**127**:104658. DOI: 10.1016/j.envsoft.2020.104658

[27] Cocuccioni S, Plörer M, Kirchner M. Stakeholder integration and participatory processes as part of an ecosystem-based and integrated natural hazard risk management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99516

[28] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. 2022. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

[29] Beguš J, Kleemayr K, Berger F, editors. Best Practice Examples of Implementing Ecosystem-Based Natural Hazard Risk Management in the GreenRisk4ALPs Pilot Action Regions. London: IntechOpen; 2021. p. 150. DOI: 10.5772/intechopen.95015

[30] Neuhauser M, D'Amboise CJL, Teich M, Kofler A, Huber A, Fromm R, et al. Flow-Py: Routing and stopping of gravitational mass flows (version 1.0). Zenodo. 2021. DOI: 10.5281/zenodo.5027275

[31] D'Amboise CJL, Neuhauser M, Teich M, Huber A, Kofler A, Perzl F, et al. Flow-Py v1.0: A customizable, open-source simulation tool to estimate runout and intensity of gravitational mass flows. Geoscientific Model Development. 2022;**15**(6):2423-2439. DOI: 10.5194/gmd-15-2423-2022

[32] Heim A. Bergsturz und Menschenleben. Zürich: Fretz & Wasmuth; 1932. p. 218

[33] Klebinder K, Fromm R, Perzl F. Ausweisung von Lawinenschutzwald mittels GIS und einfachen Modellrechnungen. In: Strobl J, Blaschke T, Griesebner G, editors. Angewandte Geoinformatik 2009 Beiträge zum 21 AGIT-Symposium Salzburg. Heidelberg: Wichmann; 2009. pp. 94-103

[34] Losey S, Wehrli A. Schutzwald in der Schweiz. Vom Projekt SilvaProtect-CH zum harmonisierten Schutzwald. Bern: Bundesamt für Umwelt; 2013. p. 29

[35] Giamboni M, Wehrli A. Improving the Management of Protection Forests in Switzerland. The project SilvaProtect-CH. In: INTERPRAEVENT 2008 – Conference Proceedings. Vol. 2. 2008. pp. 469-480

[36] Perzl F, Rössel M, Kleemayr K. PROFUNmap – Verbesserung der Darstellung der Österreichischen Wälder mit Objektschutzfunktion. Integration von Geodaten mit Aussagen über die Schutzfunktion des Waldes. In: Projektbericht V3 2019 im Auftrag des BMLRT. Innsbruck: BFW; 2019

[37] BML. Protective forest cover in Austria [Internet]. 2022. Available from: https://www.protective-forest.at/maps/protectiveforestcoverinaustria.html

[38] Teich M, Bartelt P, Grêt-Regamey A, Bebi P. Snow avalanches in forested terrain: Influence of forest parameters, topography, and avalanche characteristics on runout distance. Arctic, Antarctic, and Alpine Research. 2012;**44**(4):509-519. DOI: 10.1657/1938-4246-44.4.509

[39] Takeuchi Y, Nishimura K, Patra A. Observations and numerical simulations of the braking effect of forests on large-scale avalanches. Annals of Glaciology. 2018;**59**(77):50-58. DOI: 10.1017/aog.2018.22

[40] Feistl T, Bebi P, Christen M, Margreth S, Diefenbach L, Bartelt P. Forest damage and snow avalanche flow regime. Natural Hazards and Earth System Sciences. 2015;**15**(6):1275-1288. DOI: 10.5194/nhess-15-1275-2015

[41] Lateltin O, Beer C, Raetzo H, Caron C. Landslides in flysch terranes of Switzerland: Causal factors and climate change. Eclogae Geologicae Helvetiae. 1997;**90**(3):401-406

[42] IPCC. Climate Change 2014: Synthesis Report. In: Team CW, Pachauri RK, Meyer LA, editors. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC: Geneva, Switzerland; 2014. p. 151

[43] Perzl F, Den Outer J, Rössler M. GRAVIPROFOR – Schutzwaldkulisse in der forstlichen Raumplanung. In: Methodik – Datengrundlagen für die Modellierung von Waldflächen mit Lawinen- und Steinschlag-Objektschutzfunktion. Projektsbericht im Auftrag des Bundesministeriums für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft im Rahmen der Technischen Hilfe des österreichischen Programms LE 07-13 mit Unterstützung von Bund, Ländern und der Europäischen Union. Teilbericht. V2. Zahl: BMLFUW-LE.1.3-7/0020-II/5/2012. Innsbruck, Austria: BFW; 2014, 2014

[44] Teich M, Accastello C, Poratelli F, Cocuccioni S, Renner K, Rabanser M, et al. D.T2.4.2 Identification of potentially endangered assets and functional assessment of protection measures in the PARs. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 2 ACTINA)

[45] Protective Forest Assessment Tool (FAT) [Internet]. 2022 Available from: https://gr4a.geocodis.com/

[46] D'Amboise CJL, Žabota B, Poratelli F, Pecan P, Plörer M, Accastello C, et al. A.T1.6 Construction of the innovative and new protective forest assessment tool (FAT). Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[47] Poratelli F, Accastello C, Brun F, Bruzzese S, Blanc S. D.T3.3.1 Report 'TEGRAV analysis: an integrated model to compare risk management strategies'. Torino, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[48] Poratelli F, Accastello C, Brun F, Bruzzese S, Blanc S. D.T3.3.2 Report on 'TEGRAV tool'. Torino, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[49] Kindermann G, Hasenauer H. Reassessing site index functions for tree species in Austria. Austrian Journal of Forest Sciences. 2005;**122**(4):163-184

[50] Kirchner M, Krott M. Integrating forest science into natural hazard management praxis: An international case study based on the innovative RIU approach. International Forestry Review. 2020;**22**(4):449-463. DOI: 10.1505/146554820831255524

[51] Whelchel AW, Reguero BG, van Wesenbeeck B, Renaud FG. Advancing disaster risk reduction through the integration of science, design, and policy into eco-engineering and several global resource management processes. International Journal of Disaster Risk Reduction. 2018;**32**:29-41. DOI: 10.1016/j.ijdrr.2018.02.030

[52] White GF, Kates RW, Burton I. Knowing better and losing even more: The use of knowledge in hazards management. Environmental Hazards. 2001;**3**(3):81-92. DOI: 10.3763/ehaz.2001.0308

[53] Edjossan-Sossou AM, Galvez D, Deck O, Al Heib M, Verdel T, Dupont L, et al. Sustainable risk management strategy selection using a fuzzy multi-criteria decision approach. International Journal of Disaster Risk Reduction. 2020;**45**:101474. DOI: 10.1016/j.ijdrr.2020.101474

[54] Ivčević A, Mazurek H, Siame L, Ben Moussa A, Bellier O. Indicators in risk management: Are they a user-friendly interface between natural hazards and societal responses? Challenges and opportunities after UN Sendai conference in 2015. International Journal of Disaster Risk Reduction. 2019;**41**:101301. DOI: 10.1016/j.ijdrr.2019.101301

[55] Jacobs S, Dendoncker N, Martín-López B, Barton DN, Gomez-Baggethun E, Boeraeve F, et al. A new valuation school: Integrating diverse values of nature in resource and land use decisions. Ecosystem Services. 2016;**22**:213-220. DOI: 10.1016/j.ecoser.2016.11.007

[56] Kirchner M, Stevanov M, Krott M. How to use scientific information: Road map for tailoring your own natural hazard risk management solution. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99518

[57] Klein JA, Tucker CM, Steger CE, Nolin A, Reid R, Hopping KA, et al. An integrated community and ecosystem-based approach to disaster risk reduction in mountain systems. Environmental Science & Policy. 2019;**94**:143-152. DOI: 10.1016/j.envsci.2018.12.034

[58] Terzi S, Torresan S, Schneiderbauer S, Critto A, Zebisch M, Marcomini A. Multi-risk assessment in mountain regions: A review of modelling approaches for climate change adaptation. Journal of Environmental Management. 2019;**232**:759-771. DOI: 10.1016/j.jenvman.2018.11.100

[59] Pedoth L, Carnelli F, Koboltschnig G, Krenn P, Rudloff A, Gallmetzer W, et al. Improving risk communication strategies through public awareness and engagement: Insights from South Tyrol and Carinthia. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London, UK: IntechOpen; 2021. DOI: 10.5772/intechopen.99517

Chapter 10

Cost-Benefit Analysis as a Basis for Risk-Based Rockfall Protection Forest Management

Christine Moos and Luuk Dorren

Abstract

Mountain forests fulfill an important protective effect being the reduction of risk due to natural hazards. Knowing the value of this service is required to efficiently allocate financial resources in protection forest and risk management. In this chapter, we evaluate the protective effect of forests against rockfall at local and regional scale using a risk-based approach. We present a method to quantify rockfall risk under current forest conditions for a case study region along the Gotthard highway (Switzerland). Rockfall runout zones and relative frequencies were determined based on the energy line principle and occurrence frequencies were estimated based on inventory data. We quantified the protective effect of the current forest using a statistical approach and calculated the potential risk without forest. The risk reduction provided by the forest varies between 23 and 60% or 400 and 4500 CHF/(year.ha^{-1}). In a second step, we evaluated a single protection forest complex calculating its Net Present Value (NPV) for a time frame of 100 years based on the risk reduction and compared it to technical protection measures. The NPV of the current forest is positive, whereas protection measure variants including rockfall nets have a highly negative NPV. The results evidence the efficient risk reduction of rockfall protection forests. The presented methods allow for a differentiated procedure for protection forest planning at local and regional scale. A simple risk approach requiring a manageable data set enables practitioners to prioritize forest management. A more detailed economic analysis of protection forest efficiency finally facilitates the planning of protection forest measures at local scale.

Keywords: protection forest, rockfall, risk analysis, net present value, nature-based solution

1. Introduction

Forests provide important protection against rockfall in steep mountain terrain [1]. Thanks to this so-called Nature-based Solution, maintenance and installation costs of technical protection measures, such as dams or nets, are financially bearable or can even be avoided at many places due to the reduction of rockfall rebound heights and impact energies by previous impacts on trees [2]. Furthermore, protection forests fulfill additional functions in terms of wood production, biodiversity or water filtration [3]. Knowing the value of the protection service of mountain forests is key to efficiently allocate financial resources in forest and natural hazard management. A realistic valuation of the protective function of forests, however, can only

be guaranteed if long-term costs and benefits are considered [4]. Often, the value of the protective function of forests is only qualitatively assessed or estimated based on general costs of replacing [5]. However, such approaches, only indirectly quantify the effect of forests on natural hazards and do not account for the potential damage prevented by the forest. A risk-based approach, on the other hand, allows for a translation of the physical effect of trees on the natural hazard process into monetary terms and thus a direct quantification of the avoided costs [6]. The latter are defined as the difference in risk with and without the protective effect of the forest [7]. To support decisions on risk prevention measures, including protection forest management or combinations of different types of measures, a cost–benefit analysis (CBA) is a method that provides standardized and quantified information on the efficacy and efficiency of the analyzed measures [8]. For a realistic long-term economic assessment of risk reduction measures, all costs and benefits must be adjusted to a common point of time, which can be done by calculating the Net Present Value (NPV), being the sum of all future expected benefits and costs discounted to today [9].

Valuing the protection service of the forest can facilitate the prioritization of protection forest management at local, regional and national scale. At local (e.g. slope) scale, a detailed quantification of the protective effect of a protection forest complex (i.e. one or multiple forest stands that protect against a natural hazard process) is required i) for the planning and comparison of risk prevention measures and ii) as basis for an efficient forest management. A valuation of the forest's protective effect at regional (e.g., valley) scale is important for the large-scale planning and prioritization of forest management measures.

In this chapter, we quantify the protective effect of forests against rockfall at local and regional scale using a risk-based approach. We present a simple method to estimate risk and the risk reduction provided by forest at regional scale and then do a profound economic valuation of a single protection forest complex based on a cost–benefit analysis and compare it to technical protection measures. The methodological approaches are presented based on a case study region along the Gotthard highway in Switzerland, where rockfall events frequently end up on the mountain side driving lanes.

2. Risk-based regional protection forest planning

As a basis for prioritization of regional protection forest planning, we determined rockfall risk under the current forest conditions for a case study region along the Gotthard highway based on a simple risk approach. We subsequently used a statistical model to determine the risk reduction potential of the forest in monetary terms (**Figure 1**). The study region comprises a section of the Gotthard highway A2 in Switzerland between Gurtnellen and Wassen with a length of ~5.5 km (Canton Uri; **Figure 2**). This highway section is continuously endangered by rockfall from cliff faces that stretch stepwise from approx. 750 to 2000 m a.s.l. There are several sections (in total ~2.2 km) that are protected by galleries from rockfall and other natural hazard processes.

2.1 Methodology

Rockfall release areas were determined using a slope threshold angle of 50°. We estimated rockfall runout zones based on the energy line principle, using the ELine tool [10], which calculates potential runout cones for each rockfall start cell. In case of multiple start cells, overlaying runout cones allow for a quantification of the reach probability of blocks in a specific cell. Based on these modeled reach probabilities, we calculated a relative reach probability along the highway by defining three probability classes ("low",

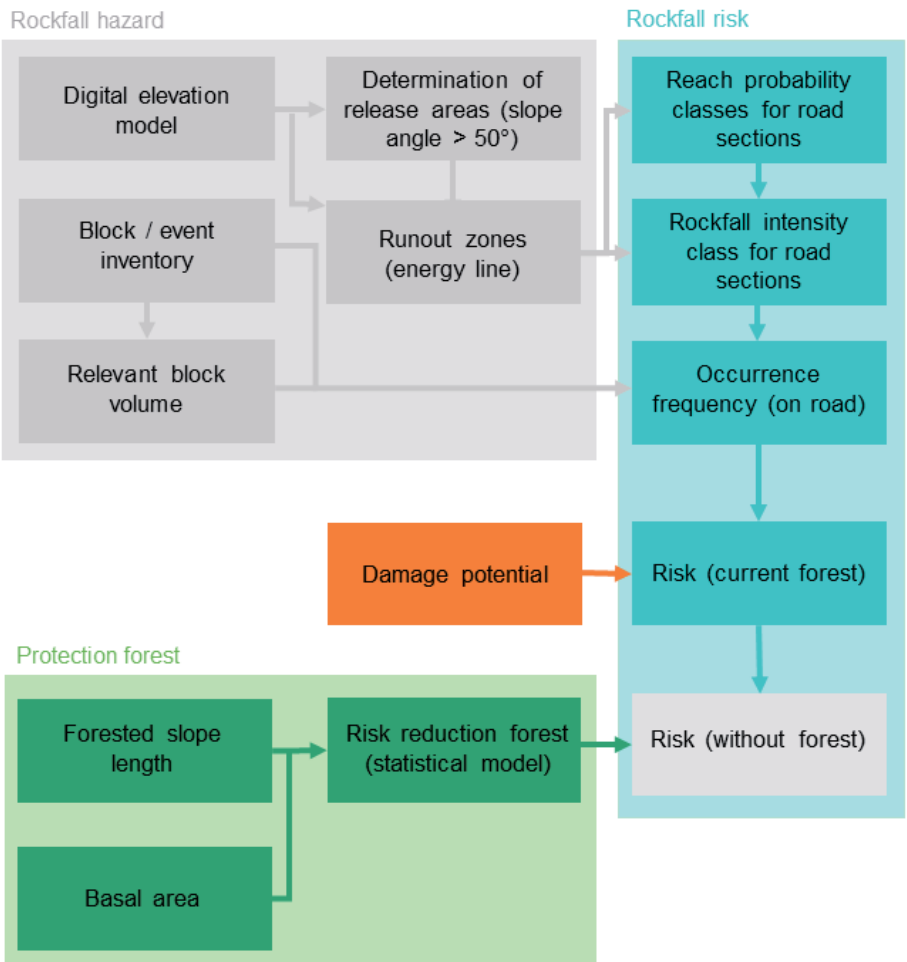


Figure 1.
Flow chart of the methodology for the risk-based evaluation of the protective effect of forests at regional scale.

"medium", "high"). We assumed an energy line angle of 30° for the total study area and additionally calculated runout zones with an angle of 35°, which did not result in changing reach probability classes. The runout zones were determined for a block volume of 2 m^3, which regularly reaches the highway. The occurrence frequency of blocks >= 2 m^3 on the highway was determined based on inventory data from the national road office [11]. The catalog contained 31 events of one or several blocks that reached the highway or stopped in nets just above in 30 years. We therefore assumed in this study an occurrence frequency of 1 rockfall event (>= 2 m^3) per year reaching the highway (galleries excluded). This frequency was then weighted for different highway sectors according to the calculated reach probability classes. We then calculated the yearly rockfall risk (CHF. $yr.^{-1}$) for each section based on [11] and accounted for the damage types "direct impact" (only for regular fluid traffic conditions), "collision" (with rock deposits on the road or other vehicles), "infrastructure damage" and "road closure after a hazard event" (see also [12] for a detailed description of risk calculation). The variable values used for the risk calculation are presented in **Table 1**. Sectors with galleries were not considered in the risk analysis. We used vulnerability values for objects and persons for the intensity classes according to [11]. The monetary value of the element at risk was calculated as the sum of the standardized object value [11] and the monetized value of persons (given as 6,600,000 CHF $person^{-1}$ in Switzerland; [14]).

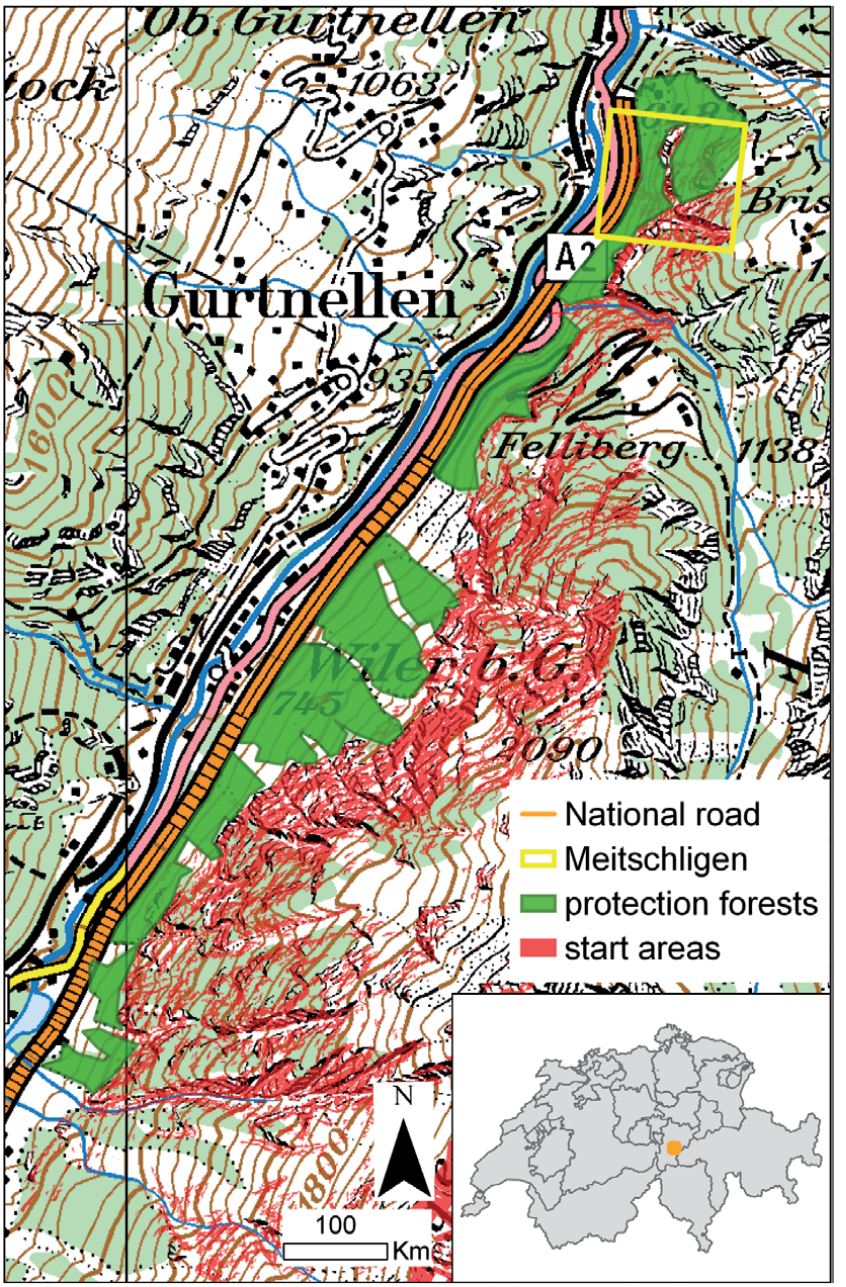


Figure 2.
Study region along the A2 Gotthard highway with protection forest complexes and release area and the local case study site in Meitschlingen.

In order to estimate the risk for the unforested slope, we determined the risk reduction potential of the current forest based on a statistical approach proposed by [13]. The model calculates the relative reduction (in percent) of the rockfall frequency and intensity depending on the basal area of the forest, the forested slope length, the block volume and the horizontal forest structure (e.g., gaps, clustered, ...). We applied it to homogenous forest areas determined based on the forested slope length. Since no regional data on forest structure (e.g. cantonal forest inventory) was available, we assumed a basal area of 15 ("bad forest condition") and 30

Variable	Value	Unit	Source
Mean daily traffic (MDT)	22,500	vehicles.day^{-1}	www.astra.admin.ch
Indicated maximum speed on the highway section	100	km.h^{-1}	Field observation
Forest intervention costs (harvesting + preparation, road maintenance)	110	CHF.m^{-3}	[13]
Revenue from wood sales	75	CHF.m^{-3}	idem.
Net installation costs (200 kJ)	1,200	CHF.m^{-1}	[4]
Net installation costs (500 kJ)	1,500	CHF.m^{-1}	idem.
Net installation costs (5000 kJ)	4,500	CHF.m^{-1}	idem.
Discount rate (mean value last 30 years in CH)	2	%	idem.
Road closure costs	87,000	CHF.day^{-1}	[11]
Costs of human life	6,6 Mio	CHF	[14]

Table 1.
Values and their sources of variables used for the calculation of risks and the NPV.

("good forest condition") m^2.ha^{-1}, respectively, covering a realistic range determined based on the forest data available from the local case study (see section 3). We only calculated frequency reduction, since we used intensity classes in the risk analysis and a direct translation of the forest effect is not applicable. Based on the derived risk without forest, we were able to assess the risk reduction provided by the forest per road section in monetary terms (CHF.yr.$^{-1}$).

2.2 Results

The risk on the total section for the current situation with forest amounts to ~330,000 CHF.yr.$^{-1}$ (**Table 2**). More than two thirds stem from direct impacts and 25% from road closure after hazard events. In other words, one fatality due to direct impacts is expected every 30 years on average. The risk reduction provided by the forest varies between 15 and 55% under good forest conditions and 0 and 30% under relatively bad forest conditions (i.e., regarding rockfall protection), respectively (**Table 2**). This results in a yearly risk reduction between 800 and 2,500 CHF and 0 and 1,000 CHF, respectively, per ha protection forest (**Figure 3**). Based on the calculated risk reduction, the total risk would increase to ~470,000 CHF.yr.$^{-1}$ without forest.

Section	Total risk with forest [CHF.yr.$^{-1}$]	Risk reduction forest (range) [%]	Total risk without forest (range) [CHF.yr.$^{-1}$]
1	13,800	0	13,800
3	19,000	0–15	19,000–22,300
5	52,200	0–16	52,200–62,400
7	113,700	30–55	157,000–208,700
9	90,300	0–21	90,300–114,600
10	40,800	0–15	40,800–48,100

Table 2.
*Calculated total risk with and without forest for the road sections (see **Figure 3**; without galleries) and risk reduction provided by the forest (reported as range for a forest with a basal area of 15 or 30 m^2.ha^{-1}).*

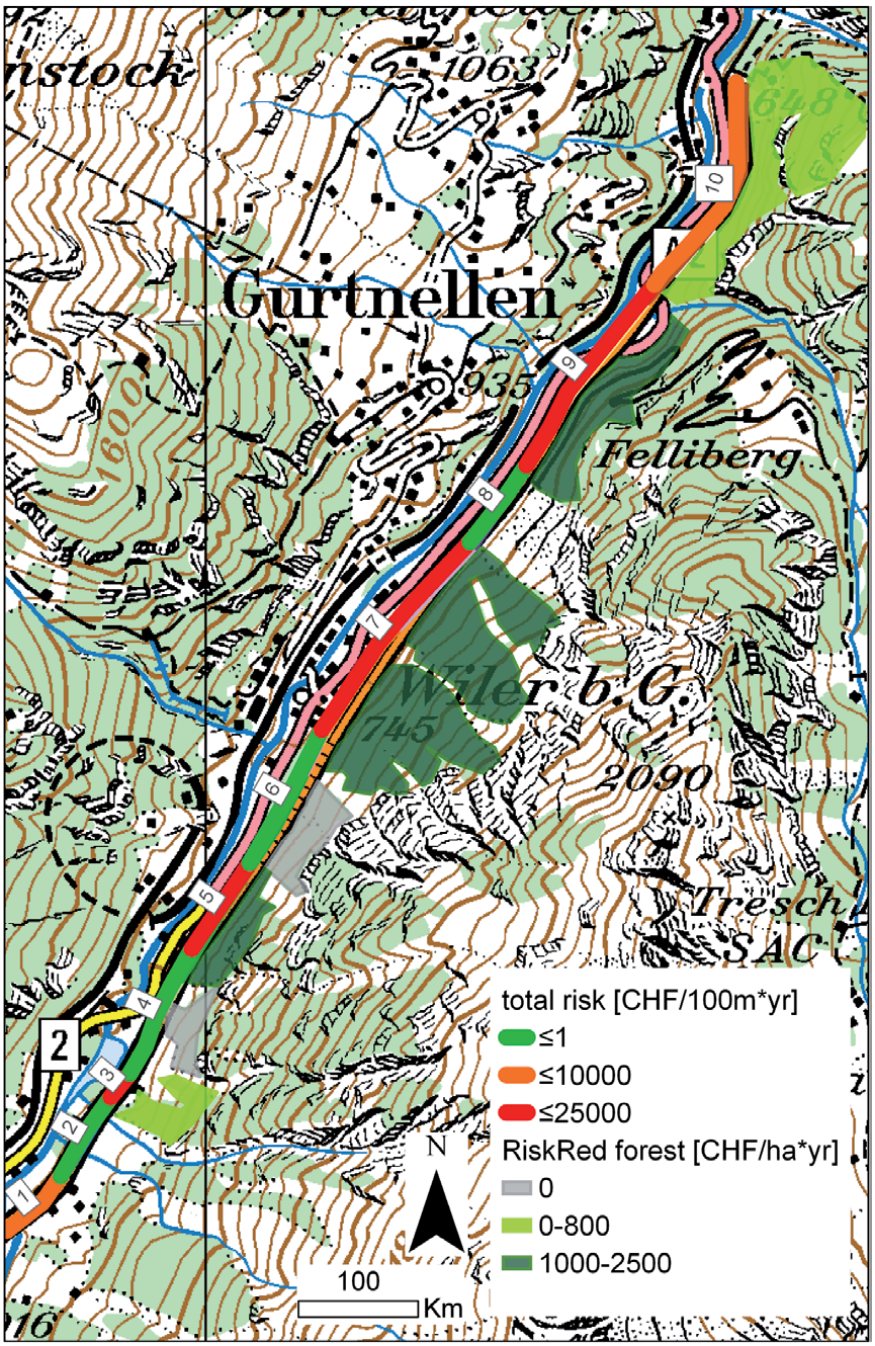


Figure 3.
Total risk with the current forest along the considered highway section, and risk reduction provided by the protection forest complexes.

3. Risk-based protection forest assessment at local scale

As a basis for comprehensive forest management at local scale, we economically assessed the performance of a particular protection forest complex in the study region and compared it to structural protective measures and a combined approach

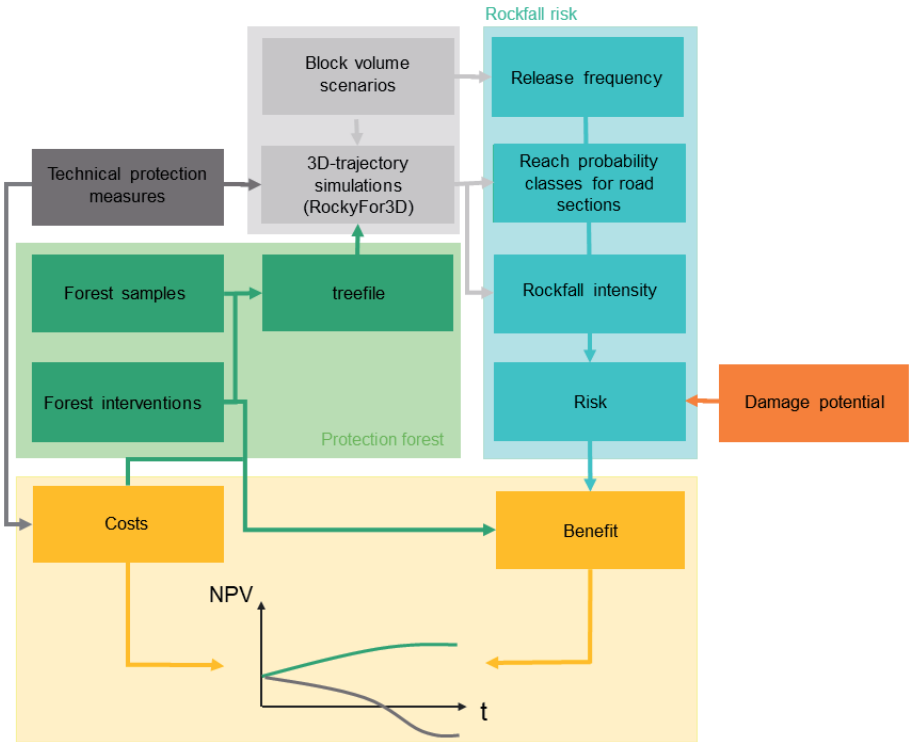


Figure 4.
Flow chart of the methodology for the economic evaluation of a protection forest at local scale based on the calculation of the net present value (NPV).

(**Figure 4**). The chosen site is the Gotthard highway section between Meitschligen and Stotzigwald (**Figure 2**).

3.1 Methodology

We determined the net present value (NPV) of the current forest with a management scenario of gap cuttings that aims at promoting regeneration (variant 1) and compared it to i) a combination of variant 1 and the currently installed flexible nets (variant 2), and ii) only currently installed flexible nets, without trees (variant 3). To determine the benefit (i.e., risk reduction), we compared the risk with a given protection measure variant with the situation without protective measures (no trees and no nets). This is the "baseline" variant.

To calculate the risk for a given protection measure, we modeled the propagation of single rectangular blocks with a maximum volume of 1, 2 and 15 m^3 with the three-dimensional rockfall trajectory software Rockyfor3D [15]. The topography was defined by a digital elevation model (DEM) with a resolution of 2 x 2 m and soil types and roughness were mapped in the field. Forest stands were delineated with orthophotos and field inventory plots. For each stand, we measured trees with a stem diameter at breast height (DBH) larger than 8 cm in randomly sampled plots of 20 by 20 meters. All trees were recorded. Subsequently, the mean DBH, the standard deviation of the DBH, the number of stems per hectare and the proportion of coniferous trees were calculated for each stand. Rockyfor3D uses this data to create a forest model consisting of individual trees with their position and DBH. We assumed that every 20 years, 25% of the total standing volume would be removed

Variant	Total risk [CHF.yr.$^{-1}$]	Difference with baseline variant [CHF.yr.$^{-1}$]	NPV [1000 CHF]	Benefit–cost ratio [–]
"Baseline" (no trees, no nets)	30,647	—	—	—
1 (current forest/no nets)	25,493	5,154	110	1.79
2 (variant 1 + current nets)	23,464	7,182	-1,314	0.24
3 (variant 1 + maximum nets)	19,743	10,904	–10,814	0.05
4 (current nets, no trees)	29,690	956	–1,469	0.04

Table 3.
Total risk per year, risk reduction (difference to baseline variant), NPV and benefit–cost ratio per protection measure variant for the case study site in Meitschligen.

by using cable crane lines and lateral regeneration gap cuttings of 20 by 30 m. We removed the trees in the intervention gaps from the generated forest model and simulated rockfall trajectories and calculated the change in risk reduction after a forest intervention. The current mean standing volume per ha is 575 m^3 (i.e., almost 6000 m^3 on 10.4 ha). The net costs of a single forest intervention add up to 165,808 CHF (intervention costs) – 113,098 CHF (revenue of wood sales) = 57,710 CHF.

The rock type is gneiss and we defined its density as 2700 kg.m^{-3}. The used block volumes were defined by a geological engineering consulting firm commissioned by the Swiss Federal Roads Office FEDRO for a hazard analysis in 2010. The attributed onset probabilities (detachment probability at the rockfall cliffs) were 0.067 (10-year recurrence interval – 1 m^3), 0.023 (30-year recurrence interval – 2 m^3), 0.007 (100-year recurrence interval – 15 m^3) and 0.003 (300-year recurrence interval – 15 m^3). The difference between the 100- and 300-year recurrence interval was determined by the number of individual blocks that descend the slope, which was randomly set to 2 to 5 blocks for the 100- and 4 to 8 blocks for the 300-year recurrence interval. The 10-year recurrence interval was a fixed single block scenario, while the 30-year recurrence interval was a randomized 1 to 3 block(s) scenario.

Upslope along the highway we placed a virtual control screen allowing for recording all relevant data for the risk calculation (number of passed rocks, energy distribution, passing height distribution). For each defined block volume and variant, we simulated 1000 trajectories per release cell.

As for the large-scale study, our risk calculation was based on [10] and accounted for the same damage types. We then calculated the NPV, based on the defined recurrence intervals, following:

$$NPV = \sum_{t=1}^{100} \frac{\left[I(w) + I(rr)\right] - \left[O(n) + O(m) + O(f)\right]}{\left[1+i\right]^t}$$

Where I(w) = revenue from wood sales (CHF); I(rr) = risk reduction (CHF); O(n): costs for installing flexible nets (CHF); O(m) = operation and maintenance costs for the flexible nets (CHF); O(f) = costs for forest interventions (CHF); i = discount rate; t = year.

Values for the variables we used for the calculation of risks and the NPV, are presented in **Table 1**. We here focused on the risk calculation on the highway only.

3.2 Results

The total risk per year (sum of the risk for the four defined rockfall recurrence intervals) for both the baseline and protection forest variant is given in **Table 3**. The current forest (without nets) provides a risk reduction of 5,154 CHF.yr.$^{-1}$. In combination with nets, the risk reduction is increased up to 10,900 CHF.yr.$^{-1}$. However, only the NPV of variant 1 (current forest without nets) is positive. All variants with nets have a distinctly negative NPV due to the high investment and maintenance costs of the rockfall nets.

4. Discussion and conclusions

The here presented large-scale risk assessment evinced a substantial risk reduction between 500 and 5000 CHF.(ha.yr)$^{-1}$ of the current protection forest along the Gotthard highway. Without the forest, risk would increase up to 150%. When additionally considering the reduction of rockfall intensity (and not only rockfall frequency), risk could even increase more. The proposed methodology allows for a simple estimation of risk and the protective effect of the forest and thus serves as an ideal basis for a rough prioritization of protection forest management at regional scale. Assuming that silvicultural interventions in a protection forest complex are required approximately once per 20 to 30 years and that they cost 12,500 CHF per hectare and intervention (maximum federal contribution to protection forest intervention in Switzerland; [16]), protection forest management is with yearly costs of ~500 CHF highly efficient. For this, however, a basal area of minimum 30 m^2.ha^{-1} is required. How much a forest reduces risk depends strongly on its structure and state. A low tree density and a short forested slope length can critically reduce the protective capacity [13, 17]. Thus, spatial data on forest structure are required to satisfactorily predict the risk reduction of the forest. In this study, such data was partially missing why we calculated risk reduction for a range of the basal area. Furthermore, the block volume strongly influences the protective effect of forests. This effect was greatly simplified by considering rockfall risk generalized for block volumes >= 2 m^3.

For a risk-based planning of protection forest management at local scale, a more detailed approach is necessary. The calculation of the NPV of a protection forest complex based on its risk reduction allowed for a long-term economic valuation of the protection service and a comparison to technical measures and combined approaches. Although the variant forest + nets provides the highest risk reduction, its NPV is highly negative (−1 million CHF over a period of 100 years) and its benefit–cost ratio is 0.05. Variant 1 (forest with management and no nets) is the only one with a positive NPV. This variant is also the only one with a benefit–cost ratio larger than 1. Comparing variant 1 to variant 4 (nets without forest) shows a substantial increase of the efficacy of the forest-nets combination with an increased risk reduction of more than 400%. Hence, combining forests and nets can significantly increase the risk mitigation capacity of nets.

Finally, the results from the regional study are in good agreement with the detailed analysis on local scale (i.e., the Gotthard highway section between Meitschligen and Stotzigwald used for the local scale study corresponds to 60% of the highway section nr. 10 in the regional study). On regional scale, we calculated a risk of 40,800 CHF.yr.$^{-1}$ and a risk reduction of the forest of 7,200 CHF.yr.$^{-1}$ for a forest with a basal area of 30 m^2.ha^{-1} in the respective section. In the local study, we revealed a risk of 25,400 CHF.yr.$^{-1}$ and a risk reduction of 5,200 CHF.yr.$^{-1}$. This indicates that the on large scale estimated risk reduction of the forest covers a realistic range.

The presented methods allow for a differentiated procedure for protection forest planning at different scales. At regional scale, the combination of a simple risk approach and a statistical model enables practitioners to determine the risk reducing effect of the forest as basis for prioritization of forest management measures. Currently, prioritization is mainly done on the basis of Eisenhower's Urgency/Importance principle, where urgency is determined by the state of the protection forest and importance on the provided protection. The latter however, is based on a rapid qualitative expert appraisal, which can be more objective based on the method proposed in this chapter. The method requires mainly i) elevation and land cover data for a rough estimation of rockfall runout and intensities; ii) basic data on the damage potential; and iii) spatial data on forest cover (i.e. basal area and forested slope length). At local scale, more detailed data on rockfall frequency and runout as well as on forest structure and the costs and benefits of protection forest interventions are necessary to conduct a detailed economic evaluation of the protection forest service. Such an evaluation allows practitioners for planning efficient (both economically reasonable and sufficiently effective) protective measure variants that take protection forests, including the required silvicultural interventions, into account. For additional risk-based evaluation approaches of forests' protective effects against gravitational natural hazards see chapters [18–20] of this book.

Conflict of interest

The authors declare no conflict of interest.

Author details

Christine Moos[1*] and Luuk Dorren[2]

1 Interdisciplinary Centre for Mountain Research, University of Lausanne, Sion, Switzerland

2 Bern University of Applied Sciences, School for Agricultural, Forest and Food Sciences HAFL, Zollikofen, Switzerland

*Address all correspondence to: christine.moos@unil.ch

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Brang P, Schönenberger W, Ott E, Gardner B. Forests as protection from natural hazards. The forests handbook. In: Evans J, editor. The Forest Handbook Volume 2, Applying Forest Science for Sustainable Management. Blackwell Science; 2001. pp. 53-81. DOI: 10.1002/9780470757079.ch3

[2] Getzner M, Gutheil-Knopp-Kirchwald G, Kreimer E, Kirchmeir H, Huber M. Gravitational natural hazards: Valuing the protective function of Alpine forests. Forest Policy and Economics. 2017;**80**:150-159

[3] Miura S, Amacher M, Hofer T, San-Miguel-Ayanz T, Ernawati, Thackway R. Protective functions and ecosystem services of global forests in the past quarter-century. Forest Ecology and Management. 2015;**352**:35-46

[4] Moos C, Thomas M, Pauli B, Bergkamp G, Stoffel M, Dorren L. Economic valuation of ecosystem-based rockfall risk reduction considering disturbances and comparison to structural measures. Sci Total Environ. 2019;**697**:134077

[5] Häyhä T, Franzese PP, Paletto A, Fath BD. Assessing, valuing, and mapping ecosystem services in Alpine forests. Ecosystem Services. 2015;**14**:12-24

[6] Moos C, Bebi P, Schwarz M, Stoffel M, Sudmeier-Rieux K, Dorren L. Ecosystem-based disaster risk reduction in mountains. Earth-Science Reviews. 2018;**177**:497-513

[7] Grêt-Regamey A, Bebi P, Bishop ID, Smid WA. Linking GIS-based models to value ecosystem services in an Alpine region. Journal of Environmental Management. 2008;**89**(3);197-208

[8] Mechler R. Reviewing estimates of the economic efficiency of disaster risk management: Opportunities and limitations of using risk-based cost–benefit analysis. Natural Hazards. 2016;**81**(3):2121-2147

[9] Spangenberg JH, Settele J. Precisely incorrect? Monetising the value of ecosystem services. Ecological Complexity. 2010;**7**(3):327-337

[10] Dorren L, Zuanon N. ELine – Energy Line Calculation. 2019: ecorisQ – International association for natural hazard risk management. Available from: https://www.ecorisq.org/ecorisq-tools

[11] FEDRO. Natural hazards on national roads: Risk concept. Methodology for risk-based assessment, prevention and response to gravitative natural hazards on national roads. Documentation 89001, V2.10. 2012, Bern: Federal Roads Office FEDRO. Available from: https://www.astra.admin.ch/astra/de/home/fachleute/dokumente-nationalstrassen/standards/risiko-sicherheitsmanagement.html

[12] Moos C, Fehlmann M, Trappmann D, Stoffel M, Dorren L. Integrating the mitigating effect of forests into quantitative rockfall risk analysis – Two case studies in Switzerland. International Journal of Disaster Risk Reduction. 2018;**32**:55-74

[13] Moos C, Dorren L, Stoffel M. Quantifying the effect of forests on frequency and intensity of rockfalls. Natural Hazards and Earth System Sciences. 2017;**17**(2):291-304

[14] FOEN. EconoMe 5.0. Effectiveness and Efficiency of Protection Measures against Natural Hazards. 2020, Bern: Federal Office for the Environment, FOEN. Available from: https://econome.ch/eco_work/

[15] Dorren L. Rockyfor3D (v5.2) revealed – Transparent description of

the complete 3D rockfall model. 2016: ecorisQ paper (www.ecorisq.org): 32 p. Available from: https://www.ecorisq.org/docs/Rockyfor3D_v5_2_EN.pdf

[16] FOEN. Handbuch Programmvereinbarungen im Umweltbereich. Mitteilungen des BAFU als Vollzugsbehörde an Gesuchsteller. Bern: Bundesamt für Umwelt/Federal Office of Environment; 2018

[17] Dupire S, Bourrier F, Monnet JM, Bigot S, Borgniet L, Berger F, Curt T. Novel quantitative indicators to characterize the protective effect of mountain forests against rockfall. Ecological Indicators. 2016;**67**:98-107

[18] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise C J L, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[19] Bebi P, Bast A, Helzel K P, Schmucki G, Brozova N, Bühler Y. Avalanche protection forest: From process knowledge to interactive maps. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99514

[20] Stritih A. Dealing with uncertainties in the assessment of the avalanche protective effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99515

Chapter 11

Avalanche Protection Forest: From Process Knowledge to Interactive Maps

Peter Bebi, Alexander Bast, Kevin Helzel, Gregor Schmucki, Natalie Brozova and Yves Bühler

Abstract

In order to prioritize protection forest management, it is essential to know where forests have an effect on avalanches and which criteria the forests have to meet to avoid avalanche releases and reduce avalanche runout distances. This contribution outlines how the current assessment of effective protection forest can be improved by combining process knowledge on forest-avalanche interactions with newly available remote sensing data, large-scale numerical modeling and cartographic visualization techniques. Within the scope of a practical application in the Canton of Grisons (Central Swiss Alps), we showcase how scenario-specific avalanche protection forest maps have been developed and implemented into natural hazard indication maps in collaboration with avalanche modelers and practitioners. We outline further developments of such combined information towards interactive, web-based decision support tools based on resulting maps of effective avalanche protection forests.

Keywords: hazard indication maps, snow avalanches, interactive maps, remote sensing, protection forest

1. Introduction

Large scale hazard indication maps of avalanche protection provide an overview of areas potentially endangered by snow avalanches [1]. Such hazard maps serve in Switzerland also as a basis to define the extent of avalanche protection forests [2]. The first available hazard indication maps of avalanche protection at the beginning of the 21st century [2, 3] were based on a relatively coarse 25-m digital elevation model and simple forest vs. non-forest scenarios. In the meantime, we have increasingly advanced remote sensing data such as airborne LiDAR data and, in particular, highly resolved digital elevation models [4, 5], and additional and refined knowledge on avalanche-forest interactions [6, 7]. In this contribution we outline how we can take advantage of newly available process knowledge, refined spatial data and numerical modeling to improve avalanche protection forest maps, related applications and visualizations.

IntechOpen

2. Process knowledge: avalanche protective effects of forest

The main effects of avalanche protection forests are that avalanches do generally not release in sufficiently dense forest and that smaller avalanches can be slowed down or stopped by forest [6–8]. These effects are not only influenced by the forest structure but also by topographical factors and the properties and thickness of the snow cover. Critical thresholds for the spontaneous release of avalanches can be different inside the forest compared to the open field. For example, avalanches in forests mainly occur on slopes with an inclination of at least 35° [9], whereas in open areas, they may also occur in less steep terrain below 30° [10]. The surface roughness of the terrain is a crucial factor, at least as long as the snow cover thickness in the forest does not exceed the effective height of the dominant objects such as trees, root plates, logs or deposited rocks [11].

There are essentially four physical processes that contribute to the stabilization of the snow cover in forests: (1) Interception of falling snow: snow is partly intercepted on branches and sublimated back into the atmosphere [12]. Intercepted snow, which is not sublimated, enters the snowpack in the form of snow lumps or meltwater [13]. (2) More balanced radiation regime: the duration of solar radiation and the long-wave radiation during the night are reduced in forests compared to open field [14, 15]. (3) Reduced wind speeds: within the forest, near-surface wind speeds are lower than in the open [16]. (4) Direct mechanical support: standing trees, but also lying dead wood, stumps, and root plates help to stabilize the snow cover with their reinforcing effect and increase the roughness of the terrain [6, 17].

As a result of these four processes, crown coverage, gap sizes and slope angle are considered the most essential characteristics for avalanche prevention in forests (see also chapter [18] of this book). Critical thresholds can be estimated from the retro analysis of events in relation to the topographical factors and snow properties [19, 20]. Based on such studies, critical lengths of forest gaps in the fall line are usually given in the range between 25 and 60 m, depending on slope inclination [18, 21]. Some authors also propose to use the height of the trees for defining the length and width of these gaps [22]. The size of gaps is also decisive in determining whether a small-medium scale avalanche (< 10′000 m^3) that starts in the forest can potentially develop into a large avalanche (≥10′000 m^3). The minimum gap width required to form avalanches is generally smaller in deciduous forests (approx. 5–10 m) than in evergreen forests (approx. 15–20 m), with considerable variation depending on steepness, terrain roughness and snow conditions. Smaller avalanches, which start in the forest or 100–200 m above the forest line, can come to a stop depending on the forest structure, topography and snow characteristics in the forest. The braking effect of the forest is a consequence of various interactions between avalanches and trees [6, 7] but is for large-scale hazard mapping usually simplified and modeled with a friction approach [8].

3. From process knowledge to maps

In order to create large-scale and applicable maps of forests with a protective effect and/or protective function (protection forest maps), it is necessary to deduce criteria from existing process knowledge and combine them with appropriate remote sensing and other available GIS-Data. For a hazard indication mapping project in the Canton of Grisons (Eastern Switzerland) we consequently aimed at the following criteria for the delineation of avalanche protection forest (**Figure 1** and **Table 1**):

1. Based on existing data: We used data on 150 avalanches released in forested terrain of the Swiss Alps and deduced a logistic regression model to quantify the effect of topographical and forest structural variables ([19, 20], **Table 1**).

2. Comprehensive and automatized: We aimed for a completely automatized and comprehensible delineation of the protection forest for the whole area of the Canton Grisons. Thus, it is necessary that all variables and criteria used to delineate the forest with an avalanche protective function and effect could be spatially deduced from newly available remote sensing data and/or additional GIS data, which are available for the whole Canton of Grisons and can potentially be repeated later with updated forest data.

3. Verified and optimized: The delineation of the avalanche protection forest had to be verified and further adapted by knowledge from scientists and local natural hazard and forest experts. In order to verify the effect of the forest structure on avalanche runout, an additional optimization loop had to be conducted after the simulation with the avalanche simulation software RAMMS [8, 23].

A central component within this framework is the logistic regression model calculated with the most important variables "slope inclination", "percentage of crown cover" and "gap width", adapted from [20]. Those variables were implemented within a GIS approach. The algorithm is described in detail in **Table 1**. Based on spatial input data sets (e.g., vegetation height model [VHM] and digital terrain model [DTM]) [24] and various GIS operations, we calculated an "avalanche disposition" between 0 (no disposition) and 100% (very high avalanche release probability). To minimize the calculation time, a forest mask was used to delimit the calculation domain of the model. This forest mask consists of a combination of forest areas defined by the Federal Office of Topography (Swisstopo) and the Swiss National Forest Inventory, NFI [4, 25]. We defined different threshold values for tree heights to assign forest gaps ("Gap-threshold") and forest cover ("Forest cover-threshold") for different avalanche scenarios (frequent scenario vs. extreme scenario according for regionally expected snow-heights snow heights according to [28]). Additionally, we accounted for two factors which could not be quantitatively deduced from the original logistic

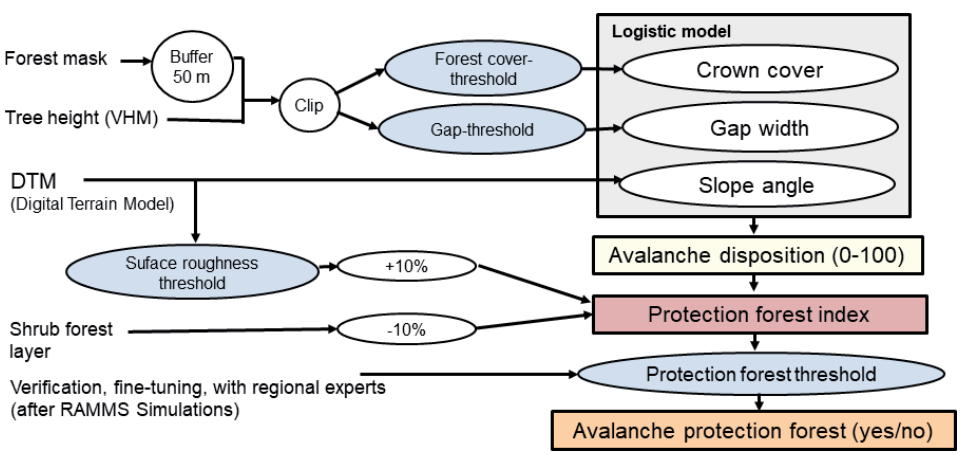


Figure 1.
Schematic structure of the model for calculating the spatial extend of avalanche protection forest. The core of the disposition model is a logistic model based on avalanche releases in forested terrain [23]. A vegetation height model (VHM) [3], a digital terrain model (DTM) [24], a forest mask [3, 25], a shrub layer [26] and a surface roughness layer according to [27] were used as input GIS-data.

Considered variables and threshold	Definition
Crown cover	The higher the crown cover, the lower the likelihood of an avalanche release. The crown cover is calculated based on a percentual proportion of pixels with a higher VHM value than the crown cover threshold. This procedure is done within a 5 m and 25 m environment, and the arithmetical mean is calculated.
Gap width	Pixels that have a lower VHM value than the Gap-threshold (see definition below) are considered as a gap. If multiple gap pixels are adjacent to each other, a polygon is drawn, which represents the gap. The gap polygon is intersected with the contour lines to extract gap width. The length of the contour line represents the width of the gap. Gaps smaller than 500 m^2 were neglected after verification of avalanche runout with RAMMS simulations. To get homogeneous results, the mean over a 10 m environment is calculated.
Slope angle	The angle of the slope was calculated based on a 10-m DTM. Values lower than 28° and higher 48° are considered as constant. In the range within 28 and 48° an increase of inclination is expected to lead to a higher potential for an avalanche release.
Forest cover-threshold	In order to take into account the coverage at different spatial scales and to optimize the detection of trees, especially in a critical range between 3 and 5 m, the following VHM limits have been set: • Frequent event: 4 m for 5 × 5 m and 3 m for 25 × 25 m environment • Rare event: 5 m for 5 × 5 m and 4 m for 25 × 25 m environment
Gap-threshold	The local snow depth for a 100-years event was calculated according to [28] and corrected by a factor of 0.85 for frequent and 1.14 for rare events. The calculated snow heights multiplied by the factor 1.5 according to Protect-Bio [29] results in the respective tree height limit. To compensate for underestimations of tree heights within the VHM, a constant height was subtracted from the VHM raster value.
Surface roughness	The surface roughness influences the likelihood of an avalanche release, especially when the snow height is low. The roughness was calculated with the "Vector Ruggedness Measure" (VRM) according to [27] based on a 2-m DTM (SwissAlti3D) and a moving window of 5 × 5 m. Based on empirical comparisons, areas with a value > 0.02 are considered as rough. For rough areas that do not show lateral convex curvature an increase of 10% of the avalanche disposition is accounted for.
Shrub forest	Shrub forests tend to protect less against an avalanche release. Trees such as green alder *Alnus viridis* (Chaix.) DC. or the shrub form of mountain pine *Pinus mugo* have more flexible stems than upright trees of the same size. Thus, they are pressed down by snow. We address the limited protection capability of shrub forests by assigning a decrease of 10% of the avalanche disposition for all areas classified as shrub forests according to [26].
Avalanche disposition	Statistically deduced disposition of each pixel to be part of an avalanche release area, given as a value from 0 to 1 according to a logistic model with following formula: $\text{Logit}_{(\text{release } 1/0)} = -6.17 + 0.18 * \text{slope angle } [°] - 0.03 * \text{crown cover } [\%] - 0.05 * \text{gap width } [m]$.
Protection forest index	Index calculated from avalanche disposition and additional parameters (roughness, shrub forest) (may have values from −10 to 110)
Protection forest-threshold	The threshold for the protection forest index, based on validation in well-documented areas. Threshold values for fulfilled protective effect were: • Frequent scenario: forest with a protection forest index < 65 • Extreme scenario: forest with protection forest index < 85

Table 1.
Variables, threshold values and definitions for delineating avalanche protection forest for a frequent (ca. 10–30 years event) and extreme (ca. 100–300 years event) scenario.

model, but which turned out to be of additional relevance and for which spatial data were available for the whole canton: (1) a scrub forest area layer [26] helped to assign an adequately higher avalanche disposition to areas covered by shrubs. (2) We delineated areas with a high surface roughness from a high resolution DTM, and which

do not show lateral convex curvature. With this combined requirement, we could exclude vertical gullies with high terrain roughness, as they are known for frequent avalanche release. Based on (1) and (2), we assigned higher values to the protection forest index for areas with considerable terrain roughness and lower values for areas that are covered by shrub forests (**Figure 1**). The resulting "protection forest index" builds the basis for the protection forest maps. The exact threshold values defining a sufficient protection forest index for frequent (ca. 10–30 years return period), and extreme (ca. 100–300 years return period) scenarios could then be defined in an iterative process after validating avalanche simulations with former avalanche events and after discussing different scenarios (with and without forests) together with the responsible regional natural hazard experts [23].

The avalanche protection forest map for the Canton of Grisons (**Figure 2**) is thus the result of an iterative process starting with an empirical statistical model of avalanche releases in forested terrain and was subsequently improved in several working and validation loops. The iterative process allowed us, for example, to better account for the stopping behavior of small and very small avalanches in forested terrain and how these processes are simulated with the avalanche dynamics software RAMMS [8]. In the applied model, the turbulent friction ξ (Xi) is set to a very high value, simulating the braking effect of the forest. Other adaptations introduced after validation loops included a stronger representation of surface roughness, leading to an increase in the protection forest index of forests with high surface roughness and may shift the categorization for some forests with a relatively open forest structure but a high surface roughness. Additionally, we considered differences between actual tree heights and how these tree heights were assessed with the available vegetation height models [3, 30]. Besides validating the forest cover map after the simulation of avalanches and besides the feedback of regional experts, it was also essential to validate the delineation of the avalanche protection forest maps specifically in well-investigated areas with known tree heights and avalanche history.

While all these validation procedures improved the quality and applicability of our map, more progress is possible during the following years by applying the map in practice and by introducing additional spatial data sets on forest characteristics. Therefore, the map will be updated once (i) reliable tree species maps are available

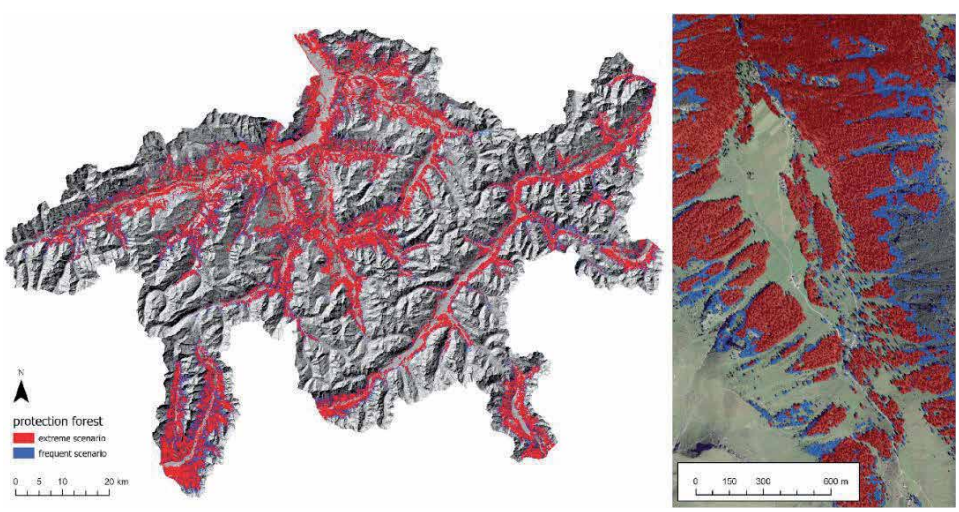


Figure 2.
Protection forest map for the Canton Grisons for a frequent avalanche scenario (corresponding to avalanche events with a 10–30-year return period, displayed in blue and red combined) and for an extreme snow cover scenario (corresponding to a ca. 100–300-year avalanche event, displayed in red).

in order for better consideration of the protective capacity of different forest types (e.g., forests dominated by evergreen coniferous trees, deciduous conifers or broadleaved trees) or (ii) after an improved understanding of the effect and the assessment of different surface roughness categories.

4. From static to interactive mapping

Two-dimensional protection forest, hazard indication or risk maps are still the standard application in the administration and consulting offices. Nevertheless, modern cartographic visualization strategies go far beyond showing a static portray of reality at a given point in time. Especially new advances in web technologies and multimedia integration, known as "web mapping", make it possible to create easily shareable, user-friendly and robust web applications via different (mobile) devices such as smartphones, tablets or personal computers.

As forests undergo permanent and often abrupt changes in time, protection forest maps should be updated when more data or better process knowledge is available and after relevant changes in the forest structure. Map updates are particularly important with expected changes due to climate change and important legacies of past land use and expected increases in the frequency and severity of natural disturbances [30]. The development from static, two-dimensional maps to dynamic, interactive maps in a 3-D environment with possibilities to regularly update the visualization of protective effects in response to different forest scenarios would not only be a logical response to the increasing availability of spatial data, cartographic capabilities and computing capacity, but also a response to increasing practical needs. Compared to existing maps, dynamic maps enable to track effects of changes to the forest cover due to natural disturbances and different management scenarios on the protective capacity and other forest functions.

Based on the avalanche protection forest layer presented in this contribution, the avalanche hazard indication map for the Canton of Grisons [31] was compiled and mapped for the first time with an interactive visualization platform (maps.wsl.ch), which is currently being developed at the WSL Institute for Snow and Avalanche Research SLF in Davos, Switzerland. In a first step, the latest findings on protection forests, RAMMS simulations of various avalanche scenarios and topographical and asset data such as buildings or roads were combined into an interactive user experience.

For the implementation, basic criteria were defined for the cartographic representation and the functional scopes of the interactive maps. In addition to a traditional two-dimensional map view, the user is offered a three-dimensional, spatial form of representation. Within this 3-D representation, all functions of "traditional" web mapping and other functions beyond are available. This means that the map reacts directly to the user, attributes and geometric data are linked, and interactive legends and diagrams are available. This encompasses the well-known functions of zooming, panning, perspective, 3-D navigation and flights through digital elevation models and three-dimensional objects like buildings or snow avalanche release areas, selection, print or an extended search function. The latest functions include the individual selection of layers, the retrieval of information via pop-ups, the creation of own bookmarks for quick navigation, the measurement of distances and areas in three-dimensional space as well as the personal editing of certain layers and the integration of shapefiles. The integration of shapefiles allows the user to upload recorded field data, for instance, and thus to overlay this data with the map content for visual analysis or prints. The functionality and design of the application will be improved in the future depending on the needs of the users and the progress in avalanche modeling.

The development of interactive web maps can broadly be categorized into three parts: 1) data preparation and visualization, 2) user interface design, and 3) application development. Hence, the map itself is only one element in a more prominent programmatically framework of digital cartography. For the detailed analysis and necessary transformations of the geospatial data that will be part of the application (step 1), conventional GIS software is used. Most of the layers are also being visualized at this stage. In order to keep the application lightweight in storage, all map data is being uploaded to a cloud or, respectively, a hosting data server. The user interface design is carried out with HTML and CSS (step 2), while for most of the application development, including all the functional parts, the programming language JavaScript is the main component. Finally, the application has to be run through a web server (maps.wsl.ch) responsible for distributing all necessary files to the client's web browser (step 3).

In addition to the existing range of functions, the interactive maps are made to be increasingly dynamic. This is an updating of the map contents, which the user can also do. For example, a forester may digitize, edit and upload areas where forest disturbances such as windthrow, insect outbreaks or forest fires occurred or where a forest intervention is planned or implemented. However, providing modeling software as RAMMS via web service is neither possible nor planned so far.

Drone images or other collected data such as forest inventory data or climate data can provide additional information on selected sites (hotspots). Such dynamic, interactive maps will not only allow a user-friendly way to represent different forest scenarios or changes in forests, natural hazards or resulting risk but can also be used as a tool for (forest) planning or for consulting issues as well as for teaching and research (**Figure 3**).

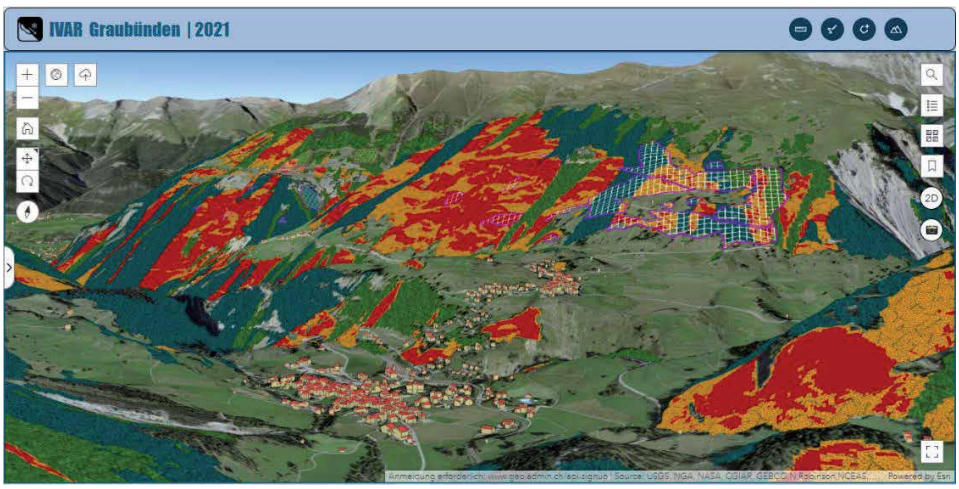


Figure 3.
Insight into the interactive map platform, which is currently being developed at WSL (maps.wsl.ch). Shown is a map section of the Bergün region, Canton Grisons, Switzerland. The example shows how remote sensing data and avalanche models are used to identify hotspots and prioritize forest management in avalanche protection forests. In the top-left and top-right corners of the web application different user interface components can be found such as functional widgets, navigational tools and elements allowing for map customization. All forest classifications have been derived from an overlay analysis between the current avalanche protection forest layer of the canton and RAMMS simulations with and without forest for a frequent scenario (approx. 10–30 year avalanche event). Forests colored in green/blue have an effect on avalanches, which do not endanger buildings. Forests colored in light orange (slope < 35°) and red (≥35° steepness) have a (building) protective function and a protective effect against snow avalanches. The threshold of 35° inclination highlights potential avalanche release areas in disturbed sites (with high surface roughness) or in forests where forest structure is not appropriate. In the area of Bergün severe storms destroyed parts of the forest in 2018 (windthrow areas highlighted with pink outline and white mesh).

5. Conclusions

Automatically produced protection forest maps (showing protective effects and functions of forests) based on a sound scientific framework and reliable spatial data are an important basis for prioritizing management interventions and for deducing hazard indication maps or even legally binding hazard maps. In view of further optimizing such maps and their application in different regions, it is important to carefully validate the mapping procedure after the simulation of avalanches with regional experts. Furthermore, as the technology to assess spatial data, and the forest cover and its ability to reduce avalanche risks are changing with time, it is necessary to regularly update such maps and calculate them for different scenarios. Thus, we propose and currently develop web-based interactive maps as a new planning and visualization tool.

Acknowledgements

The protection forest map of Grisons has been supported by the Cantonal office for forest and natural hazards of the Canton of Graubünden (Grisons). Additional funding has been provided by the WSL research program Climate Change Impacts on Alpine Mass Movements – CCAMM (ccamm.slf.ch) and by the prevention foundation of the Swiss cantonal building insurance (KGV). We thank in particular Roderick Kühne, Stephan Wohlwend, Andreas Stoffel and Stefan Margreth for support and feedback which helped to improve the maps. The map is still in evaluation. We also thank Frank Graf, Michaela Teich, Frank Perzl and Frédéric Berger for valuable comments on an earlier version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Author details

Peter Bebi*, Alexander Bast, Kevin Helzel, Gregor Schmucki, Natalie Brozova and Yves Bühler
WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

*Address all correspondence to: bebi@slf.ch

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Gruber U, Bartelt P. Snow avalanche hazard modelling of large areas using shallow water numerical methods and GIS. Environmental Modelling and Software. 2002;**22**:1472-1481. DOI: 10.1016/j.envsoft.2007.01.001

[2] Losey S, Wehrli A. Schutzwald in der Schweiz. Vom Projekt SilvaProtect-CH zum harmonisierten Schutzwald. Bern: Bundesamt für Umwelt; 2013. 29 p. + Annexes

[3] Giamboni M, Wehrli A. Improving the management of protection forests in Switzerland. The project SilvaProtect-CH. In: Interpraevent 2008 – Conference Proceedings. Vol. 2. Klagenfurt; 2008. pp. 469-480

[4] Ginzler C, Hobi ML. Das aktuelle Vegetationshöhenmodell der Schweiz: spezifische Anwendungen im Waldbereich. Schweizerische Zeitschrift für Forstwesen. 2016;**167**:128-135. DOI: 103188/szf.2016.0128

[5] Bühler Y, Marty M, Ginzler C. High resolution DEM generation in high-alpine terrain using airborne remote sensing techniques. Transactions in GIS. 2012;**16**:635-647. DOI: 10.1111/j.1467-9671.2012.01331.x

[6] Teich M, Fischer JT, Feistl T, Bebi P, Christen M, Grêt-Regamey A. Computational snow avalanche simulation in forested terrain. Natural Hazards and Earth System Science. 2014;**14**:2233-2248. DOI: 10.5194/nhess-14-2233-2014

[7] Brožová N, Fischer JT, Bühler Y, Bartelt P, Bebi P. Determining forest parameters for avalanche simulation using remote sensing data. Cold Regions Science and Technology. 2020;**172**:102976

[8] Christen M, Kowalski J, Bartelt P. RAMMS: Numerical simulation of dense snow avalanches in three-dimensional terrain. Cold Regions Science and Technology. 2010;**63**:1-14. DOI: 10.1016/j.coldregions.2010.04.005

[9] Bebi P, Kulakowski D, Rixen C. Snow avalanche disturbances in forest ecosystems – State of research and implications for management. Forest Ecology and Management. 2009;**257**:1883-1892

[10] McClung DM, Schaerer P. The Avalanche Handbook, 3rd ed. The Mountaineers Books, Seattle; 2006. 293 pp

[11] Brozova N, Baggio T, D'Agostino VD, Bühler Y, Bebi P. Multiscale analysis of surface roughness for the improvement of natural hazard modelling. Natural Hazards Earth System Sciences. 2021;**21**:3539-3562. DOI: 10.5194/nhess-21-3539-2021

[12] Moeser D, Stähli M, Jonas T. Improved snow interception modeling using canopy parameters derived from airborne LiDAR data. Water Resources Research. 2015;**51**:5041-5059. DOI: 10.1002/2014WR016724

[13] Bründl M, Schneebeli MM, Flühler H. Routing of canopy drip in the snowpack below a spruce crown. Hydrol. Process. 1999;**13**:49-58

[14] Tribeck MJ, Gurney RJ, Morris EM. The radiative effect of a fir canopy on a snowpack. J. Hydrometeorol. 2006;**7**:808-895

[15] Höller P. Tentative investigations on surface hoar in mountain forests. Annals of Glaciology. 1998;**26**:31-34

[16] Miller DH. Interception processes during snowstorms. U. S. Forest Service Research Paper PSW-18. Pacific Southwest Forest and Range Experiment Station Berkeley, USA; 1964

[17] Frehner M, Wasser B, Schwitter R. Nachhaltigkeit und Erfolgskontrolle im

Schutzwald, Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion, Vollzug Umwelt, Bundesamt für Umwelt, Wald und Landschaft, Bern. 2005. 564 pp

[18] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[19] Schneebeli M, Meyer-Grass M. Avalanche starting zones below the timberline – Structure of forest. Proceedings International Snow Science Workshop. Breckenridge, Colorado 4-8 Oct 1992. 1993:176-181

[20] Bebi P, Kienast F, Schönenberger W. Structures in mountain forests as a basis for investigating the forests' dynamics and protective function. Forest Ecology and Management. 2001;**145**:3-14

[21] Feistl T, Bebi P, Dreier L, Hanewinkel M, Bartelt P. Quantification of basal friction for technical and silvicultural glide-snow avalanche mitigation measures. Natural Hazards and Earth System Science. 2014;**14**(11):2921-2931. DOI: 10.5194/nhess-14-2921-2014

[22] Gauquelin X, Courbaud B. Guide des sylvicultures de montagne. Grenoble: Cemagref; 2006. pp. 289

[23] Bühler Y, von Rickenbach D, Stoffel A, Margreth S, Stoffel L, Christen M. Automated snow avalanche release area delineation – Validation of existing algorithms and proposition of a new object-approach for large-scale hazard indication mapping. Natural Hazards and Earth System Sciences. 2018;**18**:3235-3251. DOI: 10.5194/nhess-18-3235-2018

[24] SWISSTOPO. SwissALTI3D. Bern: Bundesamt Landestopografie. 2019. Available from: https://shop.swisstopo.admin.ch/en/products/height_models/alti3D

[25] Brändli UB, Abegg M, Allgaier Leuch B, editors. Schweizerisches Landesforstinventar. Ergebnisse der vierten Erhebung 2009-2017. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft WSL. Bern, Bundesamt für Umwelt. 2020:341 S

[26] Weber D, Rüetschi M, Small D, Ginzler C. Grossflächige Klassifikation von Gebüschwald mit Fernerkundungsdaten. Schweizerische Zeitschrift für Forstwesen. 2020;**171**(2):51-59. DOI: 10.3188/szf.2020.0051

[27] Sappington JM, Longshore KM, Thompson DB. Quantifying landscape ruggedness for animal habitat analysis: A case study using bighorn sheep in the Mojave Desert. J. Wildl. Manage. 2007;**71**:1419-1426. DOI: 10.2193/2005-723

[28] Margreth S. Lawinenverbau im Anbruchgebiet. Technische Richtlinie als Vollzugshilfe. Umwelt-Vollzug Nr. 0704. Bundesamt für Umwelt, Bern, WSL Eidgenössisches Institut für Schnee- und Lawinenforschung SLF, Davos. 2007. 137 pp

[29] Wasser B, Perren B. Wirkung von Schutzwald gegen gravitative Naturgefahren – ProtectBio. Schweizerische Zeitschrift für Forstwesen. 2014;**165**:275-283

[30] Bebi P, Seidl R, Motta R, Fuhr M, Firm D, Krumm F, Kulakowski D. Changes of forest cover and disturbance regimes in the mountain forests of the Alps. Forest Ecology and Management. 2017;**388**:43-56. DOI: 10.1016/j.foreco.2016.10.028

[31] Federal Office of Topography swisstopo. 3D Geodata in Brief. What are swisstopo landscape models and what are they used for? www.swisstopo.ch, Wabern; 2020. 36 pp

Chapter 12

Dealing with Uncertainties in the Assessment of the Avalanche Protective Effects of Forests

Ana Stritih

Abstract

Through the development of remote sensing and process-based models of natural hazards, an increasing amount of information on the protective effect of forests is becoming available. Such information can be used to map protection forests, which is an important tool for risk management. However, it is important to be aware of the uncertainty in such assessments. We used Bayesian Networks (BNs; using the software Netica) to combine remote sensing, process-based models (RAMMS), and expert knowledge to model forests' protective effect against avalanches, while taking into account the uncertainties in each model component. Using the online platform gBay, we mapped the protective effect of forests in the Dischma valley in Davos, Switzerland, as well as the associated uncertainty. In most areas with a high protective effect, the overall level of uncertainty is also high. To evaluate the importance of different sources of uncertainty, we performed a stepwise sensitivity analysis and visualized how information is transferred through the model. Most uncertainties are related to the inherent variability of snow avalanche processes and uncertainty in process modeling. Nevertheless, combining different remote sensing products can help to gain a more detailed picture of the forest structure and thus improve the mapping of avalanche protection. This type of analyses can help address uncertainties and risks in a spatially explicit way and to identify knowledge gaps that are priorities for future research.

Keywords: avalanche protection, uncertainty, mapping, remote sensing, Bayesian Networks

1. Introduction

Mapping and modeling the protective function and effects of forests can provide important information for natural hazard and forest management (see chapters [1, 2] of this book). However, the interactions of mountain forests with natural hazards are complex and associated with a high level of uncertainty (see chapter [3] of this book). Part of this uncertainty is related to the natural variability and complexity of the system, such as variability in snow conditions that affect avalanche formation, or heterogeneity in forest structure. This type of uncertainty cannot be reduced but should be taken into account in risk management, where one needs to consider not only the most likely outcome, but also less likely events that may have a large impact (such as extreme events). On the other hand, assessments of ecosystem functions also involve uncertainties that can potentially be reduced, such as measurement errors, model parameter uncertainties, and subjective judgment [4]. To realistically evaluate the level of confidence in such

assessments, all these types of uncertainty should be integrated and finally also communicated to users. Understanding how the different sources of uncertainty affect the overall assessment of forest functions can help identify knowledge gaps and contribute to more robust decision-making in natural hazard risk management.

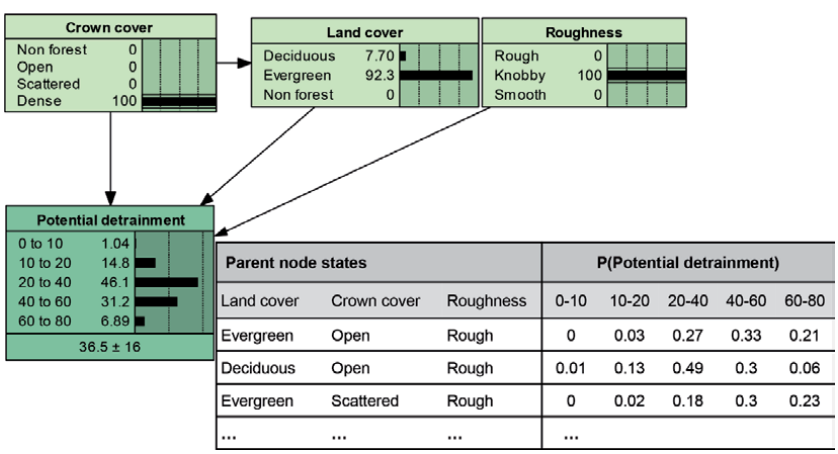
To map the protective effects of forests, we need to integrate spatially explicit data on forest structure with information on natural hazards, such as avalanche release areas and runouts under different scenarios. With the increasing availability of remote sensing technology such as LiDAR, forest structure can be mapped with increasing accuracy [5]. At the same time, process-based models of natural hazards are also being further developed. However, even remote sensing data still contain some errors and inaccuracies, and process-based models are sensitive to parameters that can take on a range of different values (e.g., release height or snow density in avalanche simulations). For specific effects of forests on natural hazards, such as their braking effect on avalanches, there is little empirical data, so models have to rely on expert judgment.

Bayesian Networks are a modeling approach that allows integrating different types of information and explicitly including uncertainty. Based on a study of uncertainties in the context of avalanche protection [6], we show how Bayesian Networks can be used to quantify uncertainty in the assessment of the protective effect of forests and to disentangle different sources of uncertainty.

2. Mapping avalanche protection and uncertainties

2.1 Bayesian Networks

Bayesian Networks (BNs) are probabilistic graphical models that consist of **nodes** (variables) and **links** between the nodes [7]. The links in the network are directed from "parent" to "child" nodes, representing **causal** relationships. The nodes have a set of states, which can be qualitative (e.g., forest type) or quantitative (e.g., canopy cover). The connections between nodes are quantified in **conditional probability tables**, where a probability distribution of a child node is defined for each combination of parent nodes (see example in **Figure 1**).



Parent node states			P(Potential detrainment)				
Land cover	Crown cover	Roughness	0-10	10-20	20-40	40-60	60-80
Evergreen	Open	Rough	0	0.03	0.27	0.33	0.21
Deciduous	Open	Rough	0.01	0.13	0.49	0.3	0.06
Evergreen	Scattered	Rough	0	0.02	0.18	0.3	0.23
...	...	...	...				

Figure 1.
Example of a Bayesian Network for potential braking effect of the forest during avalanches (detrainment of snow), which is a child node of the parent nodes crown cover, land cover, and terrain roughness, with the corresponding conditional probability table, which contains the probability distribution of potential detrainment for each combination of its parent nodes. In this example, the states of the nodes "crown cover" and "roughness" are known with 100% certainty, while "land cover" is known with some uncertainty, and this information propagates to the other nodes in the network.

Each conditional probability table in the network can be defined independently, which makes BNs a flexible tool for integrating different types of quantitative or qualitative information. The tables can be defined by "learning" from empirical data or existing simulations, calculated from existing models or filled based on expert knowledge.

Once the network is compiled, we can run it on spatial data by specifying the state of the input nodes for each pixel in a raster of the study area. The information is propagated through the network in a process called inference, resulting in an updated probability distribution of all nodes. We used the software Netica [8] to develop the network, and the online platform gBay [9] to run it with spatial data.

2.2 Avalanche protection model

We model two main forest effects that contribute to avalanche protection: release **prevention** and **detrainment**, the braking effect that affects the runout of small to medium avalanches. The probability of an avalanche release depends on topography (slope, curvature, terrain roughness) [10] but is lower in forested areas [11]. In addition, when an avalanche flows through a forest, some of the snow is stopped behind trees (detrainment), which reduces the mass and velocity of the avalanche [12].

To characterize the avalanche process in the study area, we used a probability distribution of maximum new snow heights based on long term observations in the region [13], and simulated avalanche velocities under different scenarios using the mass movement simulation tool RAMMS::Avalanche [14]. To estimate the uncertainty in the simulations, we ran the simulations with varying input parameters (including snow height, temperature, and coherence).

The capacity of a forest to provide avalanche protection depends on its structure and species composition [11], which can be assessed using remote sensing. We used high-resolution LiDAR to quantify the forest structure and terrain roughness and combined it with Sentinel-2 images to classify evergreen (spruce-dominated) and deciduous (larch-dominated) forests. Ground-truth data was collected at 110 plots in the Dischma valley to train the classification and to estimate the measurement and classification uncertainties in the remote sensing data.

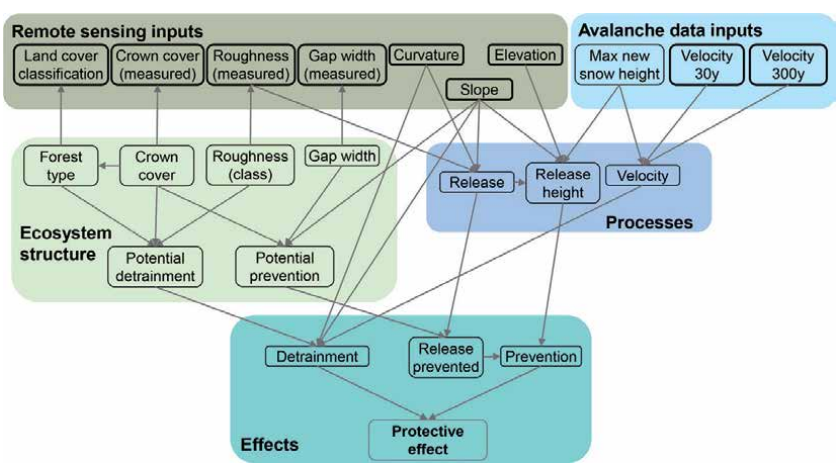


Figure 2.
Bayesian Network developed to model the avalanche protective effect of forests. The nodes are grouped and colored based on the types of variables they represent. Spatial inputs (shown with a thick outline) are linked to variables describing ecosystem structure, avalanche hazard processes, and ecosystem effects. Arrows represent causalities, not the flow of information, and are therefore oriented from ecosystem structure variables to the corresponding remote sensing inputs (the observations from remote sensing are caused by the actual state in the field, not vice-versa). Adapted from [6].

The links between forest structure and effects were defined on the basis of an existing empirical model of avalanche releases in forest areas [11] for release prevention, expert knowledge on potential detrainment (the ability of the forest to act as a brake on avalanches), and simulations of actual detrainment under different scenarios (with different release heights corresponding to 30- and 300-year scenarios for the region, and varying snow conditions). To capture the uncertainty about potential detrainment, experts were asked to estimate not only the expected value of potential detrainment, but also the lowest and highest possible value and their level of confidence. The final output of the model is a combination of release prevention and detrainment, expressed in the total height of snow stopped (see complete network in **Figure 2**).

2.3 Case study

We ran the avalanche protection BN in the lower Dischma valley, Davos, in the eastern part of the Swiss Alps (**Figure 3**). While the town of Davos (1560 m a.s.l.) is a well-developed urban and touristic center, its side valleys remain relatively rural, with a few scattered settlements and a landscape still strongly dominated by mountain agriculture. Snow avalanches are the most common natural hazard in the area, and mountain forests play a key role in reducing the risk for settlements below.

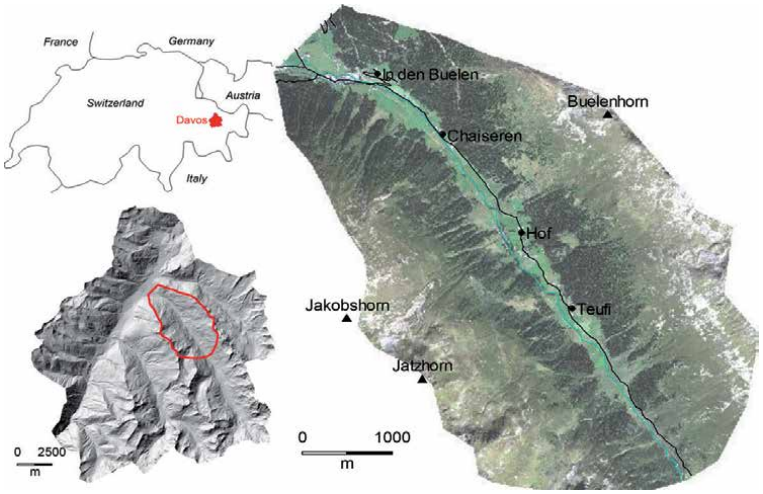


Figure 3.
Map showing the location of the study area on the DTM hillshade of Davos, Switzerland, with an orthophoto of the Dischma valley (swisstopo).

2.4 Mapping uncertainty

The output of the BN contains not only the most likely predicted value, but also a whole probability distribution for each pixel, which allows us to quantify the uncertainty of the output. As a measure of uncertainty, we use the **Evenness index** [15], where a value of 0 indicates complete certainty about the state of the output and 1 corresponds to a uniform distribution between all possible states (maximum uncertainty). In this way, both the predicted value and the uncertainty can be mapped (see **Figure 4**).

The spatially explicit modeled avalanche protection, i.e., the protective effect of forest that was quantified as the total height of snow stopped in each raster pixel, is spatially heterogeneous, and shows an overall high level of uncertainty (**Figure 4**). Areas with a high level of avalanche protection are the steeper, densely forested areas, particularly at high elevations where larger avalanche releases are more likely. Although remote sensing inputs (particularly the land cover classification) are more uncertain in heterogeneous forests near the upper tree line, this pattern is not reflected in the spatial distribution of uncertainty about avalanche protection. Most areas with a high level of avalanche protection also have a high level of uncertainty. In addition, there are many areas with a low predicted value of avalanche protection, but a high uncertainty, indicating that these forests may provide no or only limited avalanche protection under specific conditions, such as at times of very high avalanche risk, when avalanche releases can occur in less likely areas. Higher levels of certainty are achieved only in areas with a very low or zero level of protection provided by the forest.

2.5 Flow of information and sources of uncertainty

To visualize the flow of information and sources of uncertainty in the network, we use a stepwise sensitivity analysis. For each node in the BN, we calculate how much its uncertainty can be reduced by new information about the state of other

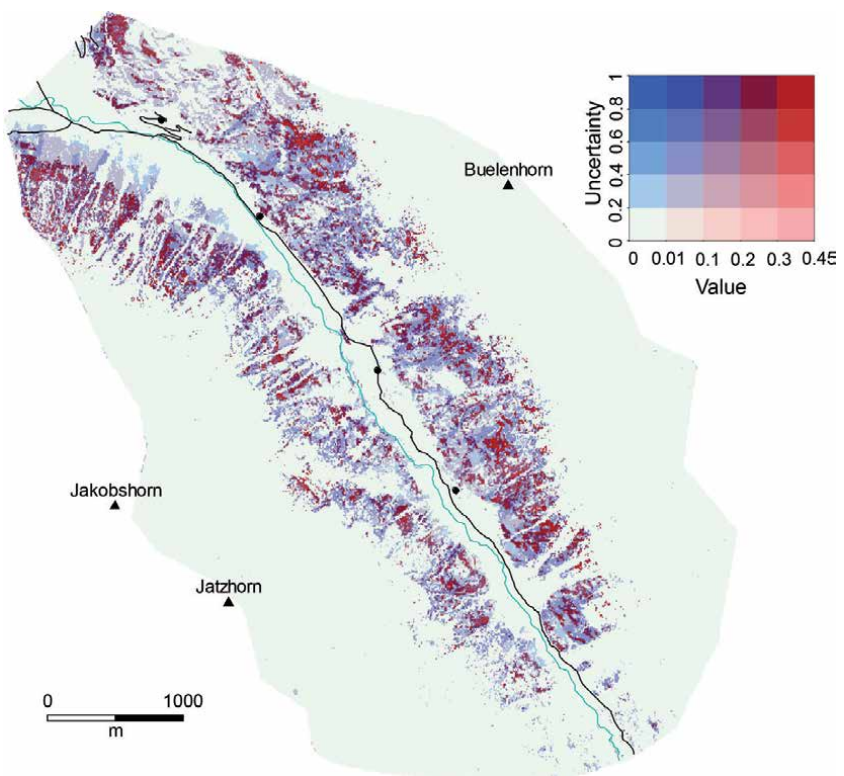


Figure 4.
Modeled avalanche protective effect in the Dischma valley (5 m resolution). Most areas with a high value also have a high uncertainty (dark red), as do some forested areas with a predicted low protective effect value (dark blue). Only areas with a zero or very low (light blue) value of the protective effect show a high certainty. Reprinted from [6].

nodes in the network. These relative **mutual information** (MI) values are used to weigh the links between nodes in a Sankey diagram of the network (**Figure 5**). The width of the connections in the diagram shows how much uncertainty about a node on the right can be reduced by information about the node on the left.

Mutual information is not additive, i.e., if both parent nodes can reduce the uncertainty of a child by 50%, this does not mean that findings on both parents will result in complete certainty on the child node. Nonetheless, plotting the MI gives an indication of the main sources of uncertainty in the model. When the value of MI for all the parents of a node is rather low (i.e., the connections on the left of a node are narrow), this means that the node will have a high uncertainty even if the states of its parents are known. If such a node has a large influence on the outcome of the network, this indicates a major source of uncertainty in the model. For example, the node "Release" (describing whether a pixel is in a potential avalanche release area) has an important influence on subsequent nodes in the network but it has a high uncertainty – even if its parents ("Slope", "Roughness (measured)" and "Curvature") are known, it is uncertain whether an avalanche release will occur.

Some remote sensing inputs have a strong influence on the knowledge about ecosystem structure ("Gap width" and "Crown cover"), while others have higher uncertainty (e.g., "Roughness"). There is some uncertainty in the land cover classification due to the chance of misclassifying vegetation types based on satellite images. More certainty about actual forest types can be gained by combining the satellite-based classification with crown cover data from LiDAR, which reduces the uncertainty about ecosystem structure. However, the information about forest types has a small influence on the overall assessment of the protective effect, partly because of the uncertainty about the detrainment capacity of different forest types (i.e., the link between forest

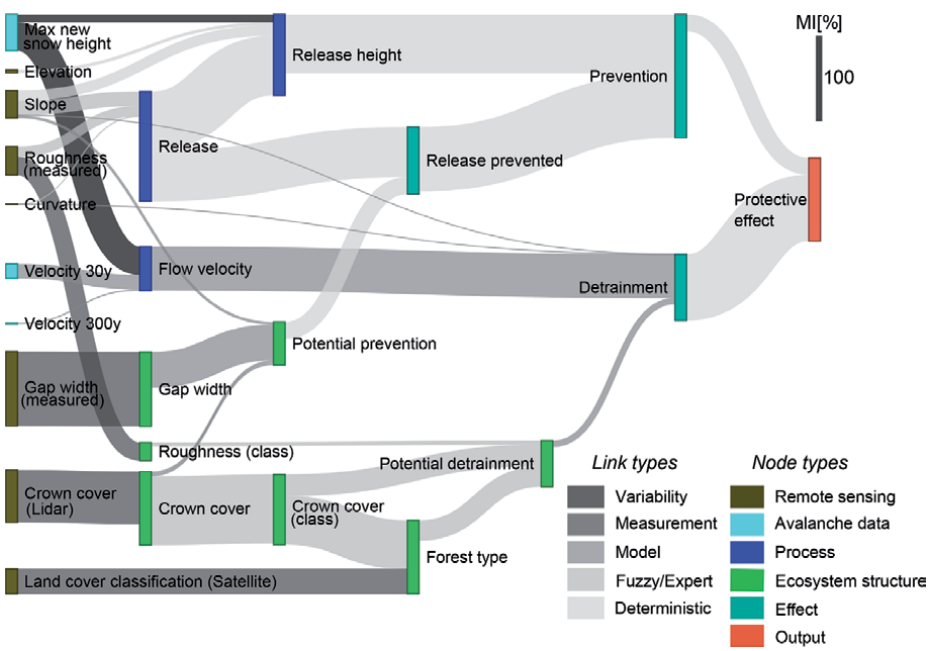


Figure 5.
*Stepwise sensitivity analysis of the BN, where the width of a link between two nodes corresponds to the relative mutual information (MI %), i.e., how much of the uncertainty of a node on the right than be reduced by information about the node on the left. When the connections on the left side of a node are narrow, this indicates a high uncertainty. The nodes are labeled and colored by the type of variable represented (see **Figure 2**), while the link colors represent the types of uncertainty taken into account while quantifying the link in the BN. Adapted from [6].*

type and potential detrainment). Furthermore, even if the detrainment capacity is known, the actual level of detrainment depends largely on the avalanche flow, as detrainment is important mainly for small and medium-sized avalanches and is therefore affected by the natural variability of the release conditions (i.e., release height).

This analysis shows that the overall uncertainty about avalanche protection is mostly affected by the uncertainties regarding avalanche processes, particularly the variability of snow heights, the probability of avalanche releases, and avalanche velocities and detrainment in forests. These uncertainties can be explained by the high natural variability of avalanche hazards, related to complex terrain and temporal variability in snow and weather conditions. In addition, currently available avalanche models and expert knowledge are based on limited observational data, which contributes to high model uncertainty.

3. Outlook

Using a Bayesian Network, we were able to analyze the information flow and quantify uncertainties related to data, models, and expert knowledge that we chose to map the protective effects of forests against avalanches. The most important sources of uncertainty are related to the avalanche process itself, both in nodes that were quantified through expert knowledge, and those based on models. Identifying such knowledge gaps could help to define research priorities. For example, improved identification of potential avalanche release areas under varying snow conditions [10, 16] would reduce the overall uncertainties about avalanche protection, while more sophisticated methods of classifying forest types would have a smaller impact on the model output.

An additional type of uncertainty that was not explicitly addressed is structural uncertainty, which relates which variables are included in the model and the links between them. Structural uncertainty is difficult to quantify, particularly when validation data is lacking, and is often not addressed. BNs can facilitate discussions about model structure with experts by visualizing the relationships between variables in the network [17] and identifying nodes with large uncertainties, which may indicate that important variables are missing from the model.

Besides modeling the protective effect of forests, this modeling approach can also be used to assess the avalanche risk to people and infrastructure, i.e., the demand for avalanche protection [6]. Because of the transparent graphical structure of BNs and their capacity to integrate both quantitative and qualitative data, they are particularly useful for participatory modeling with experts and stakeholders [18]. Even when data is lacking, a BN model can be developed based on practitioners' knowledge and used to discuss and improve the understanding of the system. While this chapter focuses on how a probabilistic model can be used to analyze the uncertainties about the current state of the system, it can also be used to address risks and uncertainties related to future scenarios, such as changes in forest structure due to climate change [19] or a changing disturbance regime. Such models can help identify strategies to not only maximize forests' protective effect in the present, but also ensure a stable protection under a range of possible outcomes [20]. However, Bayesian Network models are less well suited to model long-term dynamics since feedbacks cannot be directly included in the directed network structure. To model changes over time, each time step must be represented with a copy of the network, using the outputs of one time step as inputs to the next time step [9].

Understanding uncertainty is important for users of risk assessment tools who face trade-offs between model accuracy and time or data requirements [21]. Mapping uncertainties can improve model understanding, increase the

credibility of the modeling results and inform the decision-making process [22]. However, interpreting such maps is not straightforward. In the example shown here (**Figure 4**), we used darker colors to draw attention to areas of higher uncertainty. In other applications, different users may have different preferences for visualizing uncertainty [23], so it may be useful to include this type of information in interactive maps (see chapter [1] of this book).

4. Conclusions

Our findings show that avalanche protection provided by forests is associated with a high degree of uncertainty, largely due to the inherent variability of the avalanche process and uncertainty in current avalanche models. Although the structure of forests can be precisely mapped using remote sensing, this cannot improve the accuracy of avalanche protection maps without an improved understanding of the hazard process. However, even if more data become available for model calibration and validation, the inherent variability and complexity of the system remains, and the resulting uncertainty should be considered in decision-making.

We demonstrate that Bayesian Networks can be a useful tool to integrate different types of information, including data, models, and expert knowledge, while taking uncertainty into account. Using such tools to map risks, identify knowledge gaps, and understand the inherent uncertainties in the system can help support more robust decisions about risk.

Acknowledgements

This work was supported by the European Union's Horizon 2020 research and innovation programme [ECOPOTENTIAL project, grant agreement No 641762]. I would like to thank Yves Bühler, Marc Christen, Thomas Feistl, and Michaela Teich for their support with avalanche modeling, Peter Bebi for his comments on the manuscript, and Adrienne Grêt-Regamey for supporting this work.

Conflict of interest

The authors declare no conflict of interest.

Additional information

Further details about the models and data are available in [6].

Author details

Ana Stritih[1,2]

1 ETH Zurich, Institute for Landscape and Spatial Development, Planning of Landscape and Urban Systems (PLUS), Zürich, Switzerland

2 WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

*Address all correspondence to: astritih@ethz.ch

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Bebi P, Bast A, Helzel K P, Schmucki G, Brozova N, Bühler Y. Avalanche protection forest: From process knowledge to interactive maps. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99514

[2] D'Amboise C J L, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[3] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[4] Regan HM, Colyvan M, Burgman MA. A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological Applications. 2002;**12**(2):618-628. DOI: 10.1890/1051-0761(2002)012[0618,ATATOU]2.0.CO;2

[5] Brožová N, Fischer JT, Bühler Y, Bartelt P, Bebi P. Determining forest parameters for avalanche simulation using remote sensing data. Cold Regions Science and Technology. 2020;**172**:102976. DOI: 10.1016/j.coldregions.2019.102976

[6] Stritih A, Bebi P, Grêt-Regamey A. Quantifying uncertainties in earth observation-based ecosystem service assessments. Environmental Modelling and Software. 2019;**111**:300-310. DOI: 10.1016/j.envsoft.2018.09.005

[7] Kjaerulff U, Madsen A. Bayesian Networks and Influence Diagrams. Springer; 2013. 385 p

[8] Norsys. Netica API Programmer's Library [Internet]. Vancouver: Norsys Software Corp; 2010. p. 236. Available from: www.norsys.com

[9] Stritih A, Rabe SE, Robaina O, Grêt-Regamey A, Celio E. An online platform for spatial and iterative modelling with Bayesian Networks. Environmental Modelling and Software. 2020;**127**:104658. DOI: 10.1016/j.envsoft.2020.104658

[10] Veitinger J, Stuart Purves R, Sovilla B. Potential slab avalanche release area identification from estimated winter terrain: A multi-scale, fuzzy logic approach. Natural Hazards and Earth System Sciences. 2016;**16**(10):2211-2225

[11] Bebi P, Kienast F, Schönenberger W. Assessing structures in mountain forests as a basis for investigating the forests' dynamics and protective function. Forest Ecology and Management. 2001;**145**(1-2):3-14

[12] Feistl T, Bebi P, Teich M, Bühler Y, Christen M, Thuro K, et al. Observations and modeling of the braking effect of forests on small and medium avalanches. Journal of Glaciology. 2014;**60**(219):124-138

[13] SLF. Davos Fluelastr., 1560 m: Gumbel-Statistik. Davos: WSL Institut für Schnee- und Lawinenforschung SLF; 2017

[14] Christen M, Kowalski J, Bartelt P. RAMMS: Numerical simulation of dense

snow avalanches in three-dimensional terrain. Cold Regions Science and Technology. 2010;**63**(1-2):1-14. DOI: 10.1016/j.coldregions.2010.04.005

[15] Marcot BG. Metrics for evaluating performance and uncertainty of Bayesian network models. Ecological Modelling. 2012;**230**:50-62. DOI: 10.1016/j.ecolmodel.2012.01.013

[16] Bühler Y, Kumar S, Veitinger J, Christen M, Stoffel A, Snehmani. Automated identification of potential snow avalanche release areas based on digital elevation models. Natural Hazards and Earth System Science. 2013;**13**(5):1321-1335

[17] Voinov A, Kolagani N, McCall MK, Glynn PD, Kragt ME, Ostermann FO, et al. Modelling with stakeholders – Next generation. Environmental Modelling & Software. 2016;**77**:196-220. DOI: 10.1016/j.envsoft.2015.11.016

[18] Voinov A, Bousquet F. Modelling with stakeholders. Environmental Modelling and Software. 2010;**25**(11):1268-1281. DOI: 10.1016/j.envsoft.2010.03.007

[19] Grêt-Regamey A, Brunner SH, Altwegg J, Bebi P. Facing uncertainty in ecosystem services-based resource management. Journal of Environmental Management. 2013;**127**:145-154. DOI: 10.1016/j.jenvman.2012.07.028

[20] Stritih A, Bebi P, Rossi C, Grêt-Regamey A. Addressing disturbance risk to mountain forest ecosystem services. Journal of Environmental Management. 2021;**296**:113188. DOI: 10.1016/j.jenvman.2021.113188

[21] Vorstius AC, Spray CJ. A comparison of ecosystem services mapping tools for their potential to support planning and decision-making on a local scale. Ecosystem Services. 2015;**15**:75-83. DOI: 10.1016/j.ecoser.2015.07.007

[22] Kunz M, Grêt-Regamey A, Hurni L. Visualization of uncertainty in natural hazards assessments using an interactive cartographic information system. Natural Hazards. 2011;**59**(3):1735-1751

[23] MacEachren AM, Robinson A, Hopper S, Gardner S, Murray R, Gahegan M, et al. Visualizing geospatial information uncertainty: What we know and what we need to know. Cartography and Geographic Information Science. 2005;**32**(3):139-160

Section 3

From Risk Communication to Science-Based Political Action to Facilitate Eco-DRR

Chapter 13

Stakeholder Integration and Participatory Processes as Part of an Ecosystem-Based and Integrated Natural Hazard Risk Management

Silvia Cocuccioni, Matthias Plörer and Michael Kirchner

Abstract

Participatory processes have been receiving growing attention in recent decades, especially in the environmental field. There is no unique way for designing and managing a participatory process: different types of integrating stakeholders and communities have been applied, encompassing different scopes. Participatory processes become necessary when addressing complex environmental challenges, which require flexible and transparent approaches embracing diverse knowledge and values. Integrated risk management, including Ecosystem-based Disaster Risk Reduction (Eco-DRR) measures, is one example of such a challenge, being a joint responsibility of public institutions at different levels of public management and of the private sector. The project GreenRisk4ALPs is an example of how including local experts can be translated into practice. A stakeholder network analysis was carried out, which provided the basis to select the stakeholders involved in the subsequent participatory processes and to identify conflicts and interests related to Eco-DRR. Building upon this analysis, Rapid Risk management Appraisal workshops were carried out in different study areas to jointly analyze the strengths and weaknesses related to current risk management practices. Overall, the involvement of stakeholders from the beginning allowed to respond to their needs contributing to the improvement of risk management strategies in the Alpine Region.

Keywords: participatory processes, stakeholder integration, stakeholder network analysis, integrated risk management, Eco-DRR

1. Introduction

Participation can be described as a process by which communities work together towards change [1]. More specifically, participation can be seen as the "*process where public or stakeholder individuals, groups, and/or organizations are involved in making decisions that affect them, whether passively via consultation or actively via two-way engagement*" [2].

In recent decades, there has been growing attention to community and stakeholder participation touching a wide range of applications such as watershed,

ecosystem or forest management, agricultural development, environmental governance, and land use planning [3], and for assessing community and environmental needs, especially in the context of development projects [1, 4]. This growing interest in participatory processes is also reflected in a range of international agreements. Already in 1992, more than 150 states agreed at the Rio Conference on Environment and Development (UNCED) that environmental issues are best handled with the participation of all concerned citizens [5]. Other agreements calling for public participation include, for example, the Earth Summit, the European Landscape Convention, the Aarhus Convention, and the European Water Framework Directive [3].

Participatory approaches' purposes can vary, ranging from providing information and collecting inputs from stakeholders to negotiation and solving a problem or strengthening local capacity. Although participatory approaches did not originate as a method for research, they can also be used to produce detailed narratives of a certain topic in an interactive and collaborative manner, promoting learning and generating research data through a process of "guided discovery" [6]. Due to its application in diverse contexts for several decades, participation has acquired an ideological, social, political and methodological meaning, giving rise to a wide range of interpretations [4].

In this context, this chapter first provides an overview about the different types of participation, including their advantages and limitations (section 2). Section 3 goes more into detail about the participatory processes related to natural hazard risk management, while section 4 provides examples of participatory approaches adopted specifically within the Interreg Alpine Space project GreenRisk4ALPs [7]. Finally, some recommendations are given (section 5).

2. Types of participatory approaches, advantages and limitations

Participatory mechanisms vary greatly in form and aims, ranging from traditional (e.g., public meetings) to more innovative approaches (e.g., consensus conferences) and from instruments that collect responses of participants operating alone (e.g., surveys) to those involving participants interacting in groups (e.g., focus groups) [8]. The degree of participation can also vary, spanning from participants as passive recipients of information to engaging them in decision-making processes [9]. Moreover, also the people invited to participate vary: participatory approaches can be generally divided into methods with stakeholder involvement and methods with the involvement of the general public [10]. The distinction between public participation and stakeholder engagement is reflected in academic literature where stakeholders and citizens or the general public represent clearly differentiated entities [11, 12]. Stakeholders often represent sectorial or focused interests and shared preferences on a specific issue, while the general public generally represents the public good [12].

A necessary early step to be able to describe but also implement participatory methods is the definition and identification of stakeholders to involve [13, 14]. To achieve fair and socially representative processes, criteria have been developed. In the environmental field for instance, these criteria include classifications such as in individuals, groups and organizations who are affected by or can affect an environmental management issue and who may be interested in or impacted by it [11, 12, 15]. The practitioner is therefore required to investigate all the complex societal structures to determine who achieves the "stakeholder status" for the specific issue to be addressed within the engagement process [12].

Typologies have also been developed to classify the variety of existing participatory approaches. They can be based on different criteria: for instance, they can classify the different degrees of participation [16], the objectives for which participation is used or the direction of the communication flow [17]. These classifications can be used *post-hoc* as an evaluation tool to distinguish and categorize the form of participation that has occurred; on the other hand, they can be used *a priori* to design participatory methods on the basis of requirements set by the context and purpose of the work [18], by the available resources (e.g., time) and by the preference and expertise of those facilitating the process [9]. A good overview and classification for the field of land use management is provided in Reed et al. [2].

Among these typologies, one often-cited classification for assessing community participation that has been used for over 50 years, is Arnstein's ladder [16]. The ladder mainly refers to citizens as the main actors to engage, but it can be adapted for other contexts. It consists of eight rungs representing a continuum of increasing stakeholder involvement ranging from "Non-participation" and passive dissemination of information ("Tokenism") to active engagement ("Citizen Power").

The ladder has been used in practice and academia and was adapted or integrated throughout the years. For example, the pyramid adapted from Arnstein shown in **Figure 1** clarifies the increase in participation rights with each rung, but also shows that the obligation to assume responsibility for those increasingly involved at the same time [19]. Participatory processes are therefore more than pure communication processes; they are based on a mutual working relationship - the initiator or sponsor of the process is dependent on those involved and vice versa [19].

Within participatory approaches we can distinguish between two different phases. One is the participation of stakeholders within a research process, which aims towards solving practical problems by scientific methods and standards [20]. This participation phase, developing concrete solutions and measures for problem solving, must be planned before formulation and implementation of a specific policy output is approached. It is intended to ensure that state-of-the-art knowledge and innovative science-based information should be sufficiently included into the measures and solutions. The second phase is the participation of stakeholders within the formulation and implementation of a specific policy output. Here, participation should lead to decisions regarding the selection of concrete measures and solutions within a political program. Of course, both phases might be linked to each other or not.

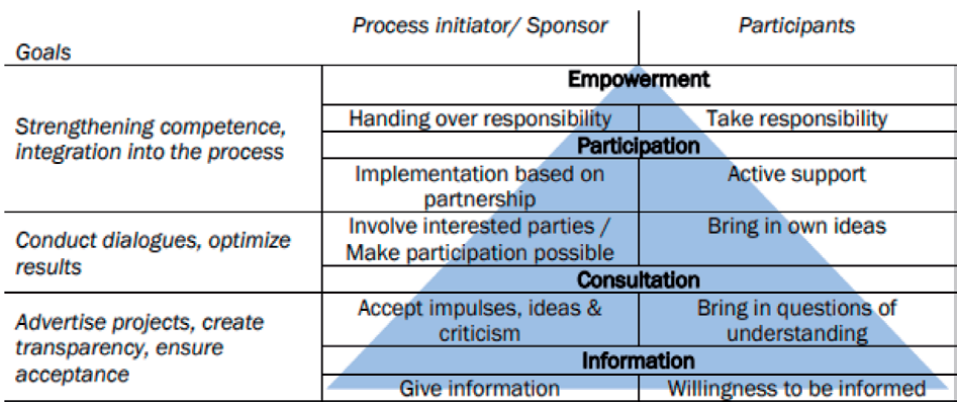


Figure 1.
Adapted "ladder of participation" [16]: levels of participation from the perspective of the process organizer and involved participants (source: [19]).

Participation within the research process builds on the co-production models for scientific knowledge transfer. Here, researchers, experts, non-academic stakeholders and policy makers interact and influence the production and use of scientific knowledge [21]. The co-production models accept the fundamental differences between practice and science. Whereas science relies on the scientific truth and logic based on empirical evidence, political actors follow the principles of political rationality, which is based on interests, power and political ideologies [20]. Due to this different logic, doing research based on a participatory approach and in transdisciplinary teams is often recognized as a time and labor intensive process for all participants [22]. Additionally, the lack of training (for working in such team structures), the length of the participation in the research process and even competing disciplinary working cultures are further challenges [23–25]. In research projects, in which resources are very limited [26], neither transdisciplinary concepts of "mode 3 knowledge production" [27] nor concepts of "collaboratively framing the problem" [23] are easily able to bridge the world of science and the world of practice. Similarly, actors from practice may not be expected to be able to work while adhering to scientific methods and standards [28].

Another common criticism to participatory approaches is that participation of divergent stakeholder groups in knowledge transfer leads often to discourses dominated by the most powerful one [29], and that, therefore, those stakeholders suppress minority interests systematically [30]. Different authors [31–33] argue that participation has to be understood as an arena of negotiation of interests due to unbalanced power relations of stakeholders by means of strategic rationality. It needs to be noted that in complex and coupled human-natural systems, like sustainability, practical problems cannot be easily solved by involving non-academic stakeholders into the research process [33–35]. However, involving stakeholders into the research might be of high relevance for defining practical problems and related research topics or for data collection.

Participation of stakeholders within the formulation and implementation of a specific policy output is traditionally connected to trying to implement measures and solutions for practical problems within the particular political programs, by using a mixture of regulative, financial and informational instruments [35]. This might be based on the state-of-the-art scientific knowledge (also with participation of non-academic stakeholders) or not. Undoubtedly, participation of different stakeholder groups ensures more legitimation for decisions and measures [23]. This may be secured by the exchange of information, expressing opinions or articulating interests and has the potential to influence the outcome [36]. This potential influence depends on the degree of co-determination of stakeholders, ranging from pure information provision to participation in decision-making processes [37].

Depending on the degree of co-determination of involved stakeholders and on the complexity of mutual conflicts, it is still a challenge for any layperson participating in the process to have a realistic opportunity of finding a sufficient solution for its own problem and conflict. Indeed, participatory approaches are based on the principle of collaboration between conflicting parties, but this does not mean that those parties will abandon their objectives. At this point, a good reason for shifting one's own interests towards a compromise is needed. Therefore, neither sophisticated (communication, mediation or moderation) techniques of experts nor the experience in the group building processes (by round tables) are enough for solving the current conflicts easily [38].

To conclude, there is no unique best way for designing and managing a participatory process: the chosen approach must reflect the specifics of the given situation and the needs of the parties involved. Moreover, several approaches can also be used simultaneously [3, 39].

3. Participation in ecosystem-based natural hazard risk management

Mountain areas face multiple challenges connected to the coexistence of natural hazards and the high presence of settlements in limited available space (i.e., valley bottoms). Natural hazards can affect society in various ways, impacting different stakeholders at different levels by directly damaging infrastructure or causing fatalities or indirectly by causing economic losses. Especially in the European Alps, the number of potentially exposed people is increasing, and the characteristics of natural hazards are changing due to climate change, modifying the different components of risk and posing increasing challenges to Alpine societies (see chapter [40] of this book).

Decision-making addressing complex and dynamic environmental challenges such as natural hazard risk management (NHRM) therefore requires flexible and transparent approaches embracing a diversity of knowledge and values. Rapidly changing risks are not manageable by one public institution alone or by a single discipline. The risk influencing factors are so vast and inter-dependent that many disciplines and institutions are required to deal with natural hazard and risk management. Therefore, integrated risk management is a joint responsibility of public institutions at different levels (e.g., national, regional and local) and of the private sector. Without combining participatory approaches in NHRM with strong financial, informational and regulative instruments, the success in reaching risk reduction targets will be limited, especially in protective forest management [41].

The importance of participatory approaches in the planning phase of (protective) forest management activities to achieve a sustainable use of this resource has been acknowledged by several authors and institutions such as the UN and the EU [42–44]. Integrating various stakeholders allows for the increase of public acceptance of policy decisions and to build an inclusive platform for constructive discussion. These aspects are even more important when dealing with forests and their management due to the multitude of conflicting interests and demands that are related to them [45, 46].

In addition to strong or weaker country specific regulative instruments affecting natural hazard management, for example, forest, flood protection or civil protection acts, many authorities increasingly prefer financial and informational instruments for solving practical issues. This is because regulative instruments and their rigorous implementation encounter resistance by recipients, especially in protective forest management [37, 47, 48]. However, even the usage of financial and informational instruments does not always lead to sufficient solutions to solving issues related to protective forests (e.g., sufficient regeneration, adequate forest maintenance or restoration). This deficiency can be overcome by newer participatory approaches that include all relevant stakeholders such as mountain farmers, outdoor recreationists or hunters, who have considerable influence on helping to reach the targets of protective forest policies [37, 47, 48]. Therefore, participatory approaches should be understood as an additional political instrument for involving important stakeholder groups into the policy making process.

4. Participatory approaches and scientific method in GreenRisk4ALPs

This section provides an overview on the participatory approaches and the scientific methods that were developed and applied within the GreenRisk4ALPs

project, spanning from expert consultation and developing new science-based knowledge to stakeholder integration and the transfer of knowledge into practice.

4.1 Stakeholder network analysis and application in Austria

Within the framework of GreenRisk4ALPs, stakeholder network analyses were carried out in six Pilot Action Regions (PARs) as a first step to identify the relevant stakeholders to be included in the following activities. This section presents the outcomes for the Austrian PAR (municipalities of Vals and Gries am Brenner, Tyrol). The analysis consisted in the identification of the different administrative levels (local, regional, national) responsible for ecosystem-based NHRM and related topics.

Although the Austrian PAR covers an area of only 105 km^2 (which is approximately the size of one third of Munich), a total of 36 stakeholder groups dealing with NHRM was identified. Of these, 30% are located at the federal level (Austria), 25% at the federal state level (Tyrol), 10% in the political district (Innsbruck Land), and another 30% at the municipal level. Three points were taken particularly into account in the initial identification of these stakeholder groups, which were also relevant in the following activities (e.g., round tables, surveys, interviews or expert workshops):

- Some institutions have a hierarchical departmental structure (superior and subordinate departments) within their organization. For instance, the Landesforstdirektion Tirol (Tyrolean Forest Service) is subdivided into several departments and groups as well as in the Bezirksforstinspektionen (forestry offices at district level). When identifying relevant stakeholders, the umbrella organization (Landesforstdirektion), a subordinate department (Bezirksforstinspektion) or all experts of the respective institution that are somehow connected to the topic can be considered, depending on the question.

- Some stakeholders are organized at the federal level, but are fragmented into regional bodies, where they are also partly incorporated into regional institutions. For example, the Federal Agency for Water Management is an organizational unit within the Ministry of Agriculture, Forestry, Regions and Water Management (BML), which is located in Vienna. The operational offices, however, are at the Hydrographic Service of the Austrian provinces (federal states) or in the administrative building of the districts.

- In terms of stakeholder groups, a distinction must be made between government institutions, non-governmental organizations, companies, associations, voluntary aid organizations, landowners and pure user groups (e.g., tourists). Of course, the power positions as well as decision-making and influence potentials of the different groups vary considerably.

It is therefore obvious that the understanding of administrative and official structures has the highest priority, as (not only) in Austria the distribution of responsibilities and competences is not always clear, which can lead to difficulties in fully identifying the relevant stakeholders.

After the most important stakeholders related to the project-relevant topics had been identified and listed, a network of their representatives was established (see **Figure 2**). This network helped to understand which stakeholders are in direct contact with other stakeholders, which stakeholders are possibly in a competitive relationship, or which had to be introduced among each other. This graphical

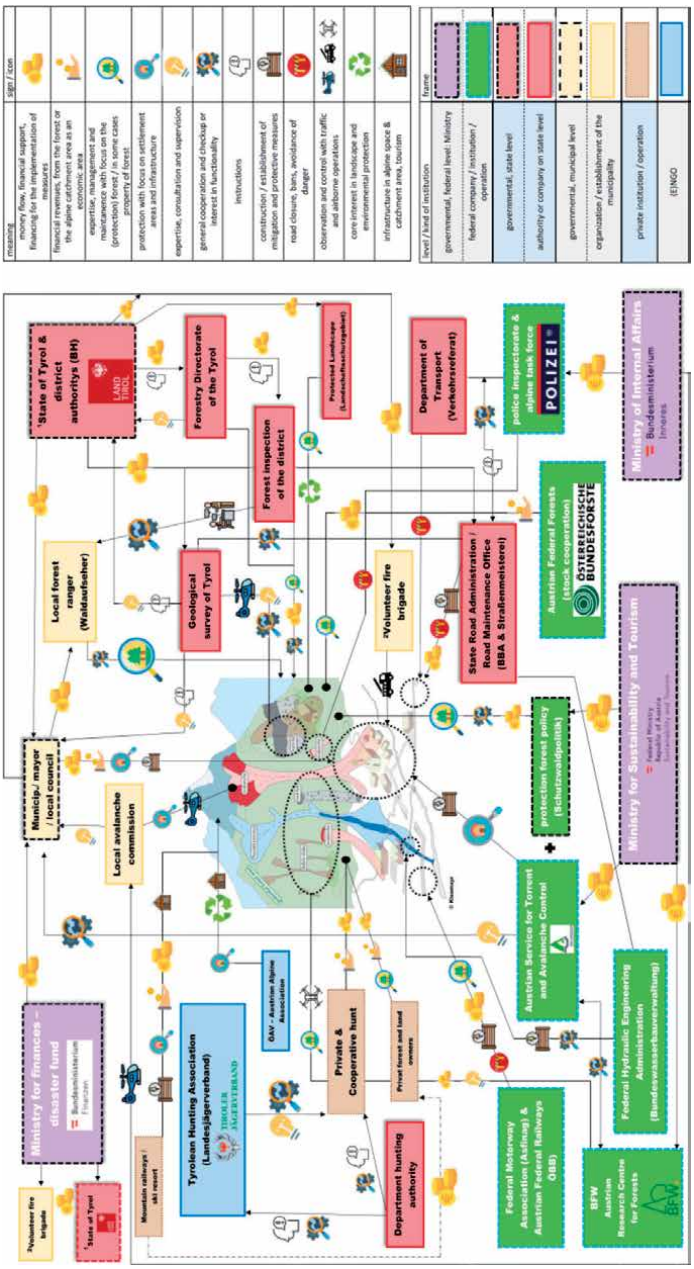


Figure 2.
Network of actors involved in (ecosystem-based) natural hazard risk management: exchange of information, influences and financial streams exemplified by the Austrian GreenRisk4ALPs Pilot Action Region.

representation of the stakeholders' network helped to decide which stakeholders ultimately needed to be brought together to participate in the project. Here, the analysis unit is the relationship between two entities and not the entity itself, considering that the networks consist of connections measured through communications or exchanges among actors [49, 50]. Analyzing the stakeholder network allowed us to highlight strengths and weaknesses of social structures, providing relevant information to improve the governance processes. These results are useful whenever institutional stakeholders are involved in a participatory process aiming at a consensual agreement and to overcome possible conflicts of interests.

More details about the stakeholder analyses conducted in the other PARs can be found in the GreenRisk4ALPs project report 'Actors and networks for ecosystem-based risk management for the Alpine Space' [50].

4.2 Steps of participatory processes and stakeholder integration activities

The following is a (chronologically sorted) summary of the events, site inspections, meetings, etc. that were held to achieve the best possible integration and participation of the relevant stakeholders in terms of the project objectives.

4.2.1 First round tables and questionnaire (January 2019)

As a kick-off for the stakeholder involvement process in the project, the mayors of the two municipalities that constitute the Austrian PAR were interviewed. A detailed questionnaire was answered by these political decision-makers and evaluated [50]. The questionnaires primarily served to summarize past natural hazard events and to identify expected future challenges in natural hazard and protective forest management.

4.2.2 Second round table (March 2019)

Based on the identification of stakeholders carried out in the network analysis, the project was presented to a wider audience, which was introduced to its objectives. Important issues (e.g., where the overpopulation of game is severely damaging protective forests locally) were addressed. During a lively discussion on the current status and the urgent challenges in the region, several topics were defined for further investigation within the framework of GreenRisk4ALPs, one of which was addressed by Plörer and Stöhr [51]. During this discussion, representatives of the stakeholder groups also recommended to include additional relevant actors. These stakeholders had already been identified in the stakeholder network analysis and therefore only needed to be contacted.

4.2.3 Site inspection (October 2019)

The site inspection resulted from the lively discussion at the second round table. The focus was on the massive impairment of specific protective forests caused by the high population of game and a prominent rock face from which boulders regularly endanger infrastructure. The present stakeholders showed great interest and the need to communicate the most pressing challenges of the community.

4.2.4 Interview at the Tyrolean Hunters' Association (October 2019)

After controversial discussions about the general conflict between forest and game management, contact was made with the Tyrolean Hunters' Association. An interesting exchange on highly relevant topics (e.g., ungulate browsing) took place. It was highlighted that the interests of various stakeholders naturally differ and that this can also influence the setting of objectives and goals of a project.

4.2.5 Expert round table (September 2020)

The expert round table had the aim to discuss and critically examine various modeling results generated within the framework of GreenRisk4ALPs with experts from various disciplines. Representatives from forest and natural hazard

management were invited; most of them were already familiar with the project or had previously worked together. For various reasons, three stakeholders (more than half) canceled the meeting at short notice. This experience highlights the challenges underlying participatory approaches. Nevertheless, the discussion was very lively and the questions and technical input from the experts showed that the constant involvement of stakeholders is highly relevant for adaptations in every step of a project.

4.2.6 GreenRisk4ALPs Mountain Forest Conference (June 2021)

Stakeholders from all relevant areas were invited to a hybrid event (both online and on-site) at the end of the project [52]. The decision support tools developed in the project - which were based on stakeholder inputs, among others - were presented to practitioners, policy makers, scientists and to the general public. Finally, the extent to which stakeholders and practitioners can practically use new findings and tools from science was discussed. The indispensable feedback from practitioners and the realization by scientists that there is still a long way to go to understand the gaps that exist in practice were important discussion points during this final GreenRisk4ALPs event.

To summarize, a lively participation was quickly achieved at the beginning of the project. Helpful follow-up events involving additional stakeholders and the definition and concretization of local objectives in the context of the project GreenRisk4ALPs could be generated.

4.3 Stakeholder interests, ecosystem services and stakeholder roles

Within the GreenRisk4ALPs project, further analyses regarding stakeholders were conducted to better plan the participatory processes and to pinpoint potential actors' interests and possible conflicts between them. In this context, conflicts were defined as a result of different interests in ecosystem services (ES), which cannot be fulfilled simultaneously [20].

Ecosystem services are "the benefits people obtain from ecosystems" [53]. In regard to NHRM in the Alpine Space we used an ES classification with four classes [53]: (i) regulating services such as green prevention measures entailing the maintenance, afforestation or reforestation of protective forests; (ii) provisioning services such as wood or game provision; (iii) supporting services such as biodiversity or habitats; and (iv) cultural services such as outdoor recreation, esthetics of cultural landscapes or tourism.

Out of these four classes we selected 12 ES relevant for NHRM in the Alpine Space [54]. They provided a first link to individual or collective actors that might be affected by the ES provision. This ES perspective builds up necessarily on actors who have a stake in the issue of NHRM. This NHRM issue is linked to the achievement of their goals, objectives or conditions to which specific ES can contribute [55]. In this context, actors can be divided in two groups: users and regulators. Users can be defined as the actors who benefit from ES and, for instance, include protective forest owners, hunters, environmental actors and citizens. Regulators on the other hand include different levels of the administrative system and subordinate agencies (e.g., federal state agencies for agriculture or forestry). Both, users and regulators can benefit or influence ES in different ways: (i) by direct use, primarily by harvesting, consuming and even producing services [56] or (ii) by indirect influence exerted through the decision-making system (for instance by elections) [57]. Governmental actors themselves are responsible (by their mandate) for the public task of managing, maintaining, restoring or distributing ES related to natural hazards risks. These

tasks become constitutive for the social role of regulators and link them to various collective actors, whose specific goals, objectives or conditions result in a variety of ES-related interests. Regulator's influence is visible directly in the ecosystems and their services or indirectly as a consequence of changing the behavior of users (which is more frequent), that is, by providing subsidies for forest management or enforcing regulations on hazard zone plans. Normally, regulators receive their mandate as a result of formal institutional settings [58]. The social role which an actor has influences the formation of its interests and limits the available sources and/or political instruments to enforce the own interests in decision-making processes.

Figure 3 shows the area affected by three natural hazards, snow avalanches, rockfall and shallow landslides, and reflects the ES approach adapted for the GreenRisk4ALPs project. It reveals the two different social roles of actors – user (red) and regulator (blue) - and possible ways of actors' influence on NHRM. The role of science is not visualized but it includes the provision of innovative NHRM strategies to regulators and/or users. They can accept (or reject) the scientific information and, after merging it with their existing knowledge and experiences, new knowledge emerges [59], which is used to enforce their own interests.

4.4 Rapid Risk management Appraisal

Building up on the information gained from the stakeholder analysis, roundtables with local experts were organized in the framework of the project. Among the different roundtables, a series of workshops was organized, applying a specific method developed within the project, the Rapid Risk management Appraisal (RRA).

The RRA is a participatory tool which aims to identify the strengths and the points for improvement in the field of NHRM in the different PARs for the implementation of future risk reduction measures. Consequently, this tool aims at supporting municipalities to increase their resilience to natural disasters.

The RRA uses local knowledge through the involvement of local experts in a short (few hours to half-day), collaborative workshop. This way, qualitative

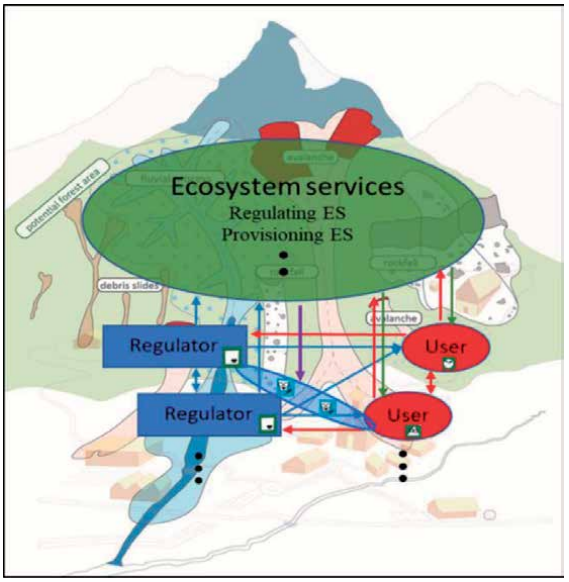


Figure 3.
Stakeholder (actor) roles in natural hazard risk management.

information as well as detailed knowledge on local particularities can be collected in a short time frame within a group setting. The personal information exchange which takes place through such a participatory approach also fosters mutual learning and information exchange among experts with a diverse technical background. The results gained from this participatory exercise can serve as a starting point for a more in-depth analysis, providing also a more specific direction in which to focus the detailed spatially explicit risk assessment and scientific research in general.

The selection of participants to the RRA workshop aimed to provide both technical and applied expertise within the field of risk management (e.g., geology department, torrent and avalanche control experts, but also foresters, civil protection engineers, land use planners and municipality technicians). Moreover, the technical expertise covered a range of gravitational natural hazards addressed by the project.

The RRA approach follows a series of steps, adapted from the ISO standard 31,000 for risk management [60]. The standard focuses on providing guidelines for the management of risks. Although it mainly addresses organizations and industries, it can be customized and applied to different activities, including decision-making at all levels. ISO31000 is here applied as a general framework to guide the collection of information and the discussion during the workshop. The three steps are the following: risk identification (1), risk analysis (2), and risk evaluation (3).

4.4.1 Step 1: risk identification

This step aims at identifying the two natural hazards which are the most relevant from a risk perspective for each PAR. Thus, the focus of this step is discussing about damages and losses that the different hazards have caused in the past and which are likely to damages cause in the future. The indirect consequences caused by such events (i.e., impact on reputation, interruption of activities) are also addressed. Consequently, this step provides information about the general sensitivity to natural hazards starting from the lessons we can learn from the past and moving on to potential and future risks. Maps are also used to visualize the areas mentioned by the different experts. If available, maps can include past natural hazard events or hazard zone plans.

4.4.2 Step 2: risk management analysis

The risk management analysis step builds on the previous discussion and represents the core of the RRA. The aim of this step is therefore to analyze risk management practices in place in the PAR, related to the two previously selected natural hazards. In order to cover all risk management activities, questions are structured following the integrated risk management cycle steps [61]. The adopted measures should therefore cover the preparedness, the response and the recovery phases [62].

The selected questions, which constitute this step of the RRA are divided in eight categories and are listed in the GreenRisk4ALPs project report "Preparation for risk analysis and strategy workshops" [63]. Each of the questions is presented together with three possible answers which correspond to different scenarios of expert satisfaction. The first scenario describes the case in which the participants perceive the specific risk management practice as a best practice or if they are highly satisfied with its quality or implementation. On the contrary, the third scenario, foresees a low expert satisfaction and ample room for improvement. The second scenario provides the intermediate or average case, where experts see space for desirable improvements. Along with the three scenarios, discussion points such as concrete best practice examples from the European Alps are listed to provide examples or comparisons to which experts could refer to during the discussion. The different

experts are asked to answer and discuss each question in detail, explaining how each risk management-related practice functions in their PAR, considering the differences and similarities for the selected natural hazards. Finally, experts are asked to come to an agreement and to select one of the three proposed scenarios.

Furthermore, different scores are attributed to the three scenarios. The maximum number of points is assigned to the best practice scenario (scenario one); on the contrary, the least is given in case some points are missing and an improvement is considered as necessary (scenario three). The full answer, the selected scenarios and the respective points are all recorded and used in the risk management evaluation step. An example of a question, the scenarios and respective discussion points are provided below (**Figure 4**).

4.4.3 Step 3: risk management evaluation

The points assigned in the previous steps are used to generate a spider chart. For this scope, the assigned points are inserted in an Excel Sheet and the average for each category is then calculated.

The spider chart, called here **Risk Management Profile**, allows one to easily compare different natural hazards and various study areas (see **Figure 5**). The larger the area of the polygon (different color lines for each hazard), the more the activities in the field of risk management are considered as best practices by the participants.

The spider chart is presented and discussed with the participants as a final step of the workshop. By presenting the Risk Management Profile, the participants receive an immediate picture which summarizes the risk management practices addressed during the half-day RRA workshop. This way, the strengths in risk management can be underlined and entrance points for improvement can be summarized.

Finally, after the execution of the RRA workshops in the different study areas, the results from different PARs are compared, considering not only the profile but also the fully recorded answers. Best practices or strengths which arise from the analysis of the results of one PAR could be transferred or proposed to PARs presenting specific weaknesses. This way, one PAR can learn from the risk management of

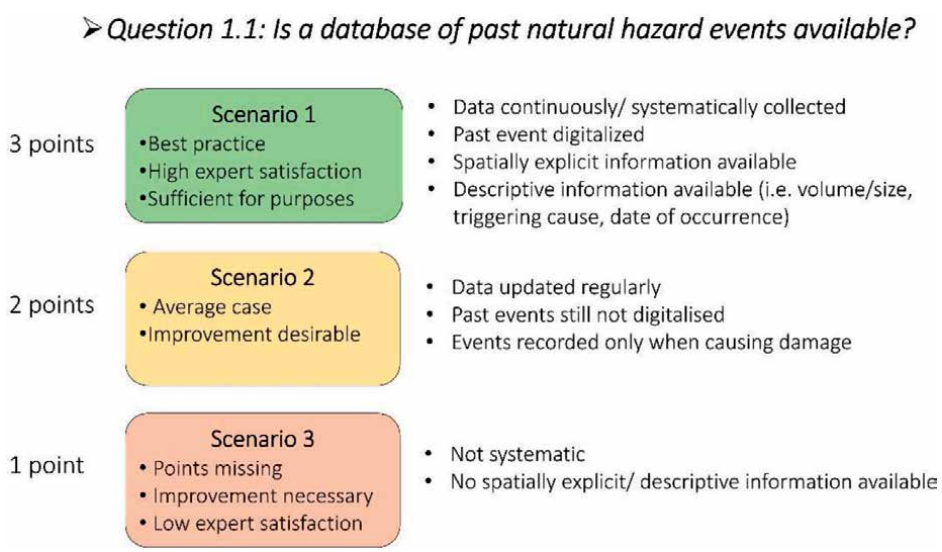


Figure 4.
An example of a question of the RRA, including scenarios on which the experts should agree on, and possible discussion points attributed to each scenario. On the left, also the points assigned to each scenario are reported.

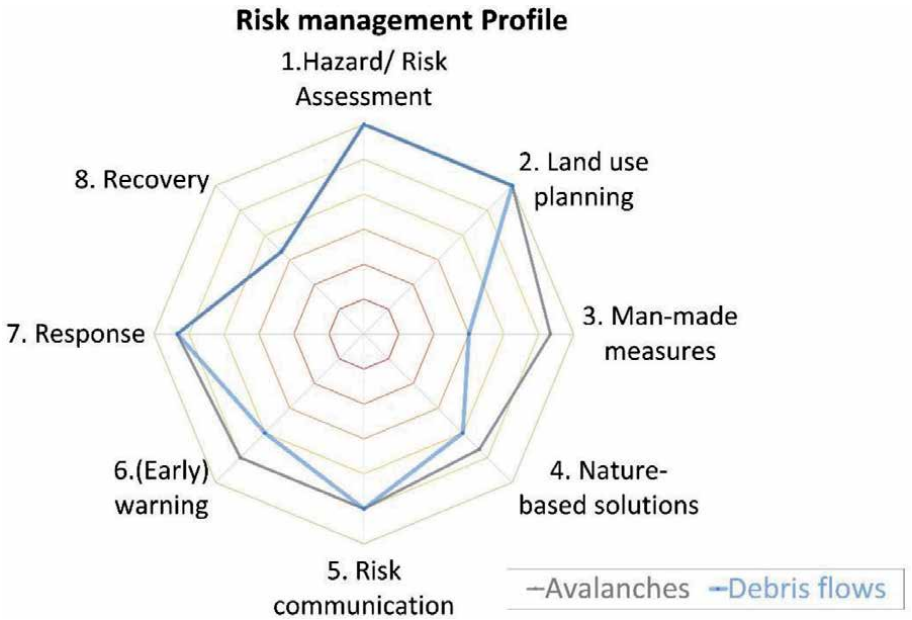


Figure 5.
Example of a Risk Management Profile: a spider chart that allows to compare the risk management capacities in place related to different natural hazards.

the others and a more successful ecosystem-based strategy can be proposed. The final results of the RRA activity are presented in the respective project report [64].

4.5 Levels of participation achieved

The involvement of local actors in participatory processes can be placed on different rungs or steps of the "ladder or pyramid of participation" (section 2, **Figure 1**); therefore, different levels of participation were achieved throughout the project GreenRisk4ALPs.

Since the project focused primarily on the modeling of natural hazards and on the respective risk identification, many activities described in the previous sections belong to the consultation level of participation. Participants were asked to bring in questions and comments to provide a solid basis and knowledge for the development of decision support tools (see also chapters [65, 66] of this book).

On the other hand, participatory processes such as the Rapid Risk management Appraisal belong to the "Participation" rung of the pyramid or ladder. Participants were indeed asked to actively support the process, contributing their own ideas and perceptions on current risk management practices and on potential ways for future improvements.

A higher level of participation (e.g., Empowerment) could be achieved beyond the project if the involved local experts use the RRA or other project outputs to improve the risk managament in practice.

5. Conclusions and recommendations

As highlighted in the introduction, environmental issues are best addressed by involving affected citizens and stakeholders [5]. Regarding the stakeholder analysis and involvement in the project GreenRisk4ALPs, not all citizens or the general

public could be involved [10], but - as described in section 3 - all relevant public institutions and private stakeholders were considered. The example of the Austrian Pilot Action Region was used to show what a stakeholder network analysis in this region might look like and which specific characteristics may have to be considered.

For a stakeholder network analysis, it is important to become familiar with the administrative and political structures in the region of interest. This is particularly challenging in a country such as Austria, where the division of administration and legislation often differs between the provinces.

When involving stakeholders (e.g., through roundtables or interviews), it is essential that they are not given the impression of being pitted against each other. Such situations were also relevant during the GreenRisk4ALPs project. Even if all possible stakeholders should not be brought together at the same table from the beginning, it is important that all stakeholders who are identified as relevant are involved during a project. In this context, clear, unambiguous and comprehensive communication is essential. This is how results can be successfully achieved in projects with the need for stakeholder involvement. It should be considered that transparent and integrative participatory processes are the central prerequisite for integrating research results in practice, for any necessary political solution strategy, and for the implementation of transnational management programs [19].

If new methods are developed during a project, they can ideally be applied and tested during stakeholder involvement activities. One example is the Rapid Risk management Appraisal, which can contribute to the potential generation of risk management plans in the context of specially tailored workshops. The Protective Forest Assessment Tool (FAT) is another GreenRisk4ALPs decision support tool [67, 68], which can offer stakeholders support for decision-making in NHRM. The development of FAT was guided by feedback from the involved stakeholders throughout the project, which highlights that the involvement of stakeholders from the beginning allows to respond and to tailor the outputs to their needs.

Acknowledgements

We thank all the stakeholders who dedicated their expertise and time. This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by Interreg Alpine Space programme, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy.

Conflict of interest

The authors declare no conflict of interest.

Author details

Silvia Cocuccioni[1*], Matthias Plörer[2] and Michael Kirchner[3]

1 Eurac Research, Institute for Earth Observation, Bolzano, BZ, Italy

2 Department of Natural Hazards, Austrian Research Centre for Forests (BFW), Innsbruck, Austria

3 Chair Group of Forest and Nature Conservation Policy, Georg-August University of Göttingen, Göttingen, Germany

*Address all correspondence to: silvia.cocuccioni@eurac.edu

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Pain R, Francis P. Reflections on participatory research. Area. 2003;**35**(1): 46-54. DOI: 10.1111/1475-4762.00109

[2] Reed MS, Vella S, Challies E, de Vente J, Frewer L, Hohenwallner-Ries D, et al. A theory of participation: What makes stakeholder and public engagement in environmental management work? Restoration Ecology. 2018;**26**:S7-S17. DOI: 10.1111/rec.12541

[3] Luyet V, Schlaepfer R, Parlange MB, Buttler A. A framework to implement stakeholder participation in environmental projects. Journal of Environmental Management. 2012;**111**:213-219. DOI: 10.1016/j.jenvman.2012.06.026

[4] Lawrence A. 'No personal motive?' Volunteers, biodiversity, and the false dichotomies of participation. Ethics, Place Environ. 2006;**9**(3):279-298. DOI: 10.1080/13668790600893319

[5] United Nations (UN). A/CONF.151/26/Vol.I: Rio Declaration on Environment and Development; 1992

[6] Mercer J, Kelman I, Lloyd K, Suchet-Pearson S. Reflections on use of participatory research for disaster risk reduction. Area. 2008;**40**(2):172-183. DOI: 10.1111/j.1475-4762.2008.00797.x

[7] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

[8] Rowe G, Marsh R, Frewer LJ. Evaluation of a deliberative conference. Science, Technology & Human Values. 2004;**29**(1):88-121. DOI: 10.1177/0162243903259194

[9] Bell S, Morse S, Shah RA. Understanding stakeholder participation in research as part of sustainable development. Journal of Environmental Management. 2012;**101**:13-22. DOI: 10.1016/j.jenvman.2012.02.004

[10] Rauschmayer F, Risse N. A framework for the selection of participatory approaches for SEA. Environmental Impact Assessment Review. 2005;**25**(6):650-666. DOI: 10.1016/j.eiar.2004.09.005

[11] Fischer ARH, Wentholt MTA, Rowe G, Frewer LJ. Expert involvement in policy development: A systematic review of current practice. Science and Public Policy. 2014;**41**(3):332-343. DOI: 10.1093/scipol/sct062

[12] Colvin RM, Witt GB, Lacey J. Approaches to identifying stakeholders in environmental management: Insights from practitioners to go beyond the 'usual suspects'. Land Use Policy. 2016;**52**:266-276. DOI: 10.1016/j.landusepol.2015.12.032

[13] Reed MS, Kenter J, Bonn A, Broad K, Burt TP, Fazey IR, et al. Participatory scenario development for environmental management: A methodological framework illustrated with experience from the UK uplands. Journal of Environmental Management. 2013;**128**:345-362. DOI: 10.1016/j.jenvman.2013.05.016

[14] Miles S. Stakeholder theory classification: A theoretical and empirical evaluation of definitions. Journal of Business Ethics. 2017;**142**(3):437-459. DOI: 10.1007/s10551-015-2741-y

[15] Reed MS, Graves A, Dandy N, Posthumus H, Hubacek K, Morris J, et al. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management. 2009;**90**(5):1933-1949. DOI: 10.1016/j.jenvman.2009.01.001

[16] Arnstein SR. A ladder of citizen participation. Journal of the American

Institute of Planners. 1969;**35**(4):216-224. DOI: 10.1080/01944366908977225

[17] Rowe G, Frewer LJ. Public participation methods: A framework for evaluation. Science, Technology & Human Values. 2000;**25**(1):3-29. DOI: 10.1177/016224390002500101

[18] Reed MS. Stakeholder participation for environmental management: A literature review. Biological Conservation. 2008;**141**(10):2417-2431. DOI: 10.1016/j.biocon.2008.07.014

[19] Arzberger M, Eisele H, Schreiber R. D.T5.3.1 Report New Recommendations for governance of protection forests and ecosystem-based risk mitigation. Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2022. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 5 RIGOR)

[20] Böcher M, Krott M. Science Makes the World Go Round. Cham: Springer International Publishing; 2016. p. 207. DOI: 10.1007/978-3-319-34079-1

[21] Maasen S, Weingart P. What's new in scientific advice to politics? In: Maasen S, Weingart P, editors. Democratization of Expertise? 1st ed. Netherlands: Springer; 2005. pp. 1-19. DOI: 10.1007/1-4020-3754-6_1

[22] Mattor K, Betsill M, Huayhuaca C, Huber-Stearns H, Jedd T, Sternlieb F, et al. Transdisciplinary research on environmental governance: A view from the inside. Environmental Science & Policy. 2014;**42**:90-100. DOI: 10.1016/j.envsci.2014.06.002

[23] Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, et al. Transdisciplinary research in sustainability science: Practice, principles, and challenges. Sustainability Science. 2012;**7**(S1):25-43. DOI: 10.1007/s11625-011-0149-x

[24] Pohl C. From science to policy through transdisciplinary research. Environmental Science & Policy. 2008;**11**(1):46-53. DOI: 10.1016/j.envsci.2007.06.001

[25] Morse WC, Nielsen-Pincus M, Force JE, Wulfhorst JD. Bridges and barriers to developing and conducting interdisciplinary graduate-student team research. Ecology and Society. 2007;**12**(2):art8. DOI: 10.5751/ES-02082-120208

[26] Böcher M, Krott M. The RIU model as an analytical framework for scientific knowledge transfer: The case of the "decision support system forest and climate change". Biodiversity and Conservation. 2014;**23**(14):3641-3656. DOI: 10.1007/s10531-014-0820-5

[27] Carayannis EG, Campbell DFJ. Mode 3 knowledge production in quadruple Helix innovation systems. In: Mode 3 Knowledge Production in Quadruple Helix Innovation Systems. New York, NY: Springer New York; 2012. pp. 1-63. DOI: 10.1007/978-1-4614-2062-0_1

[28] Roux DJ, Rogers KH, Biggs HC, Ashton PJ, Sergeant A. Bridging the science–management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing. Ecology and Society. 2006;**11**(1):art4. DOI: 10.5751/ES-01643-110104

[29] Toomey AH, Markusson N, Adams E, Brockett B. Inter-and Trans-disciplinary Research: A Critical Perspective. 2015. Available from: https://sustainabledevelopment.un.org/content/documents/612558-Inter-andTrans-disciplinaryResearch-ACritical Perspective.pdf

[30] Hubacek K, Prell C, Reed M, Boys D, Bonn A, Dean C. Using stakeholder and social network analysis to support participatory processes. International Journal of Biodiversity Science and

Management. 2006;**2**(3):249-252. DOI: 10.1080/17451590609618137

[31] Frantzeskaki N, Rok A. Co-producing urban sustainability transitions knowledge with community, policy and science. Environ Innov Soc Transitions. 2018;**29**:47-51. DOI: 10.1016/j.eist.2018.08.001

[32] Leeuwis C. Reconceptualizing participation for sustainable rural development: Towards a negotiation approach. Dev Change. 2000;**31**(5):931-959. DOI: 10.1111/1467-7660.00184

[33] Turnhout E, Metze T, Wyborn C, Klenk N, Louder E. The politics of co-production: Participation, power, and transformation. Current Opinion in Environment Sustainability. 2020;**42**:15-21. DOI: 10.1016/j.cosust.2019.11.009

[34] Stauffacher M, Flüeler T, Krütli P, Scholz RW. Analytic and dynamic approach to collaboration: A transdisciplinary case study on sustainable landscape development in a Swiss Prealpine region. Systemic Practice and Action Research. 2008;**21**(6):409-422. DOI: 10.1007/s11213-008-9107-7

[35] Krott M. Politikfeldanalyse Forstwirtschaft. Eine Einführung für Studium und Praxis. Ulmer (Eugen); 2001

[36] FAO, ECE, ILO. Public participation in forestry in Europe and North America. In: Report of the Team of Specialists on Participation in Forestry. 2000. pp. 1-144

[37] Rappold G. Partizipation als Instrument einer erfolgreichen Schutzwaldsanierung. Wien: Universität für Bodenkultur Wien; 2000

[38] Krott M. Forstliche Raumplanungspolitik: Praxis und Zukunft des österreichischen Waldentwicklungsplanes. Vol. 2. Wien: Universität für Bodenkultur; Österr. Gesellschaft für Waldökosystemforschung u. Experimentelle Baumforschung; 1989. p. 200

[39] Connor DM. A new ladder of citizen participation. National Civic Review. 1988;**77**(3):249-257. DOI: 10.1002/ncr.4100770309

[40] Accastello C, Cocuccioni S, Teich M. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[41] Zoormaier F. Die Rolle der Unteren Forstbehörden bei partizipativen Prozessen. Dissertation. Technische Universität München; 2006. Available from: http://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss-20060704-618422-0-0

[42] European Commission (EC). COM(2013) 659: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new EU forest strategy: For forests and the forest-based sector. Brussels; 2013

[43] Paletto A, Giacovelli G, Pastorella F. Stakeholders' opinions and expectations for the forest-based sector: A regional case study in Italy. International Forestry Review. 2017;**19**(1):68-78. DOI: 10.1505/146554817820888654

[44] Teder M, Kaimre P. The participation of stakeholders in the policy processes and their satisfaction with results: A case of Estonian forestry policy. For Policy Econ. 2018;**89**:54-62. DOI: 10.1016/j.forpol.2017.05.007

[45] Blanc S, Lingua F, Bioglio L, Pensa R, Brun F, Mosso A. Implementing participatory processes in forestry training using social network analysis

techniques. Forests. 2018;**9**(8):463. DOI: 10.3390/f9080463

[46] Kleinschmit D, Pülzl H, Secco L, Sergent A, Wallin I. Orchestration in political processes: Involvement of experts, citizens, and participatory professionals in forest policy making. For Policy Econ. 2018;**89**:4-15. DOI: 10.1016/j.forpol.2017.12.011

[47] Arzerberger M. Das Klima ändert sich. Die Verwaltung auch?: Von Beratung bis Partizipation - verändertes Verwaltungshandeln am Beispiel der bayerischen Bergwaldoffensive. 2019

[48] Himmler D, Wagner K. Suda. Participation in mountain forest management: The role of group building for the outcome of participation processes, two case studies from Bavaria. In: Borsdorf A, Stòtter J, Veulliet E, editors. Managing Alpine Future II-Inspire and Drive Sustainable Mountain Regions. Innsbruck: Eigenverlag-Universität Innsbruck; 2011

[49] Robertson PJ, Lewis LB, Sloane DC, Galloway-Gilliam L, Nomachi J. Developing networks for community change: Exploring the utility of network analysis. Community Development. 2012;**43**(2):187-208. DOI: 10.1080/15575330.2011.583395

[50] Plörer M, Schreiber R, Kirchner M, Cocuccioni S, Begus J, Perret P, et al. D.T2.2.2 Report on "Actors and networks for ecosystem-based risk management for the Alpine Space". Innsbruck, Austria: Interreg Alpine Space project GreenRisk4 ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 2 ACTINA)

[51] Plörer M, Stöhr D. Gries am Brenner/Vals pilot action region: The Tyrolean ski tour steering concept-a contribution to the protection of wildlife and object protective forests. In: Beguš J, Berger F, Kleemayr K, editors. Best Practice Examples of Implementing Ecosystem-Based Natural Hazard Risk Management in the GreenRisk4ALPs Pilot Action Regions. London: IntechOpen; 2021. DOI: 10.5772/intechopen.99011

[52] GreenRisk4ALPs Mountain Forest Conference - Virtual Conference Proceedings. In Innsbruck, Austria & online [Internet]; 2021. Available from: https://www.youtube.com/watch?v=h6iOlcZ88VY&list=PLzRvJOjES_okxKby-otQ0DCQp6MyM7KnC&index=1&ab_channel=Bundesforschungszentrumf%C3%BCrWald

[53] Millennium Ecosystem Assessment. Ecosystems and human well-being. Washington D.C.; 2005

[54] Krott M, Michael K, Hasnaoui A, Begus J, Skrjanec S, Kleemayr K. D.T2.3.1 Report on "Comparative decision structure analysis in the PAR". Göttingen, Germany: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2019. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 2 ACTINA)

[55] van Oudenhoven APE, Petz K, Alkemade R, Hein L, de Groot RS. Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecological Indicators. 2012;**21**:110-122. DOI: 10.1016/j.ecolind.2012.01.012

[56] Grunewald K, Bastian O. In: Grunewald K, Bastian O, editors. Ecosystem Services – Concept, Methods and Case Studies. Berlin, Heidelberg: Springer Berlin Heidelberg; 2015. DOI: 10.1007/978-3-662-44143-5

[57] McGinnis MD, Ostrom E. Social-ecological system framework: Initial changes and continuing challenges. Ecology and Society. 2014;**19**(2):art30. DOI: 10.5751/ES-06387-190230

[58] Felipe-Lucia MR, Martín-López B, Lavorel S, Berraquero-Díaz L, Escalera-Reyes J, Comín FA. Ecosystem services flows: Why stakeholders' power relationships matter. PLoS One.

2015;**10**(7):e0132232. DOI: 10.1371/journal.pone.0132232

[59] Stevanov M, Krott M. Embedding scientific information into forestry praxis: Explaining knowledge transfer in transdisciplinary projects by using German case. For Policy Econ. 2021;**129**:102508. DOI: 10.1016/j.forpol.2021.102508

[60] International Standard Organisation. ISO 31000:2018 (en) Risk management. 2nd ed. ISO/TC 262; 2018

[61] FOCP. Integrated Risk Management. Its importance in protecting people and their livelihoods [Internet]. Bern, Switzerland; 2014. Available from: https://www.babs.admin.ch/en/aufgabenbabs/gefaehrdrisiken.html

[62] Mikoš M. Risk management and mountain natural hazards. In: Bekic D, editor. 2nd Professional & Scientific Conference Water Management Days 2013 "Progress through Science". Zagreb, Croatia: University of Zagreb; 2013. pp. 245-268

[63] Cocuccioni S, Renner K, Steger S, D'Amboise C, Hormes A, Plörer M, et al. D.T3.2.1 Report on "Preparation for risk analysis and strategy workshops". Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[64] Cocuccioni S, Renner K, Steger S. D.T 3.5.1: "Report on 'Results of the risk analysis and the strategy prioritization". Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[65] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise CJL, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[66] D'Amboise CJL, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[67] Protective Forest Assessment Tool (FAT) [Internet]. Available from: https://gr4a.geocodis.com/

[68] D'Amboise CJL, Žabota B, Poratelli F, Pecan P, Plörer M, Accastello C, et al. A.T1.6 Construction of the innovative and new protective forest assessment tool (FAT). Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

Chapter 14

Improving Risk Communication Strategies through Public Awareness and Engagement: Insights from South Tyrol and Carinthia

Lydia Pedoth, Fabio Carnelli, Gernot Koboltschnig, Paul Krenn, Anna Rudloff, Willigis Gallmetzer, Pierpaolo Macconi and Nicola Marangoni

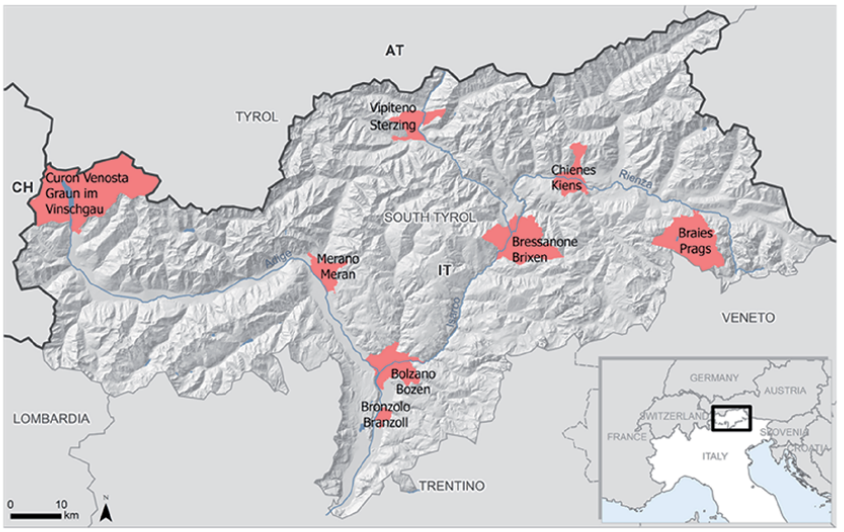
Abstract

This chapter presents experiences and results from the INTERREG Italy-Austria Project RiKoST-Risk communication strategies. The project is a collaboration between partners from research and public authorities and aims at improving target-group-oriented risk communication in South Tyrol (Italy) and Carinthia (Austria). Risk communication plays an essential role for risk governance and may address different aspects and fulfill various purposes, from informing about natural hazards, generating acceptance and awareness for structural and non-structural measures, to triggering participation, increasing resilience, and supporting the development of a risk-competent society. To be effective, risk communication needs, firstly, to acknowledge the needs of different target groups and, secondly, to develop approaches, tools and contents that are most suitable to reach and involve them. This chapter describes the results from different activities carried out in the project: a population survey to better understand people's risk perception and their knowledge about natural hazards, the information channels they use and trust; awareness raising activities in different municipalities; interactive lessons and a workshop in schools; stakeholder workshops. Our results show that that existing non-structural protection and prevention measures, especially Hazard Zone Plans, are little known among the population, that trust in the responsible authorities is high and that there is a need for a risk dialog through different risk communication activities at different stages to provide targeted information on how individual citizens can contribute to risk management. The chapter concludes on how the presented results can be used by public authorities and policy makers to innovate risk communication strategies and to initiate a risk dialog with the overall aim to improve risk governance at local level.

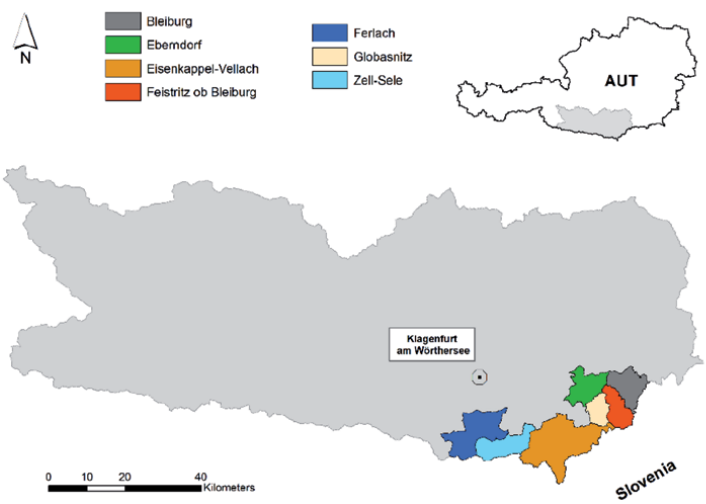
Keywords: risk communication, risk perception, natural hazards, risk governance, public awareness

1. Introduction

Ecosystem-based approaches to Disaster Risk Reduction (Eco-DRR) have multiple social, economic, and environmental benefits and their implementation needs "an inclusive, "all-of-government" and "whole-of-society" approach" [1] to ensure its legitimacy. Eco-DRR entails combining natural resources management approaches, or the sustainable management of ecosystems, with Disaster Risk Reduction (DRR) methods, such as early warning systems and emergency planning, to have more effective disaster prevention, reduce the impact of disasters on people and communities, and support disaster recovery [2]. This chapter presents experiences, results, and good practices from the INTERREG Italy-Austria project



Source: Map created by Eurac Research based on data by the Autonomous Province of Bolzano, 2020



Source: Regional government of Carinthia

Figure 1.
The RiKoST pilot municipalities in South Tyrol (above) and Carinthia (below).

RiKoST (Risk communication strategies) that aims at improving risk communication strategies for an inclusive risk governance. Indeed, risk communication should not be solely intended as a separate phase of risk management but something necessary throughout the whole risk cycle (see chapter [3] of this book) to make risk governance inclusive and effective [4]. Communication can be conceived as "meaningful interactions in which knowledge, experiences, interpretations, concerns, and perspectives are exchanged" [4] in every phase of the risk cycle, depending on different levels of complexity, ambiguity, and uncertainty. It is not only an external tool to inform or gather people, rather it is the core of risk governance, based on social learning among decision makers, stakeholders, and the public. Namely, risk communication can be structured into four components: the source of communication, the content, the communication channel, and the target group [5]. Furthermore, there is no universal strategy for risk communication, but it must be adapted to the specific context and target group. Many authors [6–8] agree that the use of maps can significantly contribute to the success of risk communication. In [6] authors even argue that maps are a fundamental tool for informing the population and justify this with the possibility of raising risk awareness, promote personal responsibility and communicate residual risks. In general, one of the prerequisites for successful dialog-based risk communication is that both the public and decision-makers are actively engaged in a social learning process [9]. Thus, to improve risk communication and foster a risk dialog, an understanding of risk perceptions among the public and of patterns of risk communication among risk governance agencies is necessary [10]. These assumptions were the premises for the RiKoST project. The project is a collaboration between partners from research and public authorities and aims at improving target-group-oriented risk communication in South Tyrol (Italy) and Carinthia (Austria) and to develop innovative measures and tools to disseminate technical content in a clear way, to raise awareness and to establish a process of dialog between institutions and population.

Within the scope of the project, 13 pilot municipalities in South Tyrol and Carinthia have been selected where different activities have been implemented. The selection includes both urban and rural municipalities, municipalities that have recently experienced a natural hazard event and municipalities that did not, and municipalities that have an approved hazard zone plan (HZP) and others without. In South Tyrol HZPs are a recently introduced legal binding planning instrument developed at municipality level, in collaboration with professionals and departments of the provincial administration. In 2018, when selecting the pilot municipalities for the project about half of the municipalities had an approved hazard map. **Figure 1** shows the pilot municipalities, in the following subsections the activities that have been implemented in these municipalities are described in more detail.

2. Questionnaires to better understand peoples' knowledge and risk perception linked to natural hazards

To improve risk communication strategies or to develop new ones, it is important to better understand the population's knowledge about natural hazards, how they perceive risks from natural hazards, but also which communication channels they use and how they think risk management can be improved. The topics of knowledge, risk perception, and action are closely linked and important issues to be considered in the context of risk communication. For this reason, the project has developed a questionnaire on these described topics (**Figure 2**). The questionnaire consisted of 42 questions of different types (closed questions, multiple choice questions, open questions) and was divided into the following 4 topics: 1) knowledge about natural

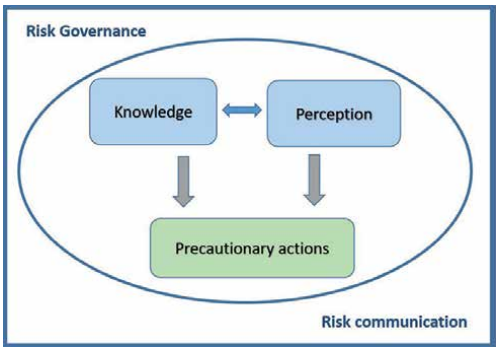


Figure 2.
Framework of the questionnaire.

hazards and existing protective measures (protective structures, emergency and hazard zone planning), 2) risk perception (feeling of safety, perceived probability of being affected, responsibilities), 3) used and preferred communication channels, and 4) suggestions for improvement measures in the field of risk management. To answer the questionnaire, a representative sample of the population in the pilot municipalities in South Tyrol was contacted by telephone. In Carinthia, the questionnaire was sent by post to the inhabitants of the pilot municipalities. A total of 2282 questionnaires were answered (1410 in South Tyrol and 872 in Carinthia).

Results show that in both regions existing protection and prevention measures, especially HZPs, are little known among the population and many citizens would like to be better informed about them. Regarding the role of citizens and institutions, the results showed that citizens clearly think that the responsibility for risk prevention and recovery lies with the public authorities and that they generally have great trust in the institutions. In Carinthia, the most important actor is considered to be the municipality, while in South Tyrol it is the Province. In South Tyrol, 38.1% of respondents think they have basic self-rescue knowledge and 44% of respondents think they are not prepared in case of an event but can rely on institutions. In terms of engagement in risk prevention measures, in South Tyrol on average one third of the interviewed citizens think that they should have a more active role in risk prevention, while in Carinthia even half of the respondents' state this. As far as risk communication is concerned, the importance of mass media (TV, newspapers, radio but also the websites of municipalities and the Province) as reliable sources to receive information about natural hazards and risk has been recorded in both regions; the request to use e-mail, SMS and social media (but also brochures/flyers) to get such information has also emerged, always followed by television as the preferred means of communication. It should be noted that in those municipalities where before RiKoST other projects and initiatives have already been implemented with the participation of citizens, such as public hearings, information events or lessons with natural hazard experts in schools, it was found that citizens are better informed, more sensitized to these topics and do prefer a more active role by the citizenship. When we look at the responses of citizens on what measures they think could improve natural hazards management, we see that in South Tyrol as well as in Carinthia, the most frequently mentioned measures come from the field of information and education followed by the suggestion to promote ecosystem-based solutions such as protective forests. **Figure 3** shows in detail the results of the South Tyrolean survey.

Finally, the results showed that in municipalities that have recently experienced an event, there is a greater sense of insecurity and local population more often feel that existing measures and policies are not adequate to protect them from the impacts of natural hazards.

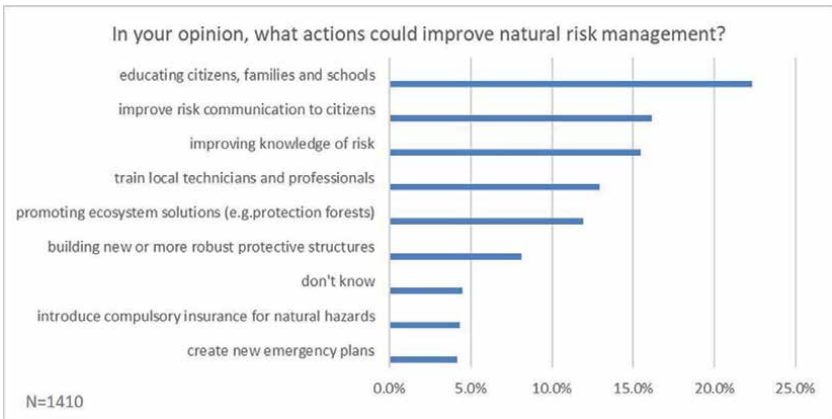


Figure 3.
Results from the population survey in 8 municipalities in South Tyrol.

3. Actions in the communities

In the pilot municipalities in South Tyrol within the framework of RiKoST, different awareness-raising activities have been undertaken: an information day and school actions, both including virtual reality (VR) activities, and an evening information event for citizens in each pilot municipality. In the pilot communities in Carinthia, stakeholder workshops with citizen representatives, local experts, relief units and representatives from local administrations were held to develop local operational plans in a participatory process. Different sources of communication, communication channels, contents, and target groups were thus used in the different actions: brochures, VR glasses with 3D videos about local natural hazards and hazard events, informal talks, maps, classes with historical local pictures and theoretical contents, online meetings and discussions, a game-based workshop, and stakeholder workshops. Different target groups were involved: mayors, citizen, local experts, members from relief units (fire brigade, police, emergency medical service), stakeholders from the tourism sector, middle and high school students. The aim of the different kind of actions was twofold: to raise risk awareness and to explore new ways for generating a collective change in understanding and tackling risk [11].

3.1 On the move in the streets and squares

Like the project slogan "If you know the risk, you know what to do!" well highlights, at the heart of the project lies the assumption that a kind of communication that directly reaches citizens, can raise risk awareness, and initiate a process of knowledge exchange on natural hazards and their management. What we called the "Scouts on the Road" campaign was an information day in the pilot municipalities, where two previously trained students, acted as "scouts", together with one or two representatives of the project, were out and about in the streets and squares. There they were talking to people, informing them about the project and the topic of dealing with natural hazards, answering questions, and giving them the opportunity to try out the VR glasses on which both HZPs and natural hazard events were simulated thanks to virtual reality. This made it possible to realistically visualize the potential impact of natural hazard events on buildings and cities in South Tyrol (**Figure 4**). In virtual reality, the intensity and probable location of hazardous events can become tangible to explore over time and space both prevention

Figure 4.
Pictures from awareness raising activities with the help of VR glasses.

measures and possible impacts. During this campaign, we observed how VR glasses were highly appreciated among the 219 people we met; what was unfortunately not well known were HZPs, while the knowledge of local natural hazards was higher in smaller municipalities than in bigger ones, excluding tourists, who resulted in having a very low risk awareness. Our experiences during the actions and our discussions with the participants have shown that the issue of risk communication is not a particular concern. In comparison, the interest and openness of the participants was greater in small communities than in large ones.

3.2 Activities in primary and middle schools

In the context of the growing attention on risk communication, the role of children and young people have been strongly emphasized by social scientists in recent years. Young people are not only often regarded as considerably vulnerable to disasters [12, 13] but it is also demanded to support their empowerment as active agents in prevention, response, and recovery [13, 14]. Students have also the potential to transmit knowledges to their peers and families, thus working as amplifier in terms of awareness raising and peer education. Furthermore, environmental education has been recently introduced in Italian schools as compulsory class to raise awareness on issues, which can have a link to natural hazards and related risk, especially in terms of climate change adaptation. For these reasons, two different kinds of activities were undertaken in schools: a) classes designed within RiKoST about natural hazards and possible prevention measures (such as the local hazard zone plans) and implemented in 8 schools, and b) a pilot simulation game with 33 high school students from one school of Vipiteno (one of the pilot municipalities of the project) (**Figure 5**).

The main activities took place between September 2019 and February 2020 and were carried out by two scouts and one or two representatives of the project partners. The schools were chosen in the 8 pilot municipalities involved, including middle and high schools and both Italian and German schools. In total, 291 students were involved in the activities. After a short introduction to the project, the classes included essentially three main components: a frontal class, the use of VR glasses, and a practical and interactive explanation of HZPs. At the end of the lesson, the students also received cardboard glasses with a QR code that allow them to watch the 3D videos on their mobile phones.

In terms of impact on the students, results from a short survey answered by the students showed that the classes were clearly understandable and gave a good overview of natural hazards. The VR glasses were much appreciated because they have been considered as useful to better understand maps and because they provide

Figure 5.
Pictures from school activities in South Tyrol.

a more realistic representation of potential local impacts of some natural hazards. Furthermore, they resulted to be a good tool to raise awareness in a more interactive way, and to address the link between risk perception, personal emotions, and believes. Finally, the use of local anecdotes, images and impacts of local events appeared to leverage senses of belonging and local knowledges.

Complementary to the described lessons, a simulation game was developed to explore if this type of action can contribute to risk communication towards young people, also in the broader context of the nexus between natural hazard risk management and sustainable development. Simulation games are recognized as favorable method in disaster and sustainability education (e.g., see [15, 16]). At the core of the simulation game was a scenario in which students took over different roles of a fictitious community (e.g., farmers, hotel owners, students) and discussed their local HZP and practical consequences based on predefined conflicting needs and aspirations and with a limited budget. The simulation game-based teaching module was tested in a pilot workshop in Bolzano with 33 students between 15 and 16 years old. It consisted of an introductory briefing phase, a simulation phase, and a debriefing phase for reflection.

The qualitative analysis of the method confirms that the developed simulation game contains different characteristics of transformative pedagogic practice[1]. It allows to experience natural hazard risks in an interdisciplinary manner as an example for complex and contested human-environment relations in mountain regions. Further, it encourages young participants to get involved with individual knowledge, experiences, and ideas. Finally, critical consciousness can be supported by experiencing and reflecting upon the role of power structures in decision-making processes on human-environment relations. Regarding objectives of risk communication, young people participating in the simulation game may increase their risk awareness through controversial discussions on natural hazard risks as a locally relevant societal challenge. Further, a comprehensive understanding of hazard risks and related challenges can be a prerequisite for making informed decisions. Although the study indicated that the developed simulation game holds potential to contribute to transformative natural hazard risk education, it also depends on the performance of the facilitator and the integration of the module in the local educational system and running teaching practice. For South Tyrol it has

[1] Transformative pedagogic practice is approached by the three indicators weak framing (i.e., strong student orientation), weak classification (i.e., weak disciplinary boundaries), and a learning environment that encourages critical consciousness [17, 18].

been concluded that the module could be integrated best in geography education or as an extracurricular workshop.

3.3 Evening information events for citizens

As a further action, the project organized evening information events, in cooperation with the mayor, councilors and/or technicians of the municipality to better fit the event to local needs. As an introduction, a representative of the Agency for Civil Protection presented the natural hazard situation in the respective community and recalled past events with the help of historical photos. In some municipalities, ongoing or planned projects for the construction of protective measures were also presented. The results of the survey for the respective municipality were then presented to the citizens. Afterwards, a joint discussion was promoted between experts, project representatives and citizens to identify possible improvements in risk communication. The discussions were sometimes hindered by the online mode of the meeting, which resulted in being the first of this kind among some municipalities and which was forced by the Covid-19 pandemic. In general, participation was higher in smaller municipalities, maybe due to a better engagement of citizens via direct information sources. During the informative evenings, some proposals were suggested and discussed to improve the involvement and role of citizens in risk prevention, especially in terms of non-structural measures. The positive role of institutions and the need to work more on what citizens "can really do" were stressed: improving knowledge of the local area and promoting actions in schools were brought up as topics to be fostered and further developed. In this regard, the role of historical memory and concrete actions to transmit the local history of the territory into the present were also brought to attention. During these events, the importance of easily accessible information, regular information events, and broader training and education in schools were highlighted as measures for the future to increase knowledge and awareness about natural hazards.

3.4 Involving stakeholders in flood risk management workshops

In case of flooding, operation checklists aim to support local authorities and relief units [19]. In contrast to common emergency plans, these checklists contain specific information and guidelines for authorities and relief units for disaster mitigation [20]. Flooding "hotspots" are identified based on hazard maps and potential damages can be minimized with prepared mitigation strategies. Especially in municipalities where structural measures cannot be realized soon due to financial bottlenecks, operation checklists are a valuable addition to concentrate available resources in time as well as to identify critical/vulnerable places, and to minimize potential disaster caused damages [19, 21]. Operation checklists are based upon 2D-hydraulic model results of critical flood levels and intensities (scenarios) where a significant increase of damage potential can be observed. In the pilot municipalities in Carinthia the modeled results were discussed with local stakeholders (e.g. citizen representatives, local experts), authorities, relief units (fire brigade, police, emergency medical service), and administrations (flood protection, road maintenance, railway, electricity, and water supplier) in a first (physical or virtual) workshop that aimed at reducing the number of relevant scenarios and considering potential counter measures based on their experiences and knowhow. A second stakeholder workshop aimed at designing detailed counter measures for each defined scenario. According to the stakeholder definition given in Ref. [22], the following actors should be part of the process: people who are a) legally involved in case of flooding and/or b) will practically use the checklist in the event of flooding (primarily district authority,

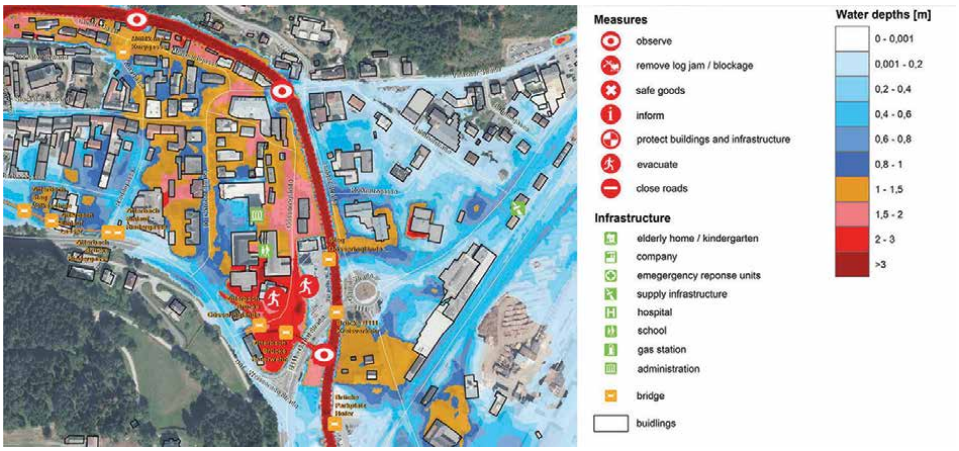


Figure 6.
Example of a map as part of an operation checklist (source: [19]).

mayor, operation controllers, relief units) and/or c) provide an essential technical input and/or d) are responsible for linking disaster control on regional and national levels and/or e) can support or block the initiative and/or f) are a representative of vulnerable groups (e.g. children, people in need of care).

The outcome of the workshops is a checklist divided into a textual part (descriptions) and maps. The relevant flood plains including prevalent water depths are mapped for each specific scenario. Additionally, these maps contain marks and labels about critical and sensitive infrastructure such as hospitals, nursing homes, schools, relief units, gas stations, etc. (**Figure 6**).

The specific markers represent local measures that are described in the textual part of the operation checklist. Moreover, the textual part of the operation checklist includes a) definitions of assumed scenarios, b) descriptions of effects and risks and c) lists and descriptions of necessary counter measures ("who does what, where, and when").

Over the past years, local stakeholders have been actively involved in the development of flood operation checklists. Local relief units, authorities and people who have witnessed major flood events added valuable information and insights in terms of their experiences, historic photographs, and personal and institutional event documentations. Having those local stakeholders involved, however, might be tricky at times since more careful handling than with experts is needed. Personal experiences have shown that organizers need to create an atmosphere where stakeholders are actively involved and can express themselves without being overstrained by too specific or technical information [23]. Hence, it is necessary to motivate and push stakeholders to actively participate in the workshops by making them aware of their personal advantage of reducing risk and potential damages caused by flooding. Past projects and results from RiKoST, however, have shown that with their knowledge these stakeholders provide an essential input during the workshops, especially when they are also actively involved in the actual disaster mitigation process.

4. Implications of results in practice and for policy making

The results of the surveys showed that especially the measures to train schools, families, and technicians are seen as the most important ones. As a result, contact has been established with the South Tyrolean school authorities and a training

course on natural hazards and risk prevention having teachers as target will be organized in the coming months. In addition, a 2-day training workshop for natural hazard practitioners will be held soon in South Tyrol, with a specific focus on risk communication.

Furthermore, our survey results have also shown that many people have an insurance for natural hazards without being aware of what is really covered by their policies. This aspect is now explicitly addressed in communication activities about natural hazards to make people aware that insurances are not enough, and additional mitigation measures are needed. For the stakeholder workshops in Carinthia, the findings of the opinion survey have already been integrated. But also, within the daily practice, when employees of the Carinthian administration dealing with natural hazards prevention are asked about protection measures by affected parties, these findings are integrated. It does not mean a huge change of administrative processes, but it mainly means to take use of a different wording. In detail, it is about to communicate:

- the specific problem of the potential natural hazard (detailed description of process and possible damages and losses),
- the probability based on documented events (even if it is only a historic newspaper article or an old picture) or on scientifically based calculations,
- that there is a problem without inciting fears (making aware but not urging),
- that the problem could affect vulnerable people (raising emotions),
- that building in endangered zones is strictly not recommended,
- self-responsibility by making people aware and support them, that even they and their contribution are part of a solution and
- residual risk by making aware, that mitigation measures are limited and bigger events with a lower probability can occur.

The process of a new risk communication has already started in Carinthia by teaching employees of the governmental administration in a first step and then to teach employees of municipalities (spatial planning and building authorities).

In both regions, our results clearly show that people do trust public agencies to apply proper methods to mitigate damages from natural hazards. This can reduce risk perception and have a negative impact on citizens' self-responsibility. For this reason, it is particularly important in risk communication to address and inform about what measures individual citizens can take and how they can better prepare and protect themselves. Indeed, in terms of risk prevention the results of the surveys and the activities carried out in South Tyrol have been supporting the development and design of a new web platform for knowledge exchange in the field of natural hazards that will be accessible also for the public and contain this type of information. This natural hazard platform will be available from October 2021.

In terms of innovative tools, the use of VR glasses resulted in being a good tool to raise awareness and to address the link between risk perception, emotions, and knowledge in a more interactive way. Simulation game approaches not only hold much potential to raise awareness for disaster risk but also empower underrepresented population groups, such as young people, for participation processes in natural hazard risk management. Eventually, this may be a keystone

for resilience-building. Nevertheless, the study on the transformative potential of simulation games in South Tyrol illuminated that the introduction of innovative approaches often faces numerous structural barriers, such as the educational system and culturally embedded pedagogic practice.

The project RiKoST gave the chance to develop and apply new methods, to evaluate them, to improve them and to give recommendations on how with to improve targeted risk communication strategies. The project related activities and experiences should not remain within the frame of a project, but as shown, they are triggering some potentially long-term risk communication activities and they should be taken up by practitioners and policy makers also in future and be integrated in institutional policies and initiatives. This is also the reason why it is so important in this type of project as RiKoST, that academic partners and partners from practice work together from the beginning, in the development and in the implementation, to enable sustainable changes.

5. Conclusions

Although the responsibility and availability of hazard maps is different in South Tyrol and Carinthia, the value of information concerning natural hazards risk is the same and both regions use hazard maps as a tool for risk communication. In Carinthia, flood operation checklists can be considered a refinement of hazard maps. They show hotspots of flood scenarios and spots where intervention measures can be most effectively applied. Effective operation checklists, however, do not only depend on the quality of maps, but they also strongly depend on stakeholders' engagement: if they have been properly involved into the elaboration process and they can acknowledge their own contribution in the final product. Our results from both regions show that it is important to use local anecdotes, local events, and local knowledge and to improve the understanding of maps.

Many of our results and experiences can also be transferred to other aspects of risk management, such as the role of protective forest or Eco-DRR (see chapter [24] of this book). One of our findings is that schools are an important actor for risk education. The topic of natural hazard and risk should become part of the school curricula and the education process and should also include topics such as Eco-DRR. The experiences and recommendations of the RIKoST project can also be applied to this field, namely, to undertake excursions in local contexts, for example by organizing an excursion with students to protective forest in the area. We realized that VR reality is a good tool to raise awareness and to start a discussion with students or citizens. A 3D video could for example visualize the role of protective forest by showing natural hazard scenarios with and without protective forest.

Just like the issue of natural hazards in general, Eco-DRR is not part of the everyday life of most citizens. Even though they might know the topic and consider it as relevant (see also results from **Figure 3**), they often do not have a concrete understanding of it or cannot imagine concrete measures that fall within its scope, cannot make a concrete connection to their immediate environment. Therefore, to raise awareness it is important to develop target specific messages and tools and to think about how they could be implemented and linked to other topics such as increase of life quality, landscape protection or sustainable development.

The main value of RiKoST was to set initiatives and to get into a risk dialog using different communication channels and contents for different targets, working with stakeholders and the public at a local "municipal" level. If stakeholders and the public are properly included in the process of risk communication, they will raise their awareness and increase the knowledge about their own responsibility and how

to respond to natural hazards. Improving risk communication and awareness is not the beginning of a process of reducing state responsibility but a process to build up effective local capacities to foster a social learning process, to promote a risk competent society which can rely on national and regional/provincial institutional support. Considering the aim of this volume the challenge for the future should be to include Eco-DRR measures, such as protective forests, into targeted risk communication actions.

Acknowledgements

The authors would like to thank Agnieszka Stawinoga, Stefan Schneiderbauer and Daniela Dellantonio from Eurac Research for their support in carrying out the described activities.

The research leading to these results has received funding from the funding programme Interreg Italia-Österreich – European Regional development Fund, under Grant Agreement ITAT3015, RiKoST – Risk communication strategies.

Conflict of interest

The undersigned hereby confirms that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work nor financial or non-financial interest in the subject matter or materials discussed in this publication that could have influenced its outcome.

Author details

Lydia Pedoth[1*], Fabio Carnelli[1], Gernot Koboltschnig[2], Paul Krenn[2], Anna Rudloff[3], Willigis Gallmetzer[4], Pierpaolo Macconi[4] and Nicola Marangoni[4]

1 Eurac Research, Bolzano, Italy

2 Regional Government of Carinthia, Klagenfurt, Austria

3 Institute for Environmental Social Sciences and Geography, University of Freiburg, Freiburg, Germany

4 Agency for Civil Protection, Autonomous Province of Bolzano – South Tyrol, Italy

*Address all correspondence to: lydia.pedoth@eurac.edu

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] UNDRR. Ecosystem-Based Disaster Risk Reduction: Implementing Nature-Based Solutions for Resilience. United Nations Office for Disaster Risk Reduction – Regional Office for Asia and the Pacific, Bangkok, Thailand; 2020

[2] Sudmeier-Rieux K, Nehren U, Sandholz S, Doswald N. Disasters and Ecosystems: Resilience in a Changing Climate - Source Book. Geneva: UNEP and Cologne: TH Köln – University of Applied Sciences. 2019

[3] Accastello C, Teich M, Cocuccioni S. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[4] Renn O, Klinke A, van Asselt M. Coping with Complexity, Uncertainty and ambiguity in risk governance: A synthesis. AMBIO 40. 2011:231-246. DOI: 10.1007/s13280-010-0134-0

[5] Holub M, Fuchs S. Mitigating mountain hazards in Austria – Legislation, risk transfer, and awareness building, Natural Hazards and Earth System Sciences, 2009;9:523-537. DOI: 10.5194/nhess-9-523-2009

[6] Wenk M, Neuhold C, Fuchs S. Zielgruppenspezifische Darstellung von Hochwassergefahren und -risiko. Österreichische Wasser- und Abfallwirtschaft. 2018;**70**:328 340. DOI: 10.1007/s00506-018-0470-z

[7] Hagemeier-Klose M, Wagner K. Evaluation of flood hazard maps in print and web mapping services as information tools in flood risk communication. Natural Hazards and Earth System Science. 2009;**9**:563-574. DOI: 10.5194/nhess-9-563-2009

[8] Faulkner H, Ball D. Environmental hazards and risk communication. Environmental Hazards. 2007;**7**(2):71-78. DOI: 10.1016/j.envhaz.2007.08.002

[9] Kellens W, Terpstra T, De Maeyer P. Perception and communication of flood risks: A systematic review of empirical research. Risk Analysis. 2013;**33**(1):24-49. DOI: 10.1111/j.1539-6924.2012.01844.x

[10] De Marchi B, Scolobig A. The views of experts and residents on social vulnerability to flash floods in an Alpine region of Italy. Disasters. 2012;**36**(2):316-337. DOI: 10.1111/j.1467-7717.2011.01252.x

[11] Murti R, Mathez-Stiefel S. Social learning approaches for ecosystem-based disaster risk reduction. International Journal of Disaster Risk Reduction. 2018. DOI: 10.1016/j.ijdrr.2018.09.018

[12] Midtbust LGH, Dyregrov A, Wittrup Djup H. Communicating with children and adolescents about the risk of natural disasters. European Journal of Psychotraumatology. 2018;**9**(sup2). DOI: 10.1080/20008198.2018.1429771

[13] Fothergill A. Children, Youth, and Disaster. Oxford Research Encyclopedia of Natural Hazard Science; 2017. DOI: 10.1093/acrefore/9780199389407.013.23

[14] Peek L, Abramson DM, Cox RS, Fothergill A, Tobin J. Children and Disasters. In: Havidán R, Donner W, Trainor JE, editors. Handbook of Disaster Research. Cham: Springer International Publishing; 2018. pp. 243-262

[15] Christenson N, Koivist J, Persson E, Hindersson E, Gustafsson K, Pettersson A. Riskville – A game for learning about disaster risks and urban planning. International Journal of Mass Emergencies and Disasters. 2018;**36**(3): 238-246

[16] Solinska-Nowak A, Magnuszewski P, Curl M, French A, Keating A, Mochizuki J, et al. An overview of serious games for disaster risk management – Prospects and limitations for informing actions to arrest increasing risk. International Journal of Disaster Risk Reduction. 2018;**31**:1013-1029. DOI: 10.1016/j.ijdrr.2018.09.001

[17] Freire P. Pedagogy of the Oppressed. London: Penguin Books Ltd; 1996

[18] Bernstein BB. Class, codes, and control. Volume 4: Structuring of pedagogic discourse [reprint]. London, New York: Routledge (Class, codes, and control, Basil Bernstein; Vol. 4); 2003

[19] Koboltschnig G, Senfter S, Unterlercher M. Operation checklists as a support for authorities and relief units in the event of flooding – A pilot project for the municipality of Hermagor (Austria). In: Interpraevent 2016 Extended Abstracts; 2016. pp. 350-351

[20] Senfter S, Koboltschnig G, Unterlercher M: Operation checklists – Pilot project to support disaster control for potential dam failures of snowmaking reservoirs in Carinthia (Austria). In: Interpraevent 2016 Extended Abstracts; 2016. pp. 366-367

[21] Koboltschnig G, Senfter S, Unterlercher M: Hochwassereinsatzplan – Leitfaden (in German). Klagenfurt: Internationale Forschungsgesellschaft Interpraevent, Schriftenreihe 1, Handbuch 4; 2018. 27 p

[22] Stickler T: Stakeholderbeteiligung und Risikobewusstsein (Talk in German). In: Integrative wasserbauliche Praxisgespräche. 2017

[23] Fleischhauer M, Greiving S, Flex F, Scheibel M, Stickler T, Sereinig N, Koboltschnig G, Malvati P, Vitale V, Grifoni P, Firus K. Improving the active involvement of stakeholders and the public in flood risk management – Tools of an involvement strategy and case study results from Austria, Germany and Italy. Natural Hazards and Earth System Sciences. 2012;**12**:2785-2798. DOI: 10.5194/nhess-12-2785-2012

[24] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

Chapter 15

How to Use Scientific Information: Road Map for Tailoring Your Own Natural Hazard Risk Management Solution

Michael Kirchner, Mirjana Stevanov and Max Krott

Abstract

In this chapter, we explain how scientific information can effectively be used in the daily work of practitioners. We lead through the process of tailoring research results and scientific information to support an integrated and ecosystem-based natural hazard risk management in the form of a Road Map. This Road Map is based on the RIU (Research Integration Utilization) model for knowledge transfer and backed-up with our long-standing research experience. To illustrate the Road Map, which can be applied to any case of transferring scientific knowledge into practice, we summarize the main results of the GreenRisk4ALPs research project, and propose three steps for integrating them into applied projects or other activities: (1) "Diagnosis" - estimating the relevance of scientific information for applied risk or forest management, (2) "Consultation" - estimating the soundness of the scientific information through consultations with researchers, and (3) "Implementation" – checking the legal framework and the economic resources for the preferred solution. Furthermore, we provide a checklist for stakeholders for tailoring science-based solutions to their practical use, which contributes to facilitating the implementation of research results and can guide policy and practice. Finally, the theoretical and methodological background of the Road Map are presented and discussed.

Keywords: knowledge transfer, RIU model, integrated risk management, checklist for stakeholders, Ecosystem Services-oriented forest use

1. Introduction

Managing natural hazard risks is highly relevant to everyone visiting or living in the Alpine Region (see chapter [1] of this book). Professional risk management is a tool that has been keeping people in the Alpine Region safe for more than 100 years where forests play a key role as risk prevention measure (see chapters [2, 3] of this book). However, natural hazards such as rockfall, landslides and snow avalanches are still causing severe damages every year [1]. Hence, there is an urgent need to continuously improve Alpine risk management strategies to ensure people's safety in the future [4].

This chapter informs stakeholders how to utilize scientific information from the Interreg Alpine Space project GreenRisk4ALPs (ASP635) [5], and how to form innovative alliances with researchers, which support the selection of science- and ecosystem-based risk mitigation measures. The main stakeholder groups are (i) public agencies involved in risk management, which often have to choose between green, technical and/or avoidance measures such as the reduction of land use in high risk areas; (ii) political actors like mayors, local parliaments or city councils and village boards, which are strongly involved in risk-related issues, and (iii) service providers, service users and citizens of the Alpine Region, for whom natural hazard risk management is highly relevant for their safety. For all these stakeholders it is usually a challenging task to be aware of the most current scientific studies or receive their results, to select the best-fitting ones and to integrate them into science-based solutions that will work in practice. Therefore, in this subsection we demonstrate how to deal with scientific results and engage scientists after receiving first information about a research project that addresses questions which are important for your own work.

The first contact with a research project may be in any phase of the research process, e.g., in the initial phase, when a research project is being designed and formulated. Or in the end, when project results are finalized, and stakeholders are able to judge their relevance while selecting scientific information that is useful to their interest-oriented action and that can help to improve their own risk management solutions. This Road Map subsection exemplifies the optimal use of scientific information produced during the GreenRisk4ALPs (GR4A) project. Yet, the way of "making sense of science" is applicable to all other project phases or other scientific projects aiming to facilitate the implementation of scientific information into practice.

1.1 Key results from the GreenRisk4ALPs project

The GR4A project aimed to provide scientific information supporting an ecosystem-based integrated risk management of natural hazards in the Alpine Space, and the acknowledgment of the key role forests have as an Ecosystem-based solution for Disaster Risk Reduction (Eco-DRR) in mountain areas (for risk and other definitions see chapters [1, 2] of this book). Within the project, an international collaboration of researchers and practitioners from 12 institutions developed various products for decision support (e.g., see chapters [6–8] of this book) by applying scientific principles, methods and standards. Many of the scientifically sound GR4A results are listed in the "Catalogue of selected GreenRisk4ALPs research products" (**Table 1**), consisting of a main product (a set of expected and aimed scientific information of a research project) and a by-product (scientific information which supported the development of the main product, but was not the aim of the project or necessarily mentioned in the documented research). The listed products were developed between 2018 and 2021, when researchers were identifying forests with protective functions and quantifying their protective effects against landslides, rockfall and snow avalanches in the six GR4A Pilot Action Regions (PARs): Val Ferret, (Italy), Kranjska Gora (Slovenia), Oberammergau (Germany), Baronnies Provençales Regional Nature Park (France), Wipptal South (Italy), and Gries am Brenner and Vals (Austria) (see [9] for descriptions). These analyses and model developments were combined with investigating risk management measures that are currently being applied in the six PARs, as a starting point for considering improvements of existing or introduction of alternative risk management solutions. If you are already active or want to become active in ecosystem-based risk management of natural hazards in the Alpine Region, then the GR4A research products may support your

Research products	Main product	By-product	Ref.
Forest protective function modeling with Flow-Py: open-source regional-scale gravitational natural hazard runout and intensity simulation tool	✓		[6, 10, 11]
Protective forest definition matrix: consistent definitions of protective forests to achieve the objectives of GreenRisk4ALPs		✓	[12, 13]
"The forest extension"* for Flow-Py: estimates the (protective) effect a forest has on the hazard process (energy reduction = reduction of velocity and runout length), dependent on the "actual" forest structure		✓	[6]
"The back-tracking extension"* for Flow-Py: identifies the hazard process paths (starting, transit and runout zones) associated with endangering infrastructure		✓	[6, 11]
Maps of "Direct Object Protective Forest": forests that are located between natural hazard starting zones and endangered infrastructure	✓		[7]
Maps of "Efficient Green Mitigation Areas": mapping of areas that are highly effective for hazard energy reduction by suggesting: (i) potential areas for afforestation for direct object protective forest, (ii) existing direct object protective forest that is highly effective	✓		[7]
Maps of "Impact Reduction Index": show differences in the process intensity from Flow-Py simulations with and without considering the protective effect of direct object protective forest		✓	[7]
GIS-based spatial modeling (spatially explicit assessments): identifying areas where the forest plays a key role in protecting infrastructure from natural hazards; provides regional-scale maps	✓		[7, 14, 15]
Exposure assessment: (i) identifies those areas where hazard exposure is reduced due to the presence of forest, (ii) ranks the forest effect by assessing the impact of each hazard type on different types of assets with and without forest effect	✓		[7, 14, 15]
Spatial analysis to identify hotspot areas: produces annotated hotspot maps, datasets, a process description, and documentation of results	✓		[7, 14, 15]
Protective Forest Assessment Tool (FAT): online decision support tool to estimate the value forest has for protecting buildings and infrastructure against gravitational natural hazards	✓		[7, 16, 17]
Economic model TEGRAV (Technical - GReen – AVoidance): cost–benefit analysis of ecosystem-based, land use avoidance and technical protection measures (and their combination); TEGRAV is linked to the hazard model in FAT		✓	[18–20]
Direct costs: originate from construction/implementation of a protection measure + maintenance + dismantling		✓	[18–20]
Indirect costs: originate from the construction/ implementation of a measure, which presumably modifies an existing situation		✓	[18–20]

Research products	Main product	By-product	Ref.
Avoided damages: all detriments to infrastructures, people and assets that could occur without protection measures		✓	[18–20]
Benefits: the sum saved or earned due to the construction/ implementation of the measure		✓	[18–20]
Rapid Risk management Appraisal (RRA): participatory approach for (i) pinpointing the most relevant natural hazards in terms of risk in a region, (ii) identifying strengths and entry points of risk management for implementing future risk reduction measures	✓		[8, 14, 15]
Risk identification: identifying those natural hazards which are considered the most relevant from a risk perspective		✓	[8, 14, 15]
Risk analysis: analyzing the existing risk management practices related to the previously selected natural hazards		✓	[8, 14, 15]
Risk evaluation: generating and discussing the risk management profile on a spider diagram, which provides a comprehensive picture of risk management practices, and comparing risk management profiles for various study areas		✓	[8, 14, 15]
**Enables users to adapt the model (here the Flow-Py simulation tool) to address a specific question.*			

Table 1.
Catalogue of selected GreenRisk4ALPs research products for risk-based decision support in protective forest and natural hazard management.

daily or strategic activities. You can use the "Catalogue of selected research products" (**Table 1**) to select and include one or more (or parts of them) into your specific science- and ecosystem-based risk management practice.

Before proceeding to the three steps needed for tailoring your own practice solution on research results (subsection 1.2), you must think about your willingness and ability to act realistically:

Willingness is linked to the tasks you are conducting and the interests you have. Both are individual and may differ from actor to actor. Yet, if interests and tasks are related to Ecosystem Services (ES; **Figure 1**), then the GR4A research products may attract your attention. Green prevention measures, as a regulating ES entail the maintenance, afforestation or reforestation of protective forests while technical prevention measures can be established in ecosystems to prevent or mitigate natural

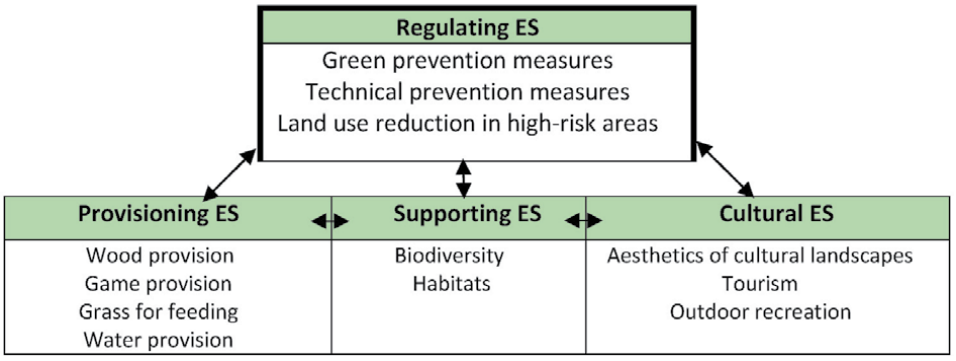


Figure 1.
Ecosystem Services (ES) important in the context of ecosystem-based natural hazard risk management. Adapted from [21].

hazards whereas land use reduction in high-risk areas is an avoidance measure that changes the previous land use to reduce natural hazard risk (see GR4A project report [21]). Both technical and avoidance risk management strategies strongly influence ecosystems, affecting simultaneously also human well-being [22]. To visualize different tasks and interests of actors in risk management we summarized technical and avoidance strategies together with green prevention measures as regulating ES that influence natural hazard risk (**Figure 1**). Regulating ES are linked to the other ES categories: provisioning, supporting and cultural ES (**Figure 1**). Even if your work is focused on natural hazard and protective forest management, you are encouraged to think in terms of ES and try to identify those ES that are related to your area of interest and professional duty.

Ability is related to your realistic judgment of the resources at your disposal to engage in a particular activity. The most important resources and constraints (e.g., legal and economic ones) will be addressed here briefly, but no guide or Road Map can capture all the particularities of a single case. Therefore, the steps listed below are one way to realistically evaluate the implementation of scientific information and research results into your own applied project and its chances for success.

1.2 Three steps to integrate the GreenRisk4ALPs research products into your applied project or practice-related activity

For becoming part of an applied project or activity, scientific information selected from the "Catalogue of selected GreenRisk4ALPs research products" (**Table 1**) has to be integrated into the existing knowledge and experience of a particular actor [23]. Based on this new knowledge, practitioners can tailor their own projects or science-based activities in three basic steps. That is, you are encouraged to carefully consider each step and proceed to the next step if you answer most questions with a YES.

1.2.1 Step 1: diagnosis

Estimate the relevance of the GR4A research products for your risk management practice OR your ES-oriented forest use.

Main question: Is the particular GR4A research product relevant for my risk management OR my ES-oriented forest use in the Alpine Region?

Main aspects:
- relevance regarding my risk management (incl. political/economic setting)
- relevance regarding potential allies
- relevance regarding public goals

1A: Is the particular GR4A research product relevant for my risk management OR my ES-oriented forest use in the Alpine Region? Yes ☐ No ☐

You or your activities are part of the Alpine Region. You may be involved in forest management, civil protection, natural hazard risk management, live in a house or own a hotel protected by forests, operate or use highway or train infrastructure passing through endangered areas protected by forests. This direct object protective effect, which forest has to ensure for your safety or which is related to your occupation, is an example for the relevance and the key to answering whether

GR4A research products related with direct object protective forests are relevant for you. Also consider all three alternatives: (1) Green prevention measures, (2) Technical prevention measures, and (3) Land use reduction in high-risk areas (**Figure 1**). In addition, consider how risk prevention against natural hazards fits into your actual economic and political agenda. It may also be the case that the specific newly designed and scientifically based prevention strategy opposes your specific interest in using a forest. In this case you are free to dismiss scientific solution(s) fully or parts of the solution(s) that you do not accept. Not all scientific solutions are appropriate for all users.

1B: Is the particular GR4A research product relevant for my potential allies?	Yes ☐ No ☐

You may find it useful to think about networks of actors connected to the ES of your interest and then consider for whom your risk management or forest use might be particularly relevant. If you identify a potential ally, then the start of an alliance could improve the chances for success of your planned action. Yet, this potential ally (or allies) has to be interested also and open for the research product you are relying on. If you want to dismiss the scientific solution(s), then partnering with allies would mean that you can hinder the solution(s) and protect yourself from its potentially negative consequences.

1C: Is there a link between my risk management OR my ES-oriented forest use and the relevant public goal(s)?	Yes ☐ No ☐

Public goals are the backbone for national-to-global policies and basically governs us all. Linking (one or more) currently relevant public goals with your risk management or forest use may provide the highly required legitimacy for your applied project or action based on a GR4A research product. Therefore, it is advised to avoid legitimization by goals that are too unspecific such as the goal of sustainable forestry, because of their limited political reach. Instead, think widely! As a basis for your ideas, but more importantly also as a reference, you should consider goals introduced by national ministry programs or national strategies, well-acknowledged norms of a civil society or current and actual goals of international strategies. For example, the new EU Strategy on Adaptation to Climate Change [24] is calling for rolling out physical solutions for more green spaces (p.12) and to do it in a cost-effective way (p.11). Protective forests are green spaces and solutions that are having certain cost–benefit advantages compared to other hazard mitigation measures [22, 25]. While including protective forests into risk management strategies, either to stabilize the soil or to reduce impacts of natural hazards, the GR4A research products may not only have the potential to contribute to increasing people's safety but may also have a broader application as a climate change mitigation measure. In contrast to immediately effective technical measures such as rockfall nets, Eco-DRR solutions have the potential to adjust to the challenges driven by global environmental change [26]. You must invest time and be creative to find out which strong public goals will serve your specific project and/or activity.

1.2.2 Step 2: consultation

Estimate the soundness of the scientific information provided by the GR4A research product that is relevant for you. Undertake this step only if most of your answers in the previous Step 1 were YES ☑.

Main question: Is the relevant GR4A research product scientifically sound and available?

Main aspects:
- looking for "open doors" to science
- consulting scientific institutions / project teams about product limitations
- consulting diverse sources about credibility of research results
- selecting (parts of) products and consulting researchers for fine-tuning (if needed)

2A. Do I or my organization have connections to science? Yes ☐ No

First of all, check the ways your organization uses scientific information in daily practice. Are there specific open doors to science like working groups, scientifically knowledgeable collaborators or other persons experienced with science that work for your institution? Or, if you are a single person, think about how you are using scientific information in your daily life. Have you obtained science-based education or do you trust that your information about scientific results reflects the current state of knowledge? In any of these cases you should consider your existing links to scientific information. In general, such links are provided by the experts within your organization. These "integration forums" (for types see subsection 2.2) may be either small or big, but they are essential to open the door to science [27].

2B. Can I or my integration forum check limitations of a particular research product(s)? Yes ☐ No ☐

The first task is to get into direct contact with the scientific organization(s) and its researchers who are offering a research product relevant for your risk management or ES-oriented forest use. Only through this direct consultation you will be in the position to get precise information that can help you to consider options for using this research product in a particular case. For example, if your tasks and interests are concerning the direct object protection provided by a particular forest, then you may want to check availability of maps of "Direct Object Protective Forest" for your region, or maps of "Efficient Green Mitigation Areas" (**Table 1**). All mentioned research products are based on scientific procedures and theoretical or data-based models, which are established within the scientific community, but they all have specific limitations. For example, models are limited in terms of included variables, available input data and uncertainties in their results (see chapters [3, 6, 28] of this book). However, the direct contact between you (or your integration forum) and the researchers will provide information into the underlying assumptions and limitations of the specific model. Based on this information, you can make a first evaluation about the suitability of its application to your needs and area of your interest.

2C. Can I or my integration forum check the credibility of research results? Yes ☐ No ☐

If you gained sufficient background information about the procedures that the research product is relying on and its limitations and you still consider including scientific information into your applied project or practice-related action, then you have to undertake the next step: to judge the scientific credibility of the research results. To do so, you can first consult organizations' websites while looking for indicators about the researchers who are offering the research product. Examples

for such indicators are research results that have passed the peer-review process of established scientific journals or the existence of networks with other researchers and institutions, especially with those you already know or have collaborated with [29]. As you may not always be in the position to judge the scientific quality of the research, you can ask another research institution for an independent evaluation. This is not only limited to the information from the websites but applicable for all sources, including various media channels (e.g., LinkedIn, Facebook or Twitter). These social media channels increasingly provide links to innovative research and results, yet their scientific basis must be checked before you can be certain about proceeding to the project implementation (Step 3). Checking means, for example, to be certain that the research results are state-of-the-art and evaluated by the scientific community through peer review. Diverse media channels communicate (scientific) information eye-catching and condensed, which is their basic mission, but they need to be cross-checked, at least with the original source and/or scientific publication.

2D. Can I or my integration forum check fine-tuning possibilities for (parts of) the research product of my interest?	Yes ☐ No ☐

The first three sub steps (finding open doors to science, checking product limitations and scientific credibility) will often not be sufficient to decide whether the particular research product fully fits your needs. Science can neither answer every specific question from practice nor provide comprehensive best-solutions. Therefore, you must identify the specific contribution of a research result to your interests or solution (e.g., calculating the likelihood of a natural hazard to reach a hotel or the costs for avoiding damages). Rarely, but it can happen that the scientific information fully supports your planned activity (no additional information is needed and no additional aspects must be covered). Then select it and use it as an argument for your planned activity or incorporate it into your own project. Typically, some additional scientific information will be needed, which might require time and resources to collect. If you have resources, then contact the researchers and ask to fine-tune the procedure, so that scientific accuracy remains intact. Sometimes, deficits of scientific information will appear too big. In that case, you may think to either initiate an additional research project or don't pursue your GR4A-based solution.

1.2.3 Step 3: implementation

Estimate chances for implementing your GR4A-based solution. Undertake this Step 3 only if most of your answers in the previous Step 2 were YES ☑.

Main question: Does my GR4A-based solution have a realistic chance to become implemented?

Main aspects:
- legal framework
- economic framework
- democracy and good governance

3A. Can my risk management or ES-oriented forest use be embedded into the existing legal framework?	Yes ☐ No ☐

Laws influence humans through enabling or restricting their actions. Therefore, check the legal basis for implementing your GR4A-based solution. If your ES-oriented forest use would, for example, increase costs for the protection measures for a municipality, then you might already look for financial instruments that particular policies might be offering and check if municipalities are eligible to apply. In addition, researching legal limitations is advised, because overcoming them later might be a long-term political process which can increase the timeline for implementing your solution.

3B. Can my risk management or my ES-oriented forest use be embedded into an existing economic framework?	Yes ☐ No ☐

Risk management is costly, and cost-efficient solutions will save resources and open a broader room of action. Whatever your case might be, the issue of sufficient economic resources must be considered wisely, either while counting on private funding or having checked public funding sources (regional, national, international). In addition, public-private partnerships may be a funding option. Be realistic about the economic constraints for your project or your ES-oriented forest use. Project activities typically consume more resources than estimated. Thus, consider sources that may be available immediately or in the short term but look also for options in the longer term by clearly avoiding wishful thinking.

3C. Can my risk management or my ES-oriented forest use be embedded into good governance and democracy?	Yes ☐ No ☐

Your GR4A-based risk management activity or ES-oriented forest use may be controlled by the law and/or available economic resources but paying attention to different strategies of good governance and democracy may enlarge your opportunities for actions. Involving multiple actors (as one of good governance principles) may, for example, raise the awareness about your problem or enhance the acceptance of your ES-oriented forest use. Participation of multiple actors may also increase political or economic support for your GR4A-based solution (see also chapter [8] of this book).

However, all participation processes related to risk governance are highly susceptible for conflicts, for example, driven by questions to what extent the costs that are covered by many will benefit only some. Past examples show that participation processes may result in shifts toward certain interests or cause a "crisis in governmentality" instead of governance. This may endanger the democratic legitimacy of your activity. Therefore, it is advised to first assess potential conflicts that your GR4A-based solution may mitigate, increase or additionally trigger. Depending on your assessment you might still find it worth to proceed. Then, finding professional support for handling multi-actor participation in risk-related issues may be advisable. Not only that these issues are prone to conflicts but the line between your goals (e.g., fostering participation for rising attention and transparency) and counterproductive effects of the participation process (e.g., triggering fear by the community members) is very thin and often better perceived and handled by a professional with experience in conflict management.

In addition, be aware that you are part of the democratic environment, which means that you must be transparent about your activities. Depending on your issue and your target groups you may use multiple channels for distributing information. If your aim is for a broader outreach, you may want to use digital and print media reaching a wider population. Or you may collaborate with the local media for very

locally specific issues. Tailored campaigns or public debates may also be a channel for spreading information. It is, for example, known from recent research that appropriate risk communication can trigger adaptive behavior (see chapter [30] of this book). Yet, for triggering such effects, you have to bear in mind that the inputs and research products used for risk communication need to be carefully considered. In this context, the modeling results from the GR4A project might be useful, for example, when trying to raise the awareness of laypersons about wider benefits of protective forests such as their benefits for mitigating climate change. Or to highlight the impacts that adaptations of protective forest management practices will have on biodiversity (e.g., selection of tree species and dead wood management). Otherwise, laypersons can hardly imagine the impact and importance of protective forests and their functions and effects on the life and livelihood in the Alpine Region.

1.3 Checklist for the successful implementation of tailored, applied risk management projects

For your final evaluation for using research product(s) offered by the GR4A project (**Table 1**), go through Step 1 to Step 3 again. They are summarized in form of a checklist below (**Figure 2**). Let these steps and their associated questions guide you, so that you arrive at a realistic estimation of your chances to solve a particular risk management problem or to realize your ES-oriented forest use in practice. The more positive answers you give, the better the chances are for the successful implementation of your tailored, applied risk management project or practice-related action. Good luck!

This Checklist is intended to be used by stakeholders in practice. For the opposite case that scientists want to use a guide for fostering the support of practice for their research, please look into our "Road Map for decision targeted communication of green risk management" [31].

STEP 1 **Is the GR4A research product relevant for my risk management OR my ES-oriented forest use?**	**1A**. Is the particular GR4A research product relevant for my risk management **OR** my ES-oriented forest use in the Alpine Region? **1B**. Is the particular GR4A research product relevant for my potential allies? **1C**. Is there a link between my risk management or ES-oriented forest use and the relevant public goal(s)?	☑ ☑ ☑
STEP 2 **Is the relevant GR4A research product scientifically sound and available?**	**2A**. Do I or my institution have connections to science? **2B**. Can I or my integration forum check limitations of a particular research product(s)? **2C**. Can I or my integration forum check the credibility of research results? **2D**. Can I or my integration forum check fine-tuning possibilities for (parts of) selected research product of my interest?	☑ ☑ ☑ ☑
STEP 3 **Does my GR4A-based solution have realistic chances to become implemented?**	**3A**. Can my risk management or ES-oriented forest use be embedded into the existing legal framework? **3B**. Can my risk management or ES-oriented forest use be embedded into an existing economic framework? **3C**. Can my risk management or ES-oriented forest use be embedded into good governance and democracy?	☑ ☑ ☑

Figure 2.
Checklist for the successful implementation of tailored, applied risk management projects.

2. Theoretical and methodological background of the Road Map

2.1 The RIU (Research Integration Utilization) model

The RIU model is a theoretical model of knowledge transfer created in 2016 [29]. Stevanov and Krott [23] provide an explanation and anchor the model within the three phases of knowledge transfer: the most recent overview from [32] discriminates between (i) linear models (in the 1960s) where knowledge was expected to be implemented linearly by politicians and bureaucrats; (ii) co-production and other models (in the 1970s–1990s) where attention was drawn to the active part that politicians and bureaucrats can play while interacting with scientists and bringing their political judgements to the knowledge transfer; and (iii) embedded models (after 2000), where an even more active part of practice is offered and, in addition to the input of politicians and bureaucrats, explicit formats for societal input are provided. The RIU model belongs to the third group of embedded models, which try to enrich solutions and include public interests and values, while simultaneously keeping scientific knowledge as the basis. The RIU model accordingly acknowledges two distinct elements – Research (R) and Utilization (U), each following its own, different rationale. That is, research follows the formal, public rationale, and scientific information is generated to describe and explain real world phenomena. Utilization, on the other hand, does not rely on the rational (deliberative) discourse, but rests upon the power to induce change in practice, which serves the interest(s) of the dominant actors. Within the processes of transferring scientific information from the Research into forestry practice (Utilization), the scientific rationale as well as interests and power of actors from practice remain separate (**Figure 3**). Yet, the bridge between them is established through Integration (**Figure 3**) and its integration forums respectively [27].

2.2 Methodological background

The Road Map is a result of a theory-based analysis that was empirically proven by the GR4A project. Empirical evidence was collected by the means of observations, document analyses and expert interviews [33]. This evidence was crosscut (triangulated) for reliability purposes [33]. The theoretical basis of the Road Map builds on the key criteria of knowledge transfer summarized by the checklist of Böcher and Krott [29]. These key criteria of knowledge transfer were tested between 2016 and 2018 within the ALTERFOR project and its ten case study areas [34]. Results led to the further development of the theoretical basis and further adjustment of the key criteria (see [23]). Based on that, the PARs of the GR4A

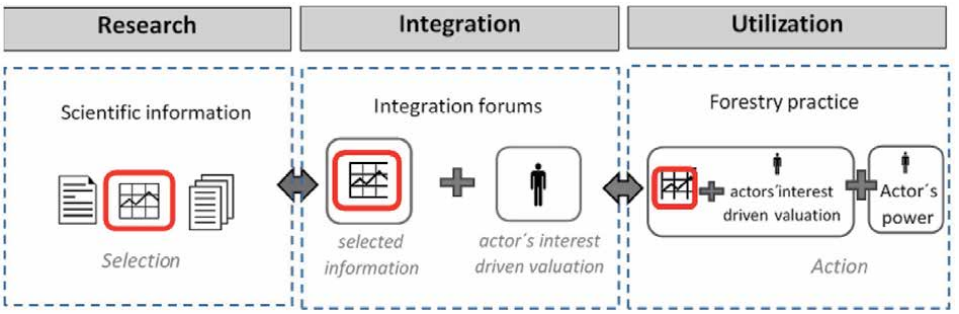


Figure 3.
The RIU model: transfer of scientific information from research into utilization by practice via integration. Adapted from [23]; for "Integration forums" see [27].

Integration forum				
Type	**Defining elements**			**Examples**
	Forum is identified as already existing	**Forum has existing links to science (gradual)**	**Forum is known by the project**	
Existing	+	+	+	• Advisory boards • Jurisprudence
Hybrid	+	+	-	• Bilateral discussion • Expert rounds • Ad-hoc task forces
New	-	+	+	• Workshops • Round tables

Table 2.
Defining elements for each type of an integration forum (yes +, no -): existing, hybrid, new forums. From [27].

project [9] served to deepen the analysis and to look into the processes driving the selection of scientific information and the modes of exchange with the actors from practice. These different modes of information exchange, called integration forums [27], were investigated in all PARs. The three types of integration forums – existing, hybrid and new forums - were determined (**Table 2**) while using the following characteristics [27]: (i) if the forum has been identified as an already existing one (yes +, no -); (ii) if the forum has an existing link to science (yes +, no -), and (iii) if the forum is known by the research project (yes +, no -). Examples for each type of integration forums are given in **Table 2**, and details can be found in GR4A project reports [35, 36]. This knowledge on different types of integration forums is useful for Step 2 of the checklist where the scientific fit of research products is checked (see subsections 1.2 and 1.3).

3. Discussion and concluding remarks

The RIU model represents a comprehensive knowledge transfer approach [29]. Each of its three elements - Research, Integration and Utilization - is related to specified tasks of knowledge transfer and backed up by empirical evidence. Empirical evidence from the GR4A project [35–37] as well as several other cases [38] shows that the transfer of scientific information from science into practice works best when both scientists and practitioners keep their specific, independent roles but strongly engage into the mutual communication.

In this mutual communication, scientists and practitioners come together to exchange information within particular integration forums [27]. For transferring scientific information into practice, workshops have been often recommended and applied within research projects [39–43]; however, workshops have been proven to be rather ineffective [44, 45]. This is because a workshop does not attract powerful actors and as such does not represent a place where relevant decisions are (or could be) made.

Most knowledge transfer models suggest continuous improvement of communication processes between researchers and actors from practice, aiming at a general consent [46, 47], that is, practitioners should be fully integrated into the research process. Such co-production approaches are often found in EU project calls, i.e., for multi-actor projects [48]. Based on the RIU model, however, we did not find empirical evidence showing that full integration of practitioners into the research

will lead automatically to more successful knowledge transfer (Utilization), which has also been confirmed by other authors (e.g. [49, 50]). According to the RIU model, integration forums are not all-inclusive but selective with respect to relevant actors [27]. If integration aims for the general consent between science and practice regarding the content of the science-based solution, then it can be expected that the communication process will typically "hurt" both the scientists as well as the relevance of the solution for practice. Furthermore, we did not find empirical evidence showing that mutual learning can help scientists by switching into the role of practitioners and vice versa, as it is proposed by most knowledge transfer models up to now.

To summarize, growing knowledge transfer efforts are positive developments. We offer a Road Map that was developed within the GR4A project for integrating research products into the risk management solutions of practice (see subsection 1.2). We found that the project duration of three years resulted in innovative research products but has been proven to be too short for establishing the process of integrating these results into practical solutions effectively. In contrast to the expectations of many scientists and research funding programs the process of knowledge transfer is a long and bumpy road and needs considerable time and resources, which should be addressed more comprehensively in the future.

Acknowledgements

This work was conducted in the context of the GreenRisk4ALPs project (ASP635), which has been financed by Interreg Alpine Space programme, one of the 15 transnational cooperation programs covering the whole of the European Union (EU) in the framework of European Regional policy.

Conflict of interest

The authors declare no conflict of interest.

Author details

Michael Kirchner*, Mirjana Stevanov and Max Krott
Chair Group of Forest and Nature Conservation Policy, Georg-August University of Göttingen, Göttingen, Germany

*Address all correspondence to: michael.kirchner@uni-goettingen.de

IntechOpen

© 2021 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Accastello C, Teich M, Cocuccioni S. The concept of risk and natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99503

[2] Teich M, Accastello C, Perzl F, Berger F. Protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) in the Alpine Space. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99505

[3] Perzl F, Bono A, Garbarino M, Motta R. Protective effects of forests against gravitational natural hazards. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99506

[4] Poratelli F, Cocuccioni S, Accastello C, Steger S, Schneiderbauer S, Brun F. State-of-the-art on ecosystem-based solutions for disaster risk reduction: The case of gravity-driven natural hazards in the Alpine region. International Journal of Disaster Risk Reduction. 2020;**51**: 101929. DOI: 10.1016/j.ijdrr.2020.101929

[5] Interreg Alpine Space project GreenRisk4ALPs (ASP635) [Internet]. Available from: https://www.alpine-space.eu/project/greenrisk4alps/

[6] D'Amboise C J L, Teich M, Hormes A, Steger S, Berger F. Modeling protective forests for gravitational natural hazards and how it relates to risk-based decision support tools. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99510

[7] Accastello C, Poratelli F, Renner K, Cocuccioni S, D'Amboise C J L, Teich M. Risk-based decision support for protective forest and natural hazard management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99512

[8] Cocuccioni S, Plörer M, Kirchner M. Stakeholder integration and participatory processes as part of an ecosystem-based and integrated natural hazard risk management. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2022. DOI: 10.5772/intechopen.99516

[9] Beguš J, Kleemayr K, Berger F, editors. Best practice examples of implementing ecosystem-based natural hazard risk management in the GreenRisk4ALPs Pilot Action Regions. London: IntechOpen; 2021. DOI: 10.5772/intechopen.95015

[10] Neuhauser M, D'Amboise C J L, Teich M, Kofler A, Huber A, Fromm R, Fischer J-T. Flow-Py: routing and stopping of gravitational mass flows. Zenodo. 2021. DOI: 10.5281/zenodo.5027274

[11] D'Amboise C J L, Neuhauser M, Teich M, Huber A, Kofler A, Perzl F, Fromm R, Fischer J-T. Flow-Py v1.0: A customizable, open-source simulation tool to estimate runout and intensity of

gravitational mass flows. Geoscientific Model Development. 2022;**15**:2423–2439. DOI: 10.5194/gmd-15-2423-2022

[12] Kleemayr K, Teich M, Perzl F, Hormes A, Markart G, Plörer M. Protection Forest Definition Matrix. Austrian Research Centre for Forests (BFW), Department of Natural Hazards, Innsbruck. 2019. Available from: https://www.alpine-space.eu/wp-content/uploads/2022/11/poster_grfa_schutzwald_englisch.pdf

[13] Kleemayr K, Teich M, Hormes A, Plörer M, Perzl F. A consistent definition of site and object protection forest, and their protective effects. 14th Congress INTERPRAEVENT 2021, Norway – Conference Proceedings. 2021

[14] Cocuccioni S, Renner K, Steger S, D'Amboise C, Hormes A, Plörer M, et al. D.T3.2.1 Report on "Preparation for risk analysis and strategy workshops". Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[15] Cocuccioni S, Renner K, Steger S. D. T 3.5.1: Report on "Results of the risk analysis and the strategy prioritization." Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[16] Protective Forest Assessment Tool (FAT) [Internet]. Available from: https://gr4a.geocodis.com/

[17] D'Amboise CJL, Žabota B, Poratelli F, Pecan P, Plörer M, Accastello C, et al. A.T1.6 Construction of the innovative and new protective forest assessment tool (FAT). Innsbruck, Austria: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 1 PRONA)

[18] Poratelli F, Accastello C, Brun F, Bruzzese, S, Blanc S. D.T3.3.1 - Report "TEGRAV analysis: an integrated model to compare risk management strategies". Torino, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[19] Poratelli F, Accastello C, Brun F, Bruzzese, S, Blanc S. D.T3.3.2 - Report on 'TEGRAV tool'. Torino, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[20] Cocuccioni S, Poratelli F. D.T 3.4.1: Report on "Development of TEGRAV risk management strategies in relation to CC and SC." Bolzano, Italy: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 3 DORA)

[21] Krott M, Kirchner M, Hasnaoui A, Begus, J, Škrjanec S, Kleemayr K. D. T2.3.1 Report on 'Comparative decision structure analysis in the PAR'. Göttingen, Germany: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2019. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 2 ACTINA)

[22] Olschewski R, Bebi P, Teich M, Wissen Hayek U, Grêt-Regamey A. Avalanche protection by forests — A choice experiment in the Swiss Alps. Forest Policy and Economics. 2012;15: 108-113

[23] Stevanov M, Krott, M. Embedding scientific information into forestry praxis: Explaining knowledge transfer in transdisciplinary projects by using

German case. Forest Policy and Economics. 2021;**129**:102508. DOI: 10.1016/j.forpol.2021.102508

[24] EC - European Commission. Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the Committee of the regions, Brussels (24.02.2021). 2021

[25] Reid H, Bourne A, Muller H, Podvin K, Scorgie S, Orindi V. A framework for assessing the effectiveness of ecosystem-based approaches to adaptation. In: Zommers Z, Alverson A, editors. Resilience. London: Elsevier; 2018. pp. 207-216

[26] Poratelli F, Cocuccioni S, Accastello C, Steger S, Schneiderbauer S, Brun F. State-of-the-art on ecosystem-based solutions for disaster risk reduction: The case of gravity-driven natural hazards in the Alpine region, International Journal of Disaster Risk Reduction. 2020;**51**:101929

[27] Kirchner M, Krott M. Integrating Forest science into natural hazard management practice: An international case study based on the innovative RIU approach. International Forestry Review. 2020;**22**(4):449-465

[28] Stritih A. Dealing with uncertainties in the assessment of the avalanche protective effects of forests. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99515

[29] Böcher M, Krott M. Science makes the world go round. Successful Scientific Knowledge Transfer for the Environment. Berlin/Heidelberg: Springer; 2016

[30] Pedoth L, Carnelli F, Koboltschnig G, Krenn P, Rudloff A, Gallmetzer W, Macconi P, Marangoni N. Improving risk communication strategies through public awareness and engagement – insights from South Tyrol and Carinthia. In: Teich M, Accastello C, Perzl F, Kleemayr K, editors. Protective Forests as Ecosystem-based Solution for Disaster Risk Reduction (Eco-DRR). London: IntechOpen; 2021. DOI: 10.5772/intechopen.99517

[31] Kirchner M, Krott M, Zavodja M, Hasnaoui A. D.T4.4.1 Report on 'Road map for decision targeted communication of green risk management'. Göttingen, Germany: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2021. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 4 ACRI)

[32] Sokolovska N, Fecher B, Wagner GG. Communication on the Science-Policy Interface: An Overview of Conceptual Models. Publications. 2019;**7**(4). DOI: 10.3390/publications7040064

[33] Babbie ER. The Practice of Social Research (14th ed). Boston, MA: Cengage Learning; 2015

[34] Stevanov M, Krott M, Biber P, Schwaiger F, Lundholm A, Masiero M, et al. Report on supporting local and national networks for forest management model alternatives. ALTERFOR Deliverable 4.2 [Internet]. 2020. Available from: https://alterfor-project.eu/wp4.html [Accessed: 10/10/2020]

[35] Kirchner M, Krott M, Hasnaoui A. D.T4.2.1 Report on 'Improved RIU model'. Göttingen, Germany: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 4 ACRI)

[36] Kirchner M, Krott M, Hasnaoui A, Zavodja M. D.T4.3.1 Report on 'Supporting actor alliances'. Göttingen, Germany: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 4 ACRI)

[37] Kirchner M, Krott M, Hasnaoui A D. T4.1.1 Report on 'Adapted RIU model'. Göttingen, Germany: Interreg Alpine Space project GreenRisk4ALPs (ASP635); 2020. Download from: https://www.alpine-space.eu/project/greenrisk4alps/ (Activity 4 ACRI)

[38] Do HT, Böcher M, Krott M. Multiple traps of scientific knowledge transfer: Comparative case studies based on the RIU model from Vietnam, Germany, Indonesia, Japan, and Sweden. Forest Policy Econ. 2020;**144**: 102134

[39] Löschner L, Nordbeck R, Scherha Ufer P, Seher W. Scientist–stakeholder workshops: A collaborative approach for integrating science and decision making in Austrian flood-prone municipalities. Environmental Science & Policy. 2016; **55**:345-352

[40] Scherhaufer P, Gruneis H. Herausforderungen und Grenzen partizipativer Projektarbeit – Zwei Beispiele aus der transdisziplinären Klimawandelanpassungsforschung und erste Lösungsansätze. Umweltpsychologie 2014;**18**:189-210

[41] Welp M, de la Vega-Leinert A, Stoll-Kleemann S, Jaeger C. Science-based stakeholder dialogues: theories and tools. Global Environmental Change. 2006;**16**:170-181

[42] Glicken J. Getting stakeholder participation 'right': a discussion of the participatory processes and possible pitfalls. Environmental Science & Policy. 2000;**3**:305-310

[43] Yosie TF, Herbst TD. Using Stakeholder Processes in Environmental Decisionmaking. An Evaluation of Lessons Learned, Key Issues and Future Challenges. Ruder Finn, Washington; 1998

[44] Menzel S, Buchecker M. Does Participatory Planning Foster the Transformation Toward More Adaptive Social-Ecological Systems? Ecology and Society. 2013;**18**(1)

[45] Thaler T, Levin-Keitel M. Multi-level stakeholder engagement in flood risk management—A question of roles and power: Lessons from England. Environmental Science & Policy. 2016; **55**:292-301

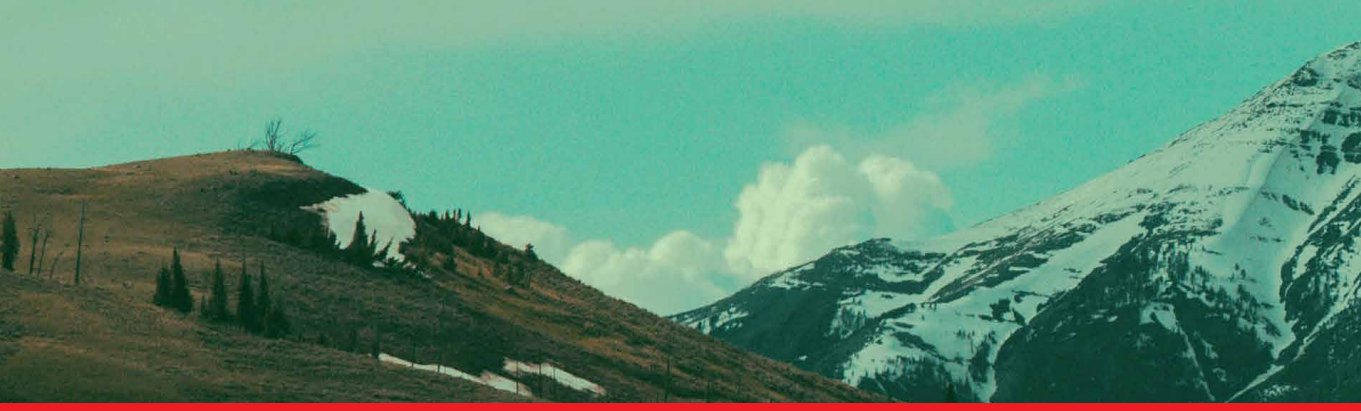
[46] Jasanoff S. States of knowledge: the co-production of science and social order (ed.). London: Routledge; 2006

[47] SAPEA Science Advice for Policy by European Academies. Making sense of science for policy under conditions of complexity and uncertainty: evidence review report Nr. 6. Berlin: SAPEA; 2019. DOI: 10.26356/MASOS

[48] EIP-AGRI Horizon 2020 multi-actor projects [Internet]. 2017. Available from: https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_brochure_multi-actor_projects_2017_en_web.pdf

[49] Oliver K, Kothari A, Mays N. The dark side of coproduction: do the costs outweigh the benefits for health research? Health Research Policy and Systems. 2019;**17**(33)

[50] Felt U, Igelsböck J, Schikowitz A, Völker T. Transdisciplinary sustainability research in practice: between imaginaries of collective experimentation and entrenched academic value orders. Science, Technology, and Human Values. 2016; **41**(4):732-761



Edited by Michaela Teich, Cristian Accastello, Frank Perzl and Karl Kleemayr

Protective forests are a key component to reduce natural hazard risks in mountain areas by preventing or decreasing the frequency, magnitude and/or intensity of snow avalanches, rockfall, landslides, floods, and debris flows. This book summarizes the state-of-the-art knowledge and introduces methods and decision support tools to facilitate the use of protective forests for Ecosystem-based Disaster Risk Reduction (Eco-DRR) as part of an integrated risk management in the Alpine Space. Moreover, it highlights how translating scientific knowledge into practical solutions can only be achieved by an active and iterative exchange with practitioners and policy makers, and a common understanding of applied concepts and definitions. Only then can protective forests be managed sustainably under constantly changing climate and socio-economic conditions.

Published in London, UK
© 2022 IntechOpen
© Eberhard Grossgasteiger / unsplash
© Trevor Wilson / unsplash

IntechOpen

ISBN 978-1-83969-327-4