# Forest management as an insurance against natural hazards – a case study of protection forests in Switzerland

**B 6**

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**Forests in mountainous regions provide crucial protection against natural hazards. This regulatory ecosystem service has historically often been provided as by-product of traditional forest management. During the past decades, economic development, land-use change, and climate change have put pressure on forest owners and the ecosystem itself. In Switzerland, a system of subsidies and guidance for practitioners has therefore been implemented to ensure that ecosystem services are provided at desirable levels. Increasing forest resilience against disturbances is one of the key concepts in this system, as resilient forests can better fulfil their role as a natural insurance. Over time, protection forest research has provided practitioners and decision-makers with a growing toolbox for identifying especially hazard-exposed areas and prioritising management accordingly, and for providing sustainable protection against natural hazards. Using a case study from the Canton of Graubünden in eastern Switzerland, we show that innovative management approaches promoting forest resilience are often in line with the provision of biodiversity and other ecosystem services. Software for integration of forest ecosystem and hazard simulation has recently been developed. The software allows for quantitative risk assessment and cost–benefit analyses of different management strategies in different climate scenarios. Simulation results from this tool can support prioritisation of management measures and help decision-makers determine whether additional investments in proactive climate adaptation measures are worthwhile. In order to assess trade-offs and co-benefits of certain management strategies, it is also important to increasingly include quantitative indices for biodiversity and other ecosystem services, and to further develop and apply tailored management strategies meeting stakeholder preferences on different ecosystem services.**

< Fig. B 6.1. The protection of local people, tourists and infrastructure from natural hazards is a very important and obvious forest function, not only in mountain areas. Forest management has to set clear priorities but still needs to respect other important forest goods and services, including biodiversity. The economic value of these forests is, apart from timber, the significant substitution effects avoiding expensive technical protection measures – but who has to pay and who will profit is the central question (Photo: Ulrich Wasem).

## Introduction

Forests provide a multitude of ecosystem services (ES) for humans and society as a whole. Besides carbon sequestration, water purification or biodiversity, one of the primary services provided by forest ecosystems in mountainous regions is the protection against natural hazards, such as snow avalanches, rockfalls, shallow landslides, and debris flows (Brang *et al.* 2006; Moos *et al.* 2018). These are rapid, gravitationally driven currents that can inundate large areas, destroying infrastructure, disrupting important transportation lines, and causing injuries and fatalities. Establishing and maintaining healthy mountain forests provides valuable

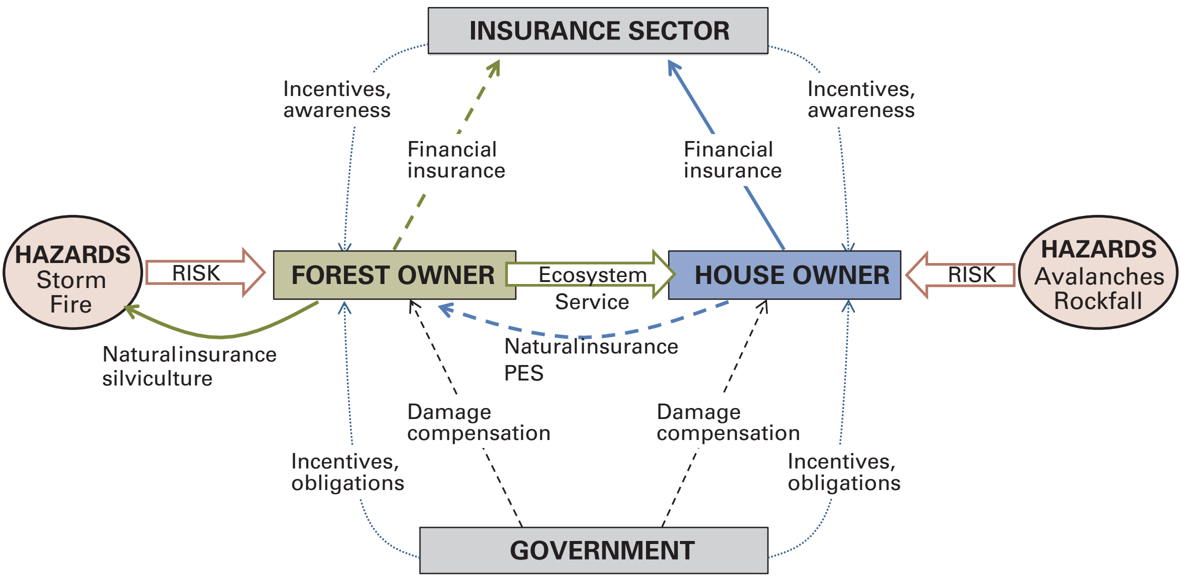


Fig. B6.2. Options for dealing with natural hazard risks. Natural hazards play a dual role as direct threats to human settlements and as important forest disturbances. By managing the forest in a sustainable way, forest owners reduce their own risk of economic losses; however, they also promote different ecosystem services such as biodiversity or protection against natural hazards. Direct payments for ecosystem services (PES) from house owners do currently not exist, possibly because protection has the character of a public good. As protection is the main forest function in hazard-exposed areas, specific management is incentivised by the government, and house owners buy financial insurance to cover the residual risk. Figure by R. Olschewski. WSL, 2017.

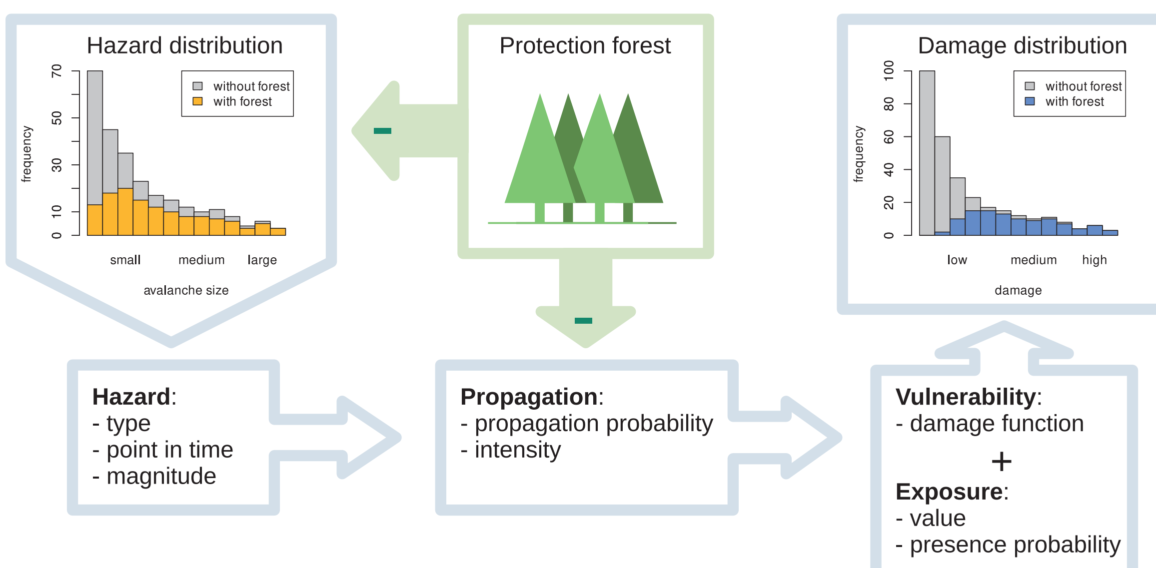


Fig. B6.3. Schematic representation of natural hazard risks and the mitigating role forests in mountain regions (see Moos *et al.* 2018).

protection and can be seen as investing in a 'natural insurance' against these hazards as damage will be smaller subsequently. As the protection capacity of forests is changing and may drastically be impaired by natural disturbances and other extreme events, there is increasing consensus that the resilience and thus sustainable protection in such forests should be maintained or enhanced (Bebi *et al.* 2016). While there are several studies quantifying the large economic value of protection forests in terms of avoided damage during past events (Teich and Bebi, 2009; Grêt-Regamey *et al.* 2013), the protection ES is typically not marketed to generate funding for forest management (Quaas and Baumgärtner 2008; Baumgärtner and Strunz 2014).

House owners living in hazard prone areas usually hedge their risk by buying financial insurance from an insurance company and do not directly pay forest owners for providing protection ES (fig. B6.2). Partly, this may be because of the existing legal obligations (FINMA 2013), but more importantly it is a consequence of natural insurance having the character of a public good: once the insurance is in place, nobody can be excluded and there is no rivalry among neighbours in being protected. Furthermore, minimum protection levels have been required by forest laws for centuries.

The provision of protection has traditionally often been seen as a by-product of traditional and sustainable land use (Schuler 1996). While protection forests in Switzerland are highly appreciated and largely taken for granted, management of these forests has become less attractive owing to falling timber prices and rising management costs. The costs for protection forest management has thus, particularly in the Alps, increasingly been covered by public subsidies (Mannsberger 2017; Sandri *et al.* 2017), while management of forests on inaccessible slopes and/or without specific protection function against natural hazards has often been abandoned (Kulakowski *et al.* 2017).

In Switzerland, the economic development, the expansion of settlements and infrastructure, and increasing property prices have led to an increase of the value exposed to natural hazards (Moos *et al.* 2018). The existing hazard management system combines hazard zoning, avoidance measures, technical constructions, and dedicated forest management. Even if this works well and ensures a good level of protection, the optimisation of resources towards sustainable protection against natural hazards remains challenging. Particularly in protection forest management, the ongoing global change (Bebi *et al.* 2016; Sandri *et al.* 2017) and the provisioning of other ES (Mina *et al.* 2017) bring about new challenges. New options related to the interplay between financial and natural insurance may thus be relevant for the optimisation of future protection functions against natural hazards and of synergies with biodiversity and other ES.

**Forests as a natural insurance against gravitational hazards.**

When aiming to combine financial and natural insurance, it is crucial to understand how protection forests actually mitigate risks from gravitational natural hazards. According to a popular definition by the Intergovernmental Panel on Climate Change (IPCC 2012) and the United Nations Disaster Relief Organization (UNDRO 1980) (as cited by Moos *et al.* 2018), risk is the product of three factors: hazard, exposure, and vulnerability. While forests cannot influence the exposure and vulnerability of houses or infrastructure at the bottom of a slope, they have a large influence on the magnitude, onset probability, and propagation probability of the hazard itself.

For example, the snow retention in a protection forest could prevent avalanches from being released at all (onset probability), and snow detrainment (the extraction of avalanche snow mass) in the forest could reduce the magnitude of small- to medium-sized avalanches, resulting in smaller, less frequent damage (propagation probability). From an insurance point of view, the protection forest would change the magnitude–frequency distribution of a certain hazard, as well as the way in which this hazard distribution translates into a monetary loss-frequency-distribution (see fig. B6.3).

**Dynamics of mountain forests and implications for management and ecosystem services**

Protection forests are dynamic ecosystems that change all the time, with interactions and feedback loops on different spatial and temporal levels. Abiotic and biotic disturbances are substantial driving forces of forest development and frequently reshape the landscape (Wohlgemuth *et al.* 2019). Interactions such as the coincidence of windthrow and warm weather favouring insect reproduction can multiply the effect of the original disturbance. Because of slow forest growth at higher altitudes or high browsing pressure, legacies of both disturbances and management interventions may remain visible for several decades. Therefore, disturbance legacies and interactions between disturbances are such pivotal factors in mountain forests, that they need to be considered in both the assessment of protection ES and forest management.

Additional to natural disturbances, effects of historic land use and former forest exploitation often have an important effect on current structure and long-term provision of ES in mountain forests. After the maximum of forest exploitation in the nineteenth century, afforestations and abandonment of former pastures have often led to an increase in forest cover and density in many mountain chains of Europe (Kulakowski *et al.* 2017). These forests are now often characterised by dense, even-aged stands with strong competition between trees, short crowns, and no regeneration below the canopy. While dense and even-aged stands often provide good protection against rockfall and avalanches, their susceptibility to disturbances may be increased and the capacity to regenerate after disturbances and adapt to climate change is reduced compared to more structurally diverse forest stands (Bebi *et al.* 2017).

With increasing growing stocks and awareness of natural disturbances in mountain forests, the focus of protection forest management has shifted during the last decades from afforestations to interventions for enhanced resilience (Brang *et al.* 2006; Bebi *et al.* 2016). The concept of resilience can thus be seen as a useful guideline to protection forest management because it aligns very well with the aim to ensure the stable provision of desired ES even in a disturbed environment (Briner *et al.* 2013; Albrich *et al.* 2018).

The dynamic nature of forests including legacies of former land use, disturbances, climate, and feedback loops between different drivers makes it highly challenging to evaluate or even predict changes of ES and risks in mountain forests. It is thus necessary to move from indicator-based steady-state assessment methods to process-based representations of the (eco)system and temporally integrated measurements of risks and ES. Important steps in this direction have been undertaken during the last years (e.g. Briner *et al.* 2013; Maroschek *et al.* 2015; Albrich *et al.* 2018; Moos *et al.* 2018); these steps have specifically focused on ecosystem resilience as a prerequisite for a stable provision of ES even in a disturbed environment. In the second part of this chapter, we propose a new tool to expand their work: a dynamic, bidirectional link between forest development and natural hazard simulations that allows simulation of damage over time and calculation of the costs and benefits of different management scenarios.

**Management for resilience in protection forests**

Ecosystem resilience is commonly defined as the capacity of ecosystems to absorb disturbances while maintaining their basic structures, functions, and feedbacks (Walker *et al.* 2004; see also Chapter A9 Lindner *et al.* in this book). As such, resilience is an ecosystem property that "determines the persistence of relationships" within the system (Holling, 1973). Mäler and Li (2010) characterise resilience as *"a kind of insurance against reaching a non-desired state"*. The higher the level of resilience the lower the risk of facing losses of ES, income, or wealth. Following the definition by Mäler and Li (2010), resilience is thus a highly desirable quality of protection forests, determining how well forests can withstand and recover from disturbances in order to provide uninterrupted protection.

Resilience in protection forests can generally be improved by enhancing diversity in terms of tree species and forest structure. The most common management approach towards promoting increased resilience in protection forests are relatively small regeneration cuts (Frehner *et al.* 2005; Brang *et al.* 2013). These management interventions aim mainly at increasing light availability and improving growth conditions for new regeneration while maintaining protection against natural hazards at acceptable levels. In the longer term such regeneration cuts would thus increase the sustainable protection against natural hazards by reducing, for example, the time when there is limited protection against rockfall or avalanches after windthrow or other disturbance events by opening new windows of opportunity for a higher tree diversity and regeneration of climate-adapted tree species (Bebi *et al.* 2016).

Having said that, all the benefits brought about by managing forests for resilience come at a cost. As Albrich *et al.* (2018) conclude *"Achieving a temporally stable and maximum ES supply will often not be simultaneously possible in ecosystem management"*. In such frequently disturbed ecosystems as mountain forests, though, accepting a lower baseline productivity and spending money on additional management measures might still pay off in the long run, if the disturbance damage is much smaller and the recovery of ES provisioning to pre-disturbance levels after an event is much faster.

Concepts for managing towards increasing resilience and a sustainable protection against natural hazards are already integrated in practical recommendations (e.g. Frehner *et al.* 2005; Mannsberger *et al.* 2017). For example, they are incorporated in the management guidelines NaiS (Sustainability and success monitoring in protection forest; Frehner *et al.* 2005); these guidelines are mandatory for all management interventions in protection forests of Switzerland and provide practical recommendations specific for forest types and natural hazard situations. Besides resilience as an overarching concept, these guidelines also consider several other aspects including the type of natural hazards, priorities according to the damage potential to be protected, or issues of pest control and climate adaptation (Sandri *et al.* 2017).

## Case study: Co-benefits of protection forest management in Davos

In order to showcase how science-based approaches and increased resilience may contribute to an optimised protection forest management and how this may also help to promote biodiversity, we present a case study in the Canton of Graubünden in eastern Switzerland. In particular, we describe how a process-based simulation model may facilitate quantitative risk assessment, and we outline how forest management for resilience could be incentivised by quantifying regulatory and other ES provided.

***Case study area Davos***

Davos is situated at an elevation of about 1550 m a.s.l. in the central Swiss Alps. Forests of the 283 km² landscape around Davos (Landschaft Davos) are generally dominated by Norway spruce *(Picea abies)*. Additional tree species include Swiss stone pine *(Pinus cembra)* on drier sites near the treeline and European larch *(Larix decidua)* in frequently disturbed avalanche runout zones and towards the treeline. The area is famous for tourism in winter and summer, whereas farming activities have consistently been in decline since the end of the nineteenth century. The forest has gradually expanded, currently occupying an area of about 22 % of the total landscape and providing a variety of ES to residents and visitors (Grêt-Regamey 2013). About 50 % of the forests fulfil direct functions against natural hazards. Gravitational natural hazard processes such as snow avalanches, rockfall, and landslides are major hazards for people and infrastructure. In addition to rapid mass movements, mountain forests may also be disturbed by other abiotic disturbances such as storms and snow breakage, but also by biotic disturbances such as ungulate browsing and bark beetle outbreaks.

***Main disturbances and natural hazards***

The dual role of mass movements and the interactions between disturbances entail positive or negative feedback loops in the ecosystem: after a storm damaging parts of a protection forest, subsequent bark beetle outbreaks may further increase the damage (Seidl and Rammer 2017) and further reduce the protection against natural hazards; or after an avalanche cutting a new avalanche path into the forest, a follow-up avalanche may be more likely to reach the village below. On the other hand, avalanche tracks may serve as hotspots for biodiversity and as breaks for fire and bark beetle outbreaks, or lying deadwood left after a disturbance can become a germination bed for forest regeneration (Bebi *et al.* 2019).

***Management system and ecosystem services***

Forest management and forest ES have changed several times in the history of Davos. After settlement of the landscape around Davos in the thirteenth century, forests were heavily grazed, and trees were used for timber, firewood, and mining (Bebi *et al.* 2017). As a result, the forest structure was more open during former centuries. Towards the end of the nineteenth century, a firmer forest law and a strong decrease in the goat population caused an increase in forest cover and forest density. A further decrease of forest management in the mostly privately-owned forests has been related to the booming winter tourism since the 1950s and a decrease of wood prices relative to high management costs in the often steep and poorly accessible slopes (Bebi *et al.* 2012). Since the 1980s, forestry benefitted from new forest regulations and financial support for the management of protection

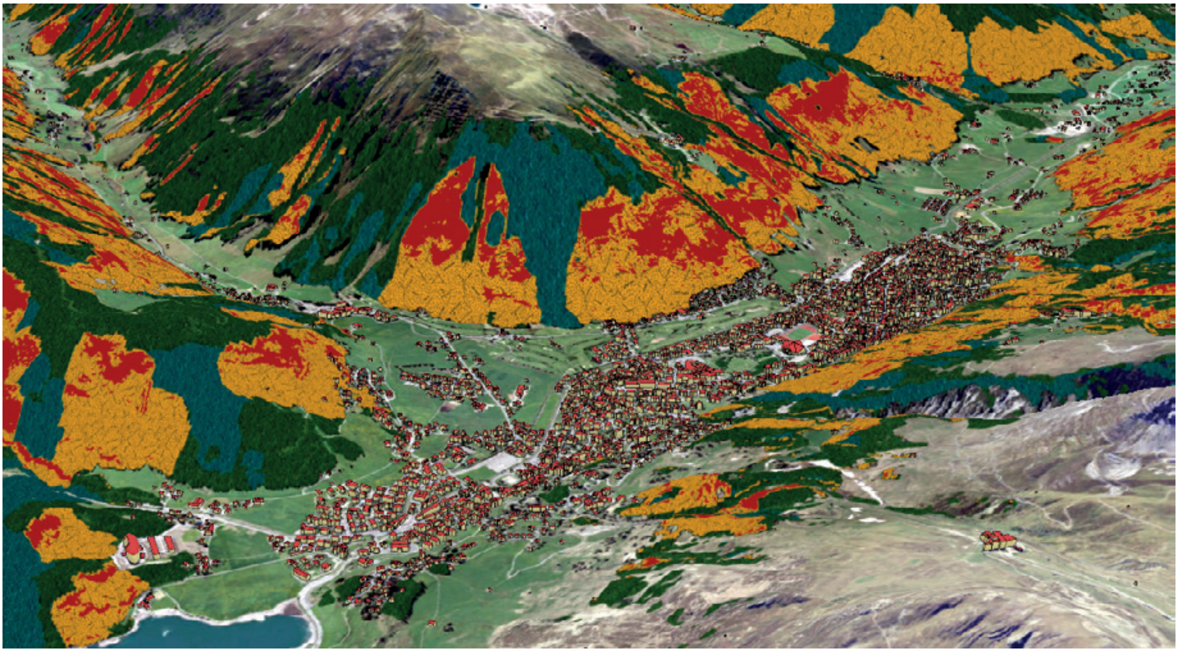

Fig. B 6.4. Example screenshot of an interactive map, showing how remote sensing data and avalanche models may be used to identify avalanche protection forests in Davos. Forests coloured in green have no direct effect on avalanches based on a comparison of RAMMS-scenarios with and without forest for a ca. 30-year avalanche event. Forests coloured in blue have an effect on avalanches, but have no direct protective effect for buildings. Forests coloured in red (≥35° steepness) and forests coloured in yellow (slope <35°) protect buildings against avalanches. The threshold of 35° in this example was chosen to highlight (in red) areas, where an appropriate forest structure is of particular high importance for the protection against avalanche releases (map created by Kevin Helzel, SLF).

forests from the Swiss Federation, the Canton of Graubüden, and the community of Davos (Sandri *et al.* 2017). Thanks to this support for protection forest management, the annual use of wood accounts on average for around 11 000 $m^3$, which corresponds to an average of about 70 % of the annual stand volume increment. As management operations without support for protection forest management is not economic, interventions are currently limited to protection forests and have to be carried out according to the NaiS-guidelines for a sustainable protection forest management (Frehner *et al.* 2005). The timber harvesting in the largely steep forests of Davos is carried mainly by cable yarding and to a smaller degree by skidding or helicopter.

**Management approaches for improved protection and biodiversity**

In the following paragraphs, we present five main fields of research and innovation in protection forest management that may play a key role in ensuring an optimal level of protection while also maintaining or enhancing biodiversity and other ES in the future. Some of them have already been implemented in Switzerland and may serve as inspiration for other regions, while others showcase methods still under development but possibly available to practitioners in the near future.

***Managing where protection is necessary***

An important requirement for an efficient management of protection forests is spatial information about the extent of forests with a risk reducing function. In Switzerland, such spatial information has been created and harmonised within the project SilvaProtect based on available data of damage potential and topography, and simulations of different natural hazards with and without forest cover (Losey and Wehrli, 2013). The relevant spatial extent of these forest patches with a relevant protection against natural hazard has been checked and consolidated by the cantons and serves today as basis for the distribution of financial support for measures in the protection forest. Within this perimeter, Swiss cantons have established multiple approaches to further prioritise measures for protection forest management. On the basis of improving data, modelling approaches, and knowledge about natural hazard processes in forested terrain, it is promising to periodically re-assess and, if necessary, improve these prioritising schemas in an operationally reasonable timeframe and to generate interactive maps of protection functions in relation to certain natural hazards. An example of how the identification of important avalanche protection forest can be supported based on interactive digital maps with newly available remote sensing data and models is shown in Figure B 6.4. Resulting interactive maps may support decision-making for prioritising forest intervention towards optimised natural hazard protection and for identifying other areas where biodiversity or other ES are more relevant. Depending on the site-specific requirements, even structurally diverse unmanaged forests with large deadwood pools can provide good protection against rockfall (Fuhr *et al.* 2015) and other regulatory ES (Seidl *et al.* 2019). This means that both biodiversity conservation and a high level of protection can be achieved by limiting management to areas where it is really necessary.

***Increasing Resilience and climate change adaptation***

Resilience in protection forests can mainly be improved by a diversification of age structure and species composition and by measures of climate adaptations (Bebi *et al.* 2016). Small intervention gaps according to Frehner *et al.* (2005) are the most important control instrument to increase the regeneration and thus the resilience in protection forest stands (Brang *et al.* 2006. In the sense of climate adaptation, regeneration cuts may additionally be used to adjust the tree species composition to the requirements of the future climate. In the mostly spruce-dominated and often relatively dense forests of Davos, it is thus important to foster advance regeneration and to promote additional tree species which are not affected by spruce bark beetles (mainly *Ips typographus*) and will be expected to tolerate warmer temperatures and drought. Beside other indigenous species like European larch and Swiss stone pine (which are only to a limited degree competitive in dense spruce forests), silver fir *(Abies alba)* and broadleaved species (e.g. *Acer pseudoplatanus* and *Fagus sylvatica*) may increasingly be introduced. In some parts of the study area, a diversification of tree species is only possible if wildlife management will be adapted in a way which allows the regeneration of these species (Didion *et al.* 2009). Management measures promoting forest resilience by increasing the structural and tree species diversity in even-aged spruce stands usually even foster biodiversity in other species groups.

***Managing disturbances and the role of deadwood***

In addition to regeneration cuts, natural disturbances offer the opportunity to adapt to climate change, whereby the pioneer vegetation can be specifically supplemented with additional (climate-adapted) plantings. After natural disturbances, it is also very important to exploit the positive effect of deadwood to increase surface roughness and protect against avalanches and rockfall (Fuhr *et al.* 2015) and to increase long-term resilience by fostering regeneration on deadwood (Brang *et al.* 2013). The positive effect of deadwood on the seedbed is well known, particularly in spruce-dominated forests with limited seedbed availability (Bače *et al.* 2012; Kalt *et al.* 2021; however, it should be noted that the time period until deadwood provides favourable conditions for regeneration in a relatively cold and dry region like Davos usually exceeds 30 years and a latent availability of deadwood in different stages may provide a more sustainable supply of seedbeds. Without additional treatment, leaving deadwood in the forest after a disturbance may increase the risk of bark beetle outbreaks. If bark beetle risk is mitigated (e.g. by peeling or stripping the bark from logs), then leaving deadwood is likely to be beneficial in multiple ways: for direct rockfall protection, for forest regeneration, and for biodiversity, in particular of saproxylic organisms (Thorn *et al.* 2018).

***Timing of management interventions***

The timing of management intervention is crucial for optimising the effects of the interventions on resilience and long-term protection (Frehner *et al.* 2005; Brang *et al.* 2016). Reducing the time between interventions and the harvested volume per management intervention may in some cases reduce

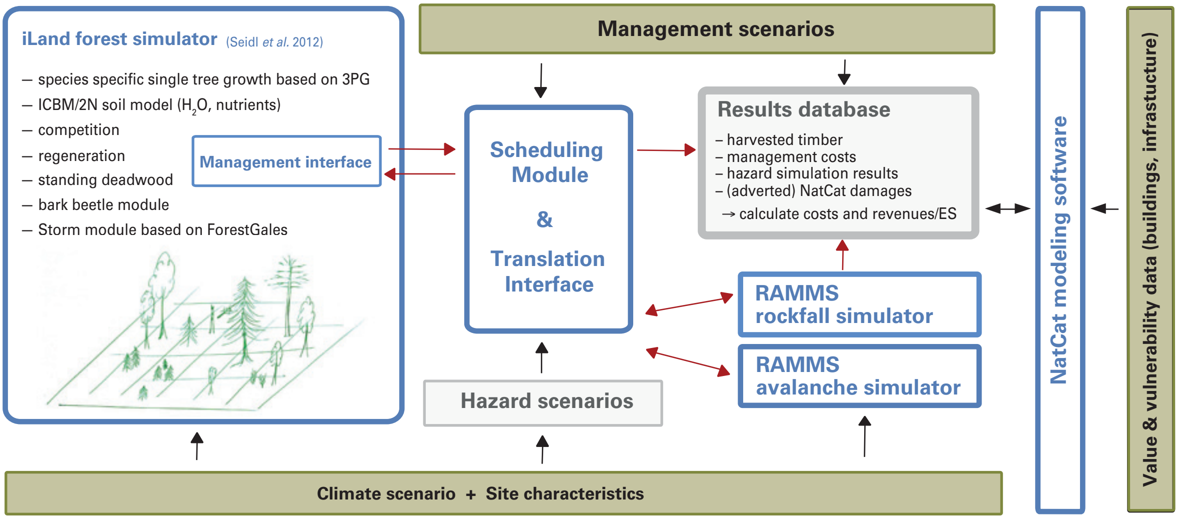


Fig. B6.5. Simulation framework. Green boxes represent input data and scenarios, blue boxes represent the core parts of the simulation software.

windthrow risk (Brang *et al.* 2016). While early and repeated forest interventions are often particularly valuable in secondary spruce-dominated forests (regrown after agricultural abandonment or afforestation in the nineteenth or twentieth century), in order to avoid the development of even-aged and short crown forest structure with a low resilience (Bebi *et al.* 2017), the timing of management intervention seems to be less important if the timing for early intervention has been missed and a forest is already in an advanced self-thinning development stage (Guetg 2020). Time periods between management interventions may also be much longer in protection forest types with naturally higher resilience (e.g. in topographically complex terrain with clustered forests patches and suitable conditions for regeneration). In such cases with naturally longer time periods between management or with only passive management there is also a higher potential for synergies between biodiversity and optimised protection against natural hazards.

### *A simulation framework for quantitative risk assessment and cost–benefit analysis of forest management strategies*

In times of climate change, it is particularly challenging for forest managers to shape forests that will keep providing essential ES even under rapidly changing environmental conditions. Unfortunately, hazard risk assessment tools often assume a steady forest state and do not take into account protection gaps resulting from interacting forest disturbances. An ongoing research project by the University of Freiburg and the Swiss Federal Institute for Forest, Snow and Landscape Research aims to overcome these limitations by dynamically linking hazard and forest simulation models. This might allow quantification of the hazard risk reduction and other ES over time and in various future climate and management scenarios.

Figure B6.5 shows the methodological approach of the project. The forest landscape simulator iLand (Seidl *et al.* 2012) is linked to the process-based avalanche and rockfall model RAMMS (RApid Mass Movement Software; Christen *et al.* 2010, 2012) through a translation interface.

Input data for the models are climate scenarios, site characteristics, and starting conditions (tree species, diameter distributions, soil nutrient pools, seedbed, sapling cohorts, etc.) for the forest stands to be simulated. The landscape is separated into subdomains according to the spatial allocation of rockfall and avalanche release areas. Hazard release events are only simulated in the respective subdomain of the landscape, which given limited computing resources saves processing time.

Using the iLand management interface (Rammer and Seidl 2015) and a scheduling module, adaptive management strategies are defined, and disturbance events are dynamically integrated into the simulation runs. To assess the costs and benefits resulting from different management strategies, realistic, site-specific stand treatment programmes are distributed in the landscape and coupled to realistic cost functions. For each combination of climate, disturbance, and management scenarios, multiple iterations are simulated. The results are transferred to a database including information about harvested timber, management costs, and hazard simulation results. Costs and revenues, as well as other ecosystems services (regulating services) are calculated per hazard domain. Using NatCat modelling software (e.g. CLIMADA, Aznar-Siguan and Bresch 2018), damage is calculated taking into account value and vulnerability data on buildings and infrastructure. The value of the protection ecosystem service can subsequently be calculated as the reduction of damage compared to a baseline scenario (no forest or no management).

To give an example, the benefits of funding additional, proactive climate adaptation measures on a critical slope could be calculated as follows: The value generated (ΔV) is the change in NatCat damage (D) compared to standard management (business as usual, BAU) minus the change in management costs (M) and the opportunity costs for all other marketable ES, in our case timber production, integrated over time.

$$\Delta V=(\Sigma D_{BAU}-\Sigma D_{add})-(\Sigma M_{add}-\Sigma M_{BAU})-(\Sigma ES_{BAU}-\Sigma ES_{add})$$

Of course, the last part of the equation subsuming other ES can be expanded as desired. Weights or utility functions according to stakeholder preferences can be added for single ES to facilitate decision-making. Hitherto, protection forest management has largely been guided by the aim of keeping hazard risks acceptably low and measures are subsequently prioritised to achieve this goal in the most economically efficient way. In a similar manner, biodiversity objectives or carbon sequestration goals could be incorporated into cost–benefit analyses of simulated management strategies and consequently play a larger role in forest planning.

Because of the stochasticity in disturbance and hazard events and the nonlinear feedback loops in the ecosystem, the outcomes of single simulation runs are not deterministic and must not be used to draw general conclusions. To account for stochasticity, we simulate several replicative runs for each combination of management and climate scenario, resulting in three-dimensional distributions of damage frequency curves, cumulative timber revenues, and management costs. To facilitate risk assessment and decision-making, these can be aggregated into cost–benefit distributions for each hazard simulation domain. This approach might in the future be extended towards a Bayesian optimisation of management strategies using expert recommendations as primers and then gradually varying management parameters.

## Outlook and considerations for practical implementation

Many features of sustainably functioning protection forests, such as structural diversity, species diversity, and high volumes of lying deadwood also promote biodiversity. The case study of Davos shows how forest managers can shape co-benefits for biodiversity conservation and other ES while investing in resilient, climate-adapted protection forests.

New tools for quantitative analysis of ES and natural hazard risks facilitate prioritisation between multiple desired ES and balancing risks over space and time. Simulations of future forest development scenarios could show whether a proactive adaptation of forests to climate change is economically beneficial and which synergies between ES could be harnessed to reach multiple objectives at the same time.

The Swiss protection forest management has succeeded in balancing the interests of various stakeholder groups to maintain crucial ES when its traditional foundation came under pressure owing to changes in land use and economic structures. Despite generally being considered a success story, the Swiss protection forest management framework has some characteristics that might limit its transferability to other regions and it highlights some limitations of natural insurance schemes: because protection ES have the character of a common good, there are as yet no market mechanisms allocating funding for protection forest management; and because of the long-time scales in mountain forests, the scenario uncertainties and the stochasticity of disturbance events are unlikely to be reduced in the future. For these reasons, funding natural insurance schemes as proposed by Baumgärtner and Strunz (2014) with payments from private actors seems unlikely in mountain regions. Nevertheless, protection forest management is generally deemed macroeconomically beneficial and desirable, as it helps protect large areas from natural hazards at a rather cheap price compared to technical solutions.

Switzerland has solved the structural challenge of privately-owned forests providing non-marketable but desirable ES for a larger public by establishing a legal and economic framework involving all levels of government. In particular, Swiss protection forest management has benefitted from specialised legislation (Swiss forest law, German: Waldgesetz, WaG 1991), science-based management guidelines (Frehner *et al.* 2005), a well-staffed forest administration, and the provision of public funds. It is, therefore, not easily transferable to other regions of the world where even the best ideas for forest management might fail owing to legal constraints or limited resources.

Finally, another very important aspect needs to be considered: acceptance. The Swiss protection forest management has gained the support of all relevant stakeholder groups – municipalities, local residents, forest owners, cantons, and the federal state – and carefully balances their interests. When applying natural insurance schemes elsewhere, possible improvements in the protection against natural hazards need to be balanced against other objectives and ES (see Paavola and Hubacek 2013 on trade-offs). Prioritisation of management measures exclusively based on economic criteria is problematic as it affects the spatial distribution of risk reduction measures: a protection forest management scheme that, for example, neglects sparsely populated side valleys and only protects village centres with a high density of properties would be economically efficient but would likely not find the acceptance of the local population. The public funding in Switzerland helps avoid this and even facilitates strengthening new objectives such as biodiversity conservation or carbon sequestration in protection forest management in the future. In fact, environmental policy research suggests that management of common goods is actually most effective if it involves all relevant stakeholder groups because their participation enhances the quality and implementation of environmental management decisions (Beierle 2002; Reed 2008). Natural insurance schemes should, therefore, go beyond a mere business model for single actors: if policy makers follow the guidelines by Farley and Costanza (2010) and consider temporal scales, local expert knowledge, and stakeholder participation, an implementation is more likely to succeed and find long-term acceptance and support among the population.

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Fig. B 6.6. Trees protect people and infrastructure from natural hazards. Hikers, for example, benefit from the protective service of forests in mountain areas, where trees prevent rockfall (Photo: Ulrich Wasem).