BFW BUNDES FORSCHUNGS ZENTRUM FÜR WALD

Avalanche Protective Forests: What Do We Know and Where Do We Grow from Here?

Michaela Teich & Momchil Panayotov

CENFORKNOW 2025
A century of forest knowledge – education, innovations, challenges

Sofia, Bulgaria
09 May 2025

Protective forests are…

(1,2,3) snow avalanches
(4) rockfall
(5) floods and debris flows
(6) landslides

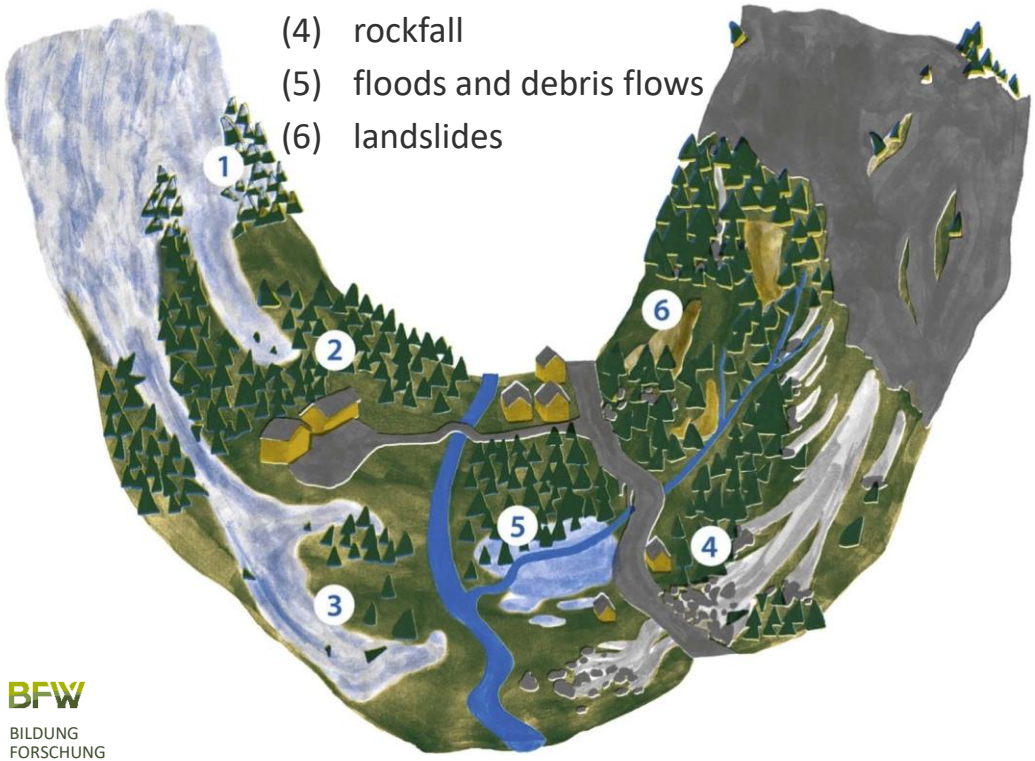


Figure: Moos et al. 2018

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

Brang et al. 2001

BFW
BILDUNG
FORSCHUNG
WALD

Protective forests within an integrated natural hazard risk management (IRM)

BFW
BILDUNG
FORSCHUNG
WALD

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

Brang et al. 2001

Protective forests within an integrated natural hazard risk management (IRM)

Model *Integrated Risk Management*
Federal Office for Civil Protection
2019

BFW
BILDUNG
FORSCHUNG
WALD

Protective forests, however, are often underutilized.

HOW COME?

Teich et al. 2021

Forests‘ protective functions and effects

How does a forest protect?

PROTECTIVE EFFECT

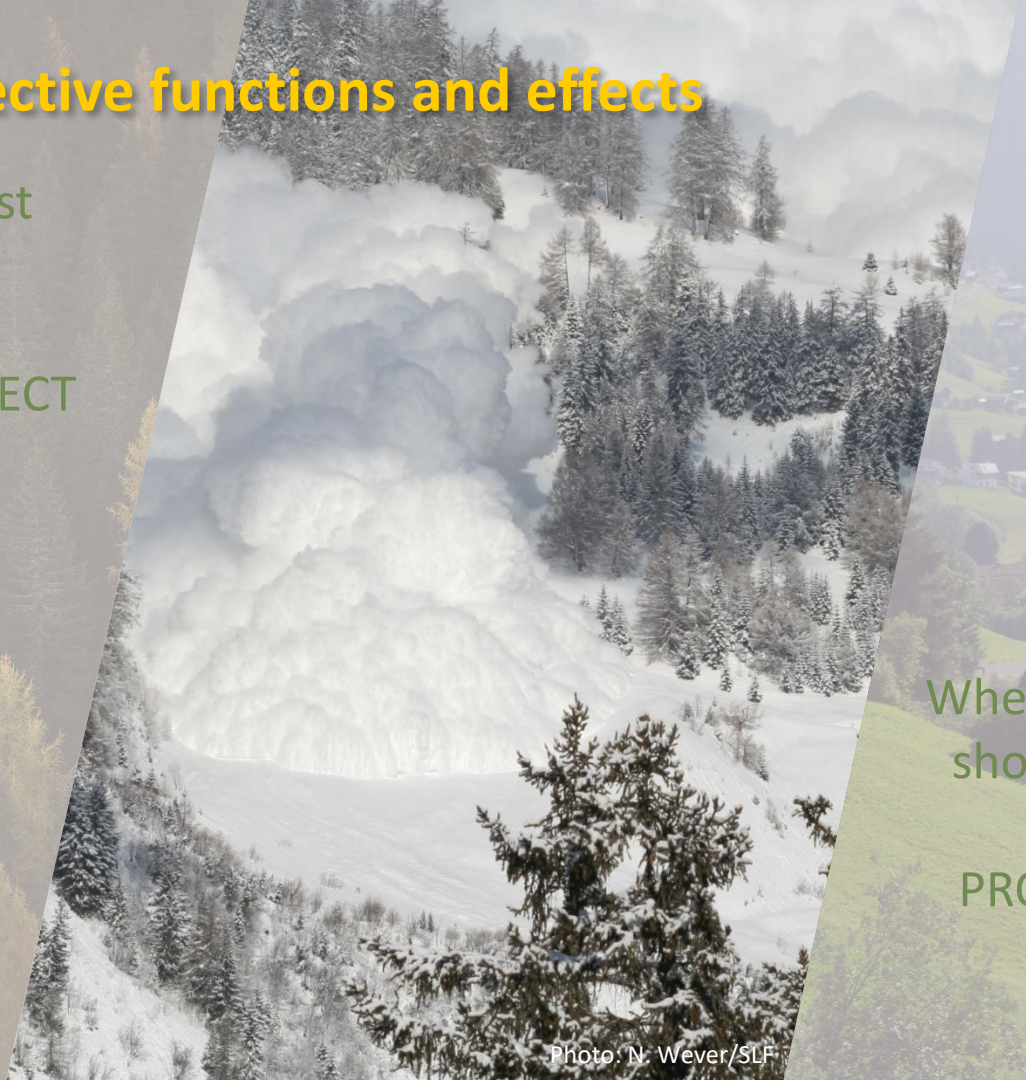
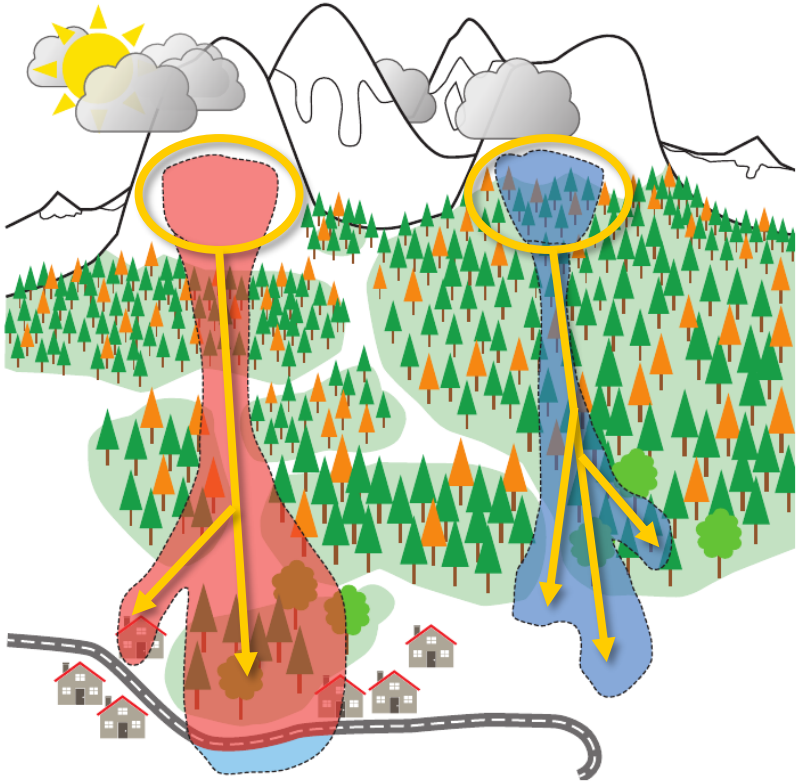


Photo: N. Wever/SLF

Where, What and Whom should a forest protect?

PROTECTIVE FUNCTION

Modeling of forests with a direct object protective function



BFW
BILDUNG
FORSCHUNG
WALD

Illustration: BFW / A. Huber

Where are the potential release areas?

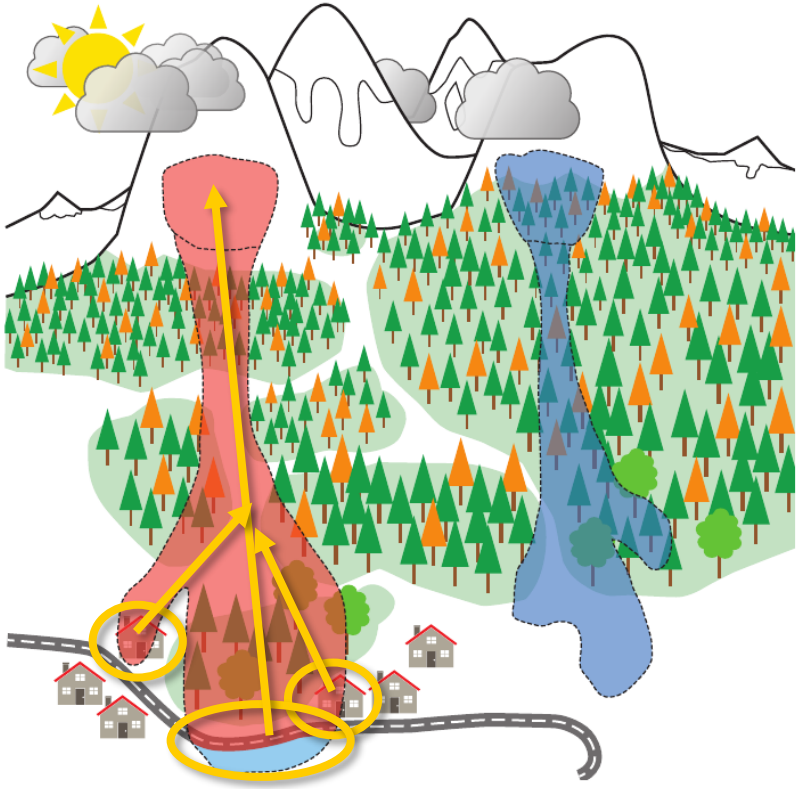
- Without considering forest effects!

Where does the process go?

- Process modeling of gravitational natural hazards (snow avalanches, rockfall, landslides)

Perzl et al. 2019

Modeling of forests with a direct object protective function



BFW
BILDUNG
FORSCHUNG
WALD

Illustration: BFW / A. Huber

Where are the potential release areas?

- Without considering forest effects!

Where does the process go?

- Process modeling of gravitational natural hazards (snow avalanches, rockfall, landslides)

Where are the objects to be protected?

- Could they be hit?

Which process paths are potentially damaging?

- Back-tracking from affected objects

Perzl et al. 2019

Modeling of forests with a direct object protective function

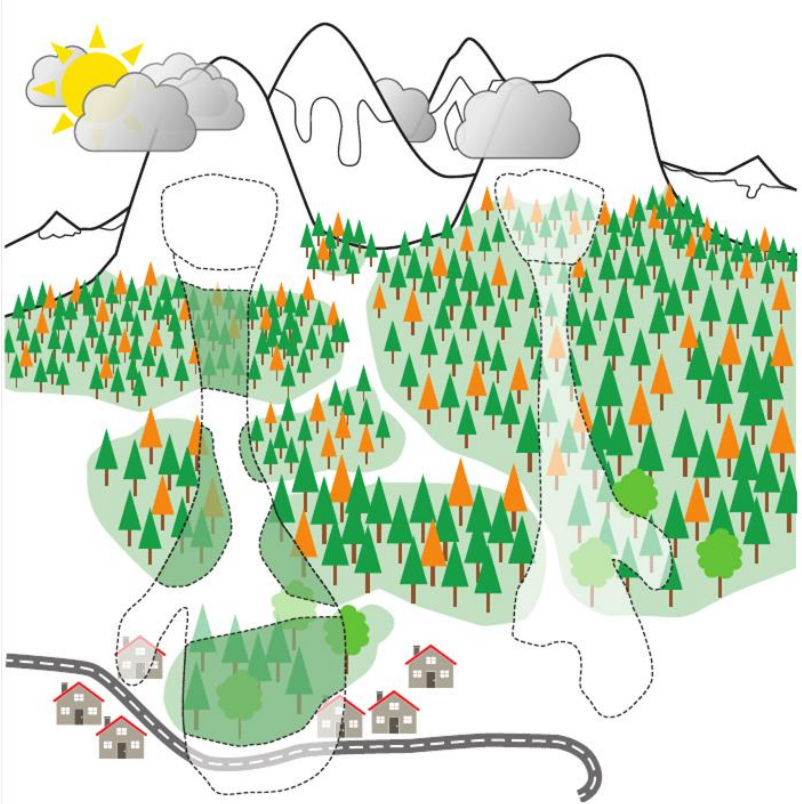


Illustration: BFW / A. Huber

Where are the potential release areas?

- Without considering forest effects!

Where does the process go?

- Process modeling of gravitational natural hazards (snow avalanches, rockfall, landslides)

Where are the objects to be protected?

- Could they be hit?

Which process paths are potentially damaging?

- Back-tracking from affected objects

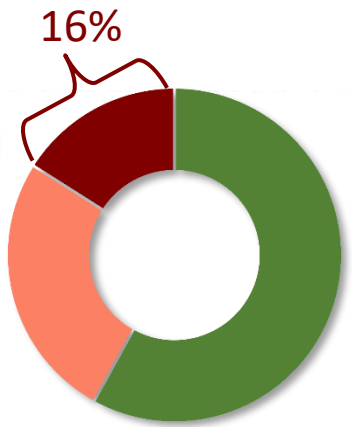
Which are the potentially damaging process paths in forest?

- Intersection with the forest area

Perzl et al. 2019

Protective forest cover in Austria

42% potential protective forest area



BFW
BILDUNG
FORSCHUNG
WALD

Bundesministerium
Land- und Forstwirtschaft,
Klima- und Umweltschutz,
Regionen und Wasserwirtschaft

Source: www.waldatlas.at

Open-access decision support tools for utilizing protective forests in IRM

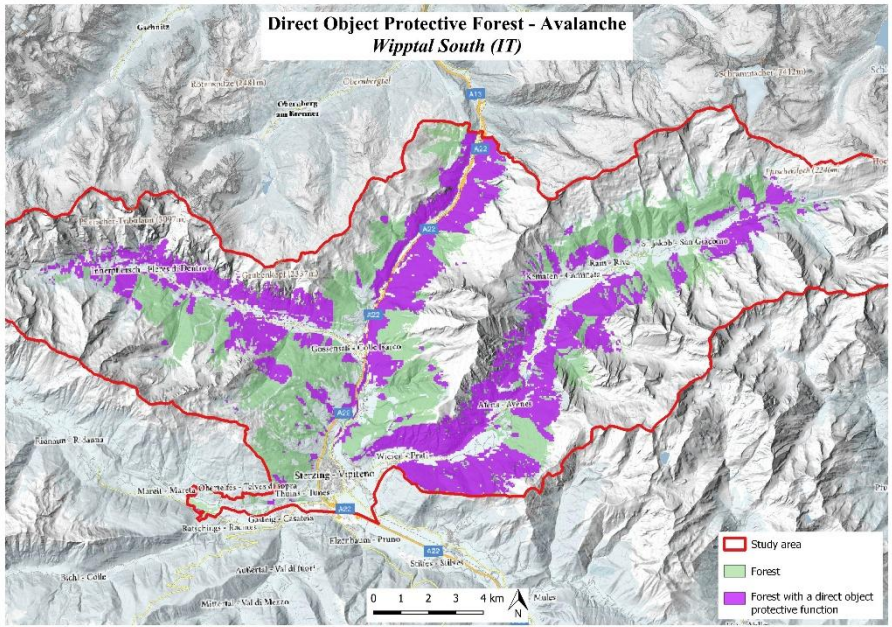


Figure: Accastello et al. 2022

The simulation tool FlowPy (D'Amboise et al. 2022) is...

- open-access & open-source software
- data-based runout and intensity model
- regional modeling of snow avalanches, rockfall and shallow landslides
- adaptable requiring few input parameters

➢ a tool to identify forests with a direct object protective function

➢ to estimate the protective effects of forest on hazard runout (Huber et al. 2024)

➢ implemented in the Open Avalanche Framework AvaFrame (Oesterle et al. 2022): https://avaframe.org/

BFW BILDUNG FORSCHUNG WALD

Interreg Alpine Space GREEN RISK 4 ALPS

AvaFrame THE OPEN AVALANCHE FRAMEWORK

Forests‘ protective functions and effects

How does a forest protect?

PROTECTIVE EFFECT

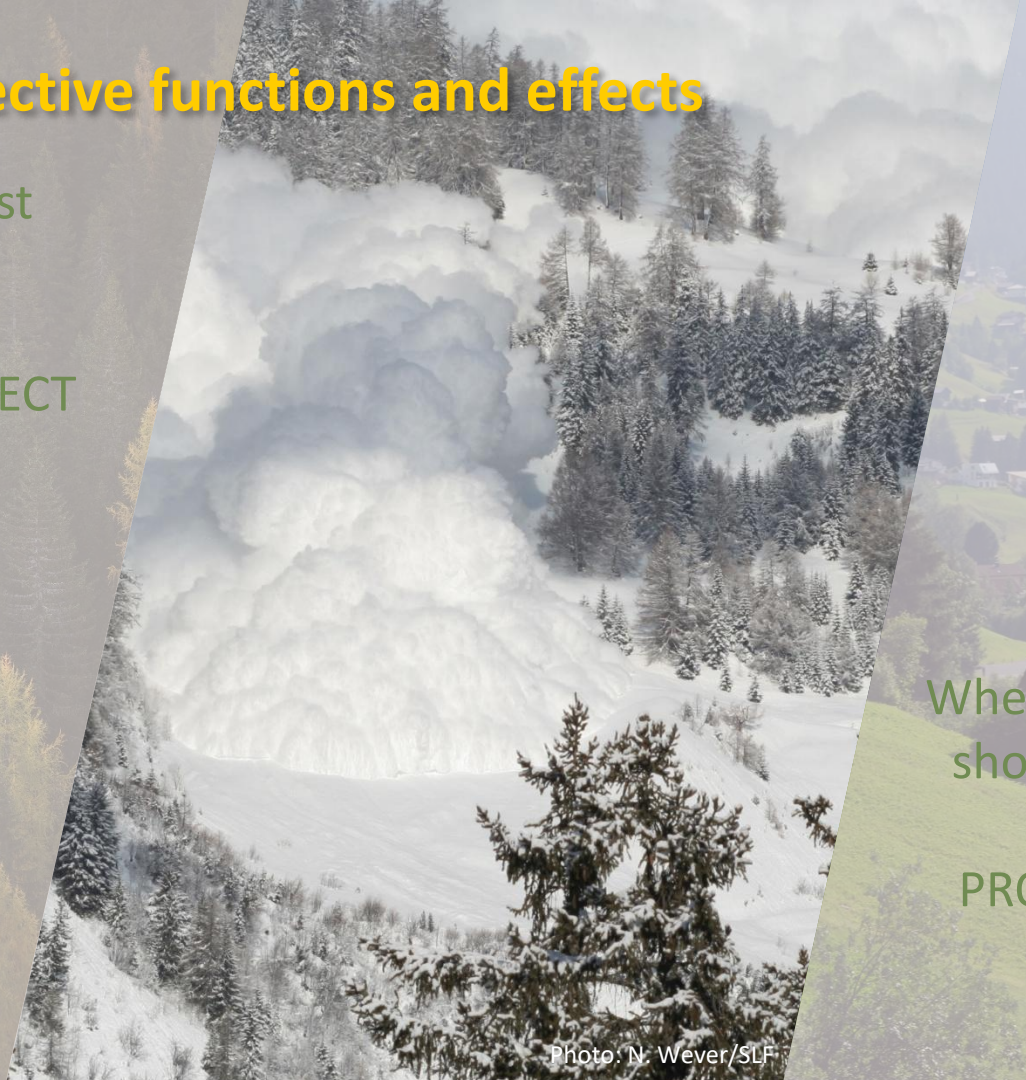


Photo: N. Wever/SLF

Where, What and Whom should a forest protect?

PROTECTIVE FUNCTION


Photo: P. Bebi


Photo: T. Feistl

Google Earth

Bruchshäusl

Protective effects of forests…

…on avalanche formation and release

?

…on avalanche runout and intensity

- Takeuchi et. al 2011
- Teich et al. 2012, 2014
- Feistl et al. 2014, 2015
- Takeuchi et al. 2018
- Brožová et al. 2020
- D'Amboise et al. 2021
- Védrine et al. 2022
- Huber et al. 2024
- Panayotov et al. 2024
- …

Protective effects of forests on avalanche formation and release

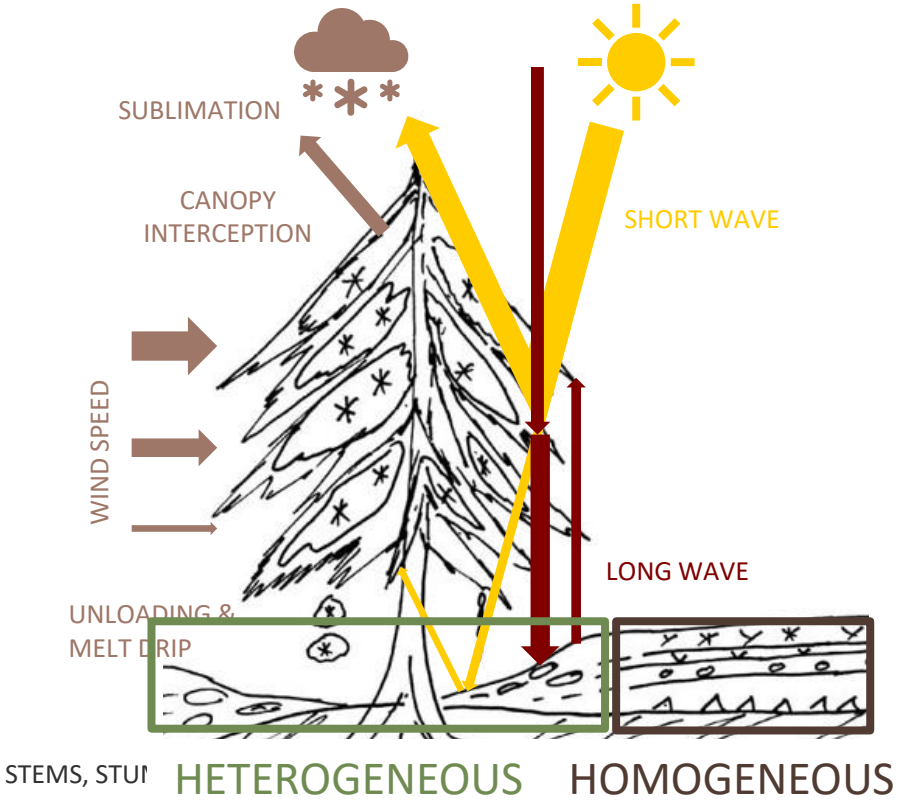
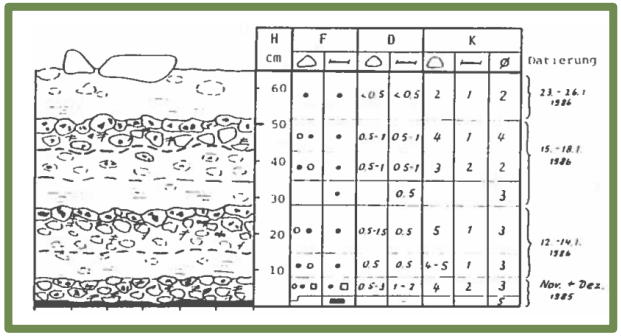
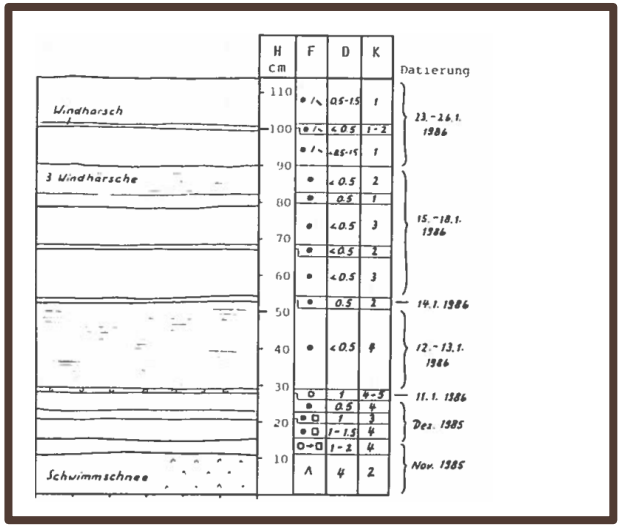


Illustration adapted from: Schneebeli & Bebi 2004





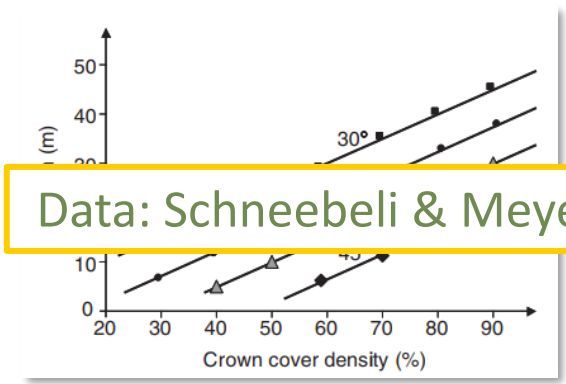
Figures: Imbeck 1987

Quantifying protective effects on avalanche formation and release

Observation-based approaches

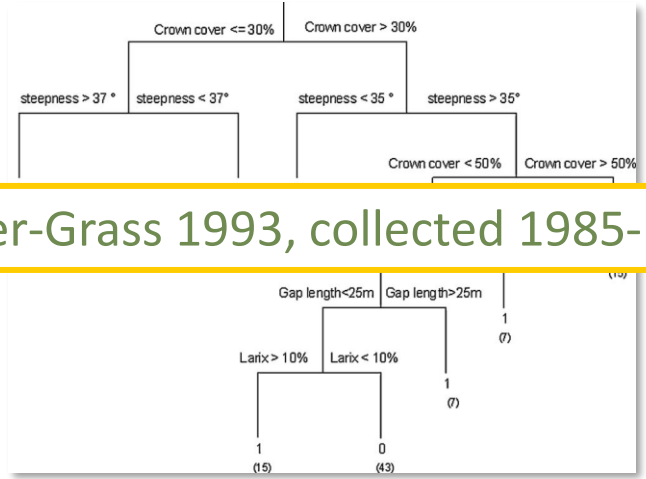
Process-based approaches

Quantifying protective effects on avalanche release: current approaches



Relationship between critical gap widths and crown cover densities for avalanches releases for different slope steepness. Based on a multiple linear regression model of 112 avalanches in subalpine coniferous forests

Schneebeli & Bebi 2004



Influence of different explanatory variables on avalanche releases in forested terrain based on the data set of 110 avalanches releases in spruce- and larch-dominated forests and 113 control stands

Bebi et al. 2009

Data: Schneebeli & Meyer-Grass 1993, collected 1985-1990

Logistic regression model for avalanche release probability (Bebi et al. 2001):

- Crown cover density (%)
- Gap width (m)
- Slope angle (°)

+

- Surface roughness
- Shrub forest layer

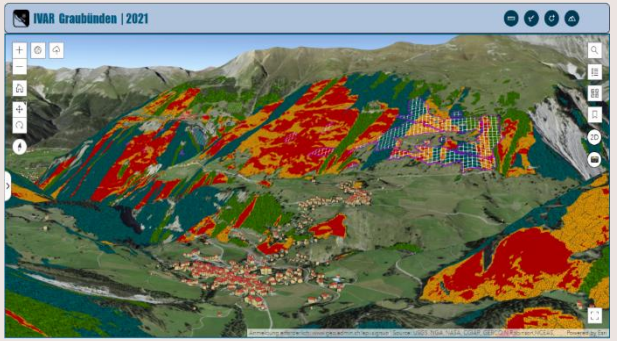
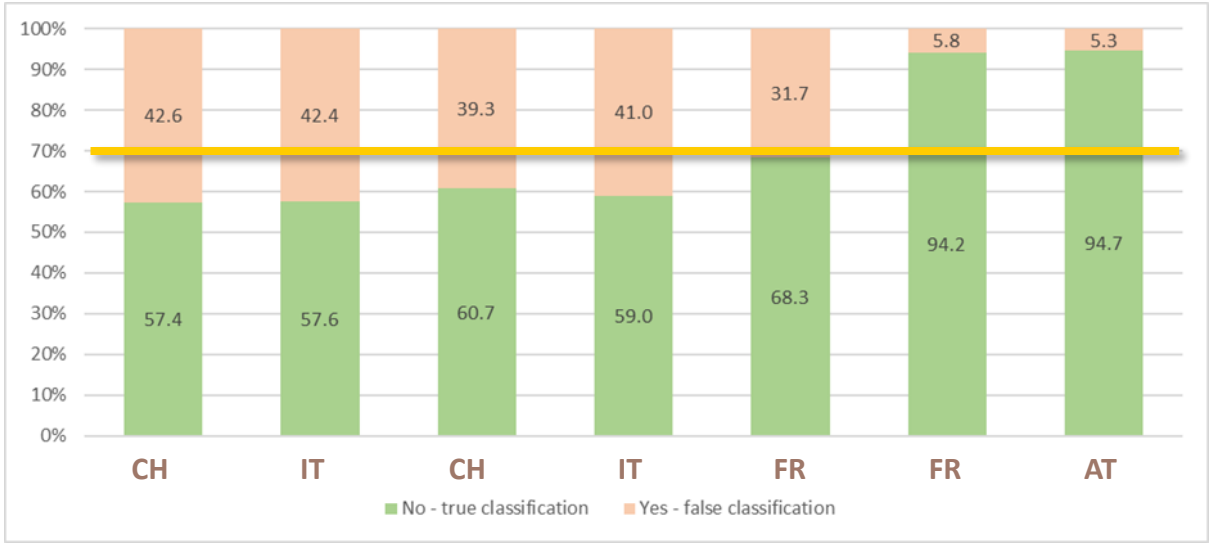


Figure: Bebi et al. 2021

Quantifying protective effects on avalanche release: associated uncertainty

Comparison of the European protective forest management guidelines with 295 actual forest avalanche events



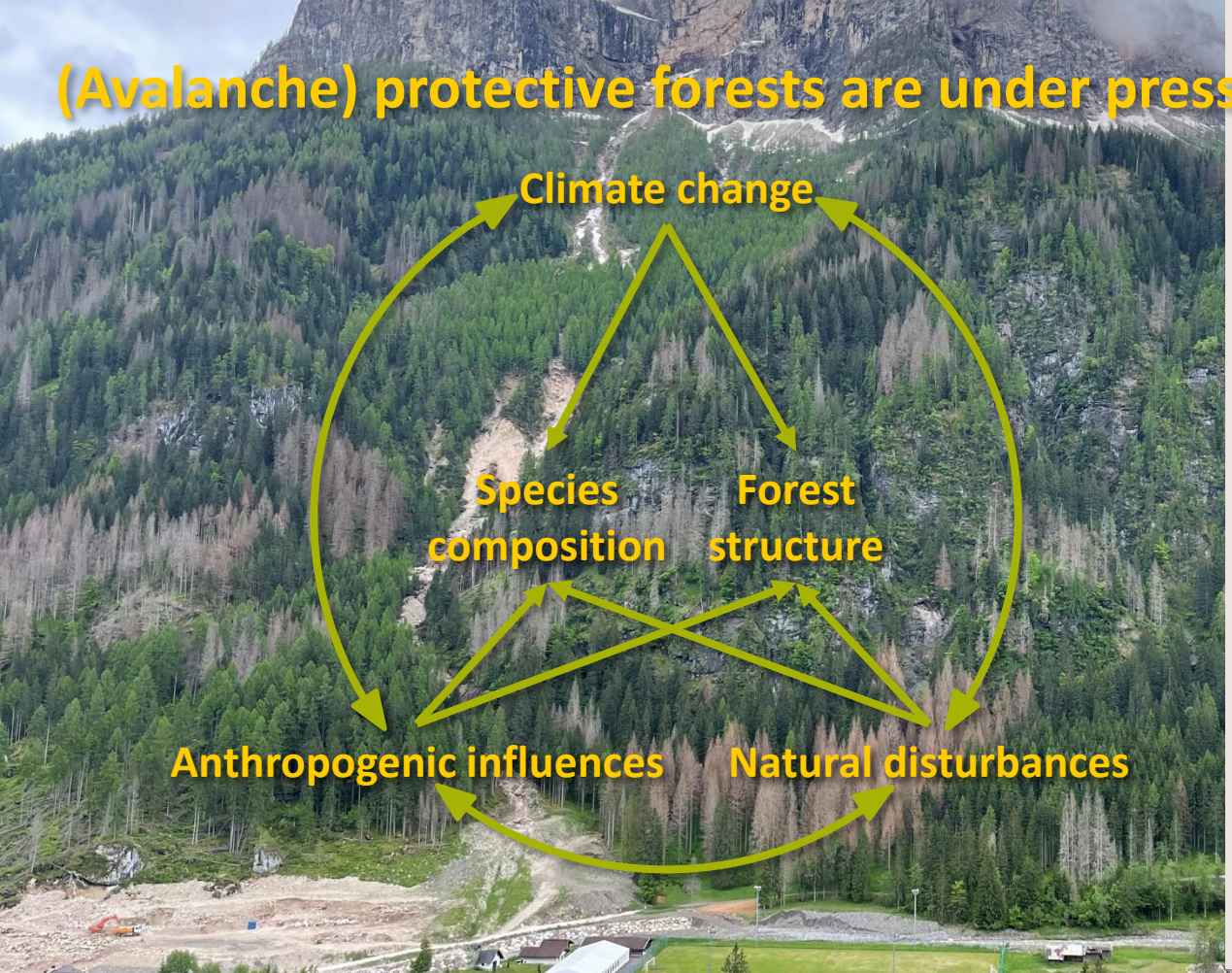
Snow avalanche release – validity of the combined targets of forest characteristics

Silvicultural targets in European protective forest management guidelines:

- Crown cover density
- Gap width
- Slope angle
- Gap length
- Evergreen crown cover
- Stem density
- Forest type
- Altitude
- Aspect
- …

Perzl & Kleemayr 2020, Perzl et al. 2021

(Avalanche) protective forests are under pressure



Do past observations still represent current and future conditions?

Where do we grow from here?

And: What does science say?

Veneto region, Italy; 05/2024

Illustration adapted from: Bottero al. 2024

Photo: BFW / M. Teich

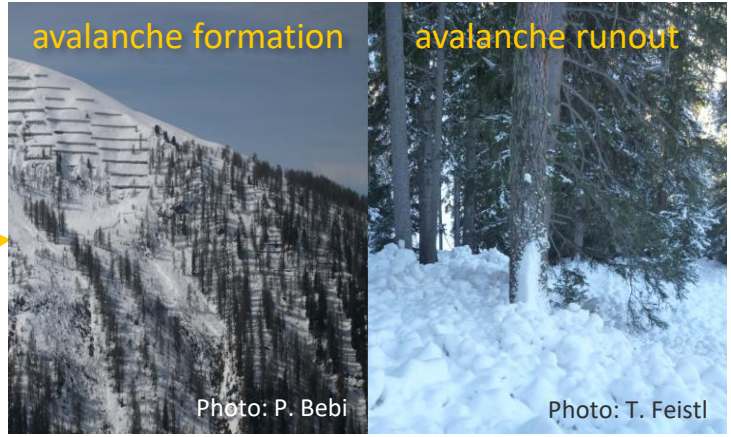
Avalanche protective forests are under pressure: what does science say?

Literature review

Clarivate Web of Science™ | Google Scholar

Protective forest	forest* OR “protection forest” OR “ forest” OR “Eco-DRR” OR Natu olution
Forest change	“clim ge” OR “global change” OR change OR ught OR disturbance OR future OR evolution OR “forest dynamics” OR “ecosystem dynamics” OR “dynamic” OR development*
Protective service	avalanche OR “snow avalanche” OR “risk reduction” OR “protective effect” OR “ function” OR “protection function” OR “protective capacity” OR “protective service” OR “protection service”

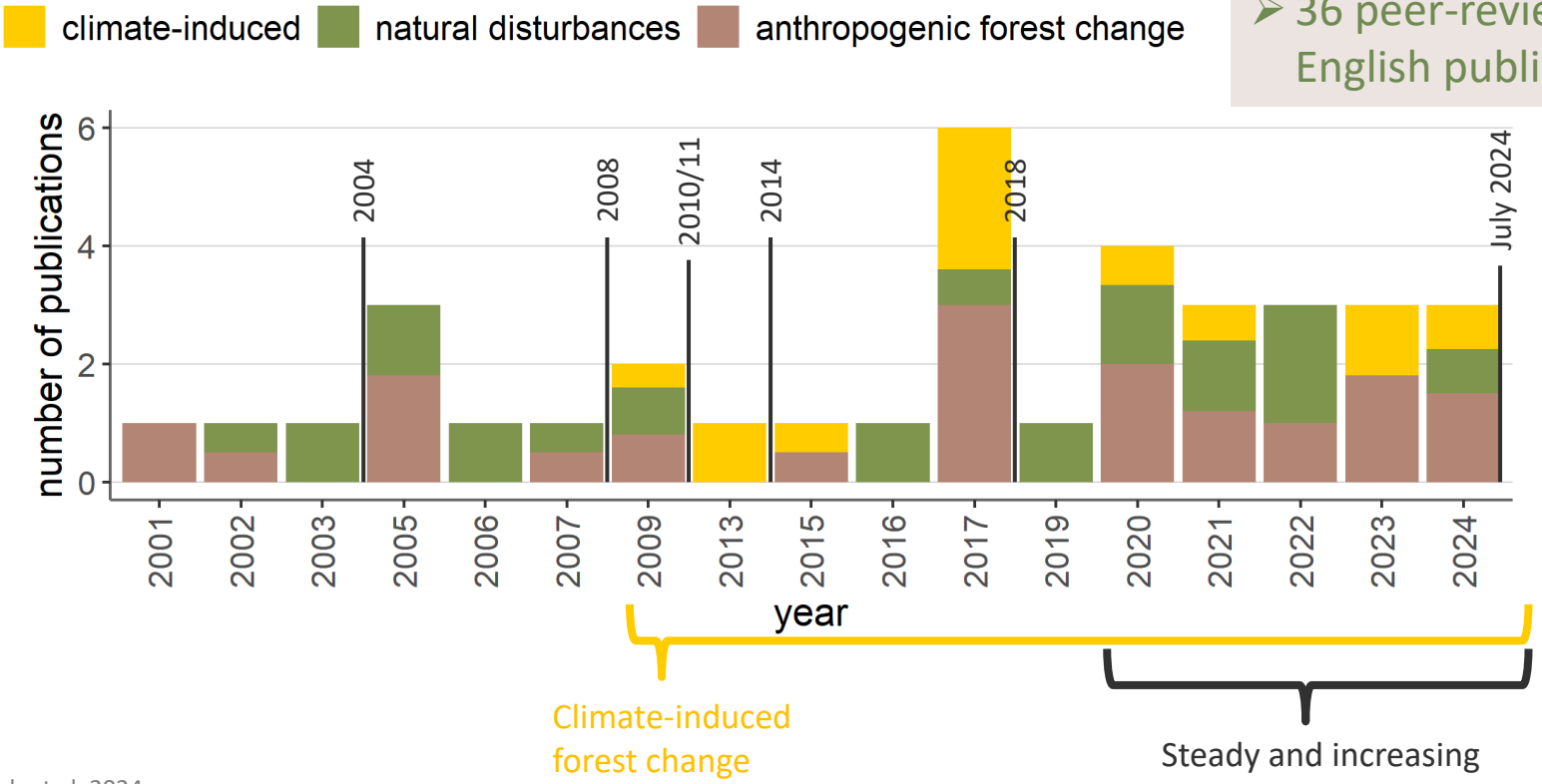
- climate-induced
- (changing) natural disturbance
- anthropogenic-driven (e.g., land-use change, management interventions)



Teich et al. 2024

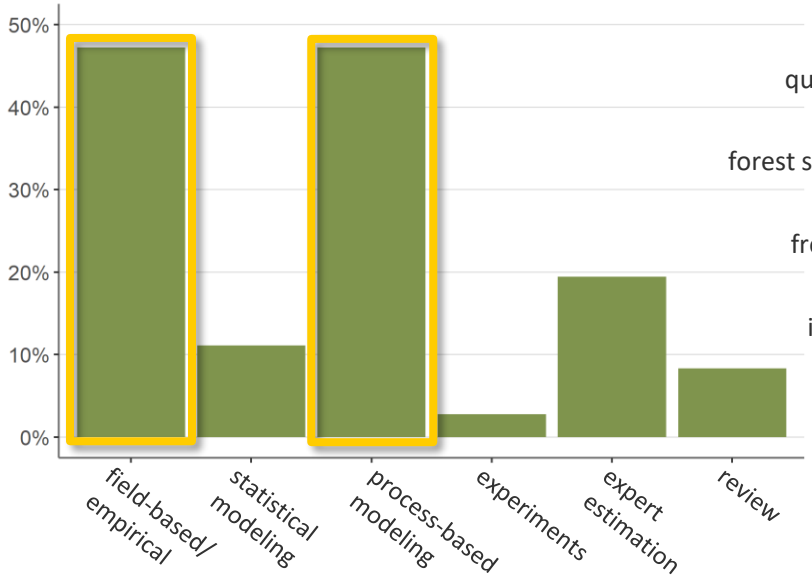
Avalanche protective forests are under pressure: what does science say?

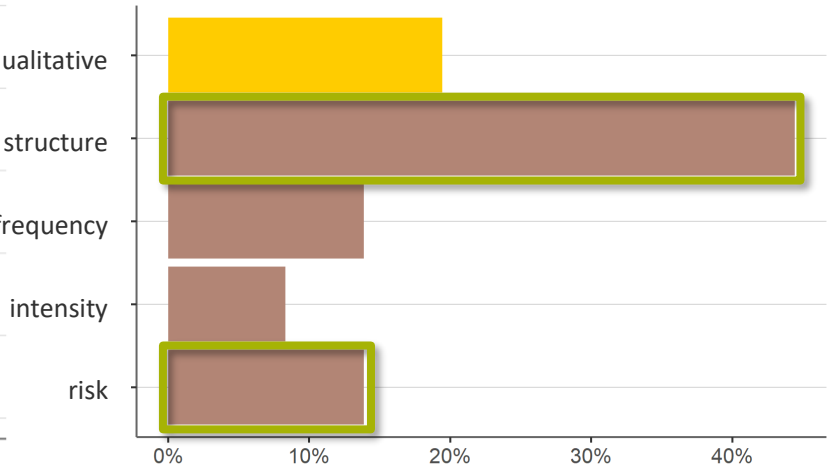
Not that much…
- 36 peer-reviewed English publications



Teich et al. 2024

Avalanche protective forests are under pressure: what does science say?





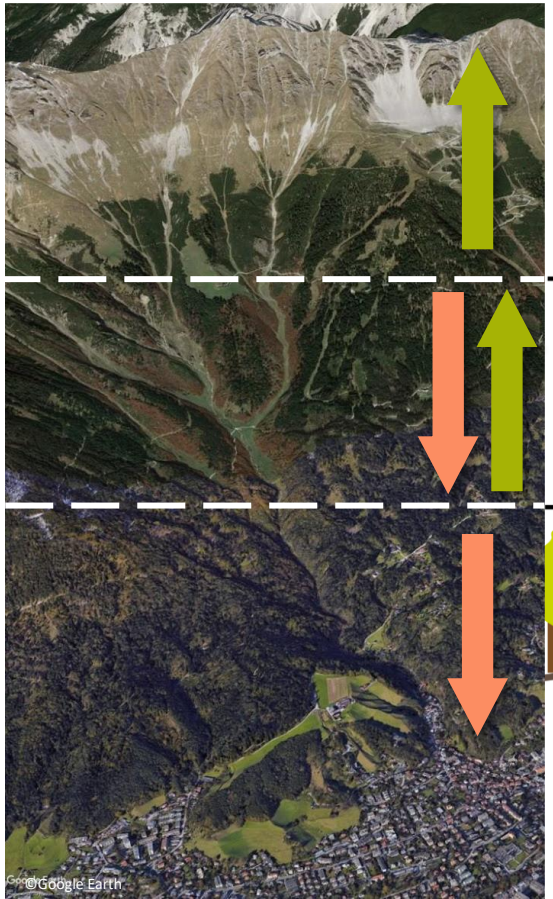
Methods:

- avalanche dynamics and forest simulation models were never combined

- 82% quantitative measures
- dimensionless protective forest indices
- only few studies considered risk

Teich et al. 2024

Climate-induced forest change: what does science say?



12 publications/
10 forest simulation studies:

It depends…

- on forest expansion and enhanced tree growth
- on local conditions and the climate scenario
- on drought, which decreases protective effects

Increasing natural disturbances counter-balance effects of enhanced tree growth!

Anthropogenic-driven forest change: what does science say?

18 publications:

It’s not a clear-cut picture…

- deforestation generally has negative impacts
- re- and afforestation enhance protective effects
- but often don't occur where most needed

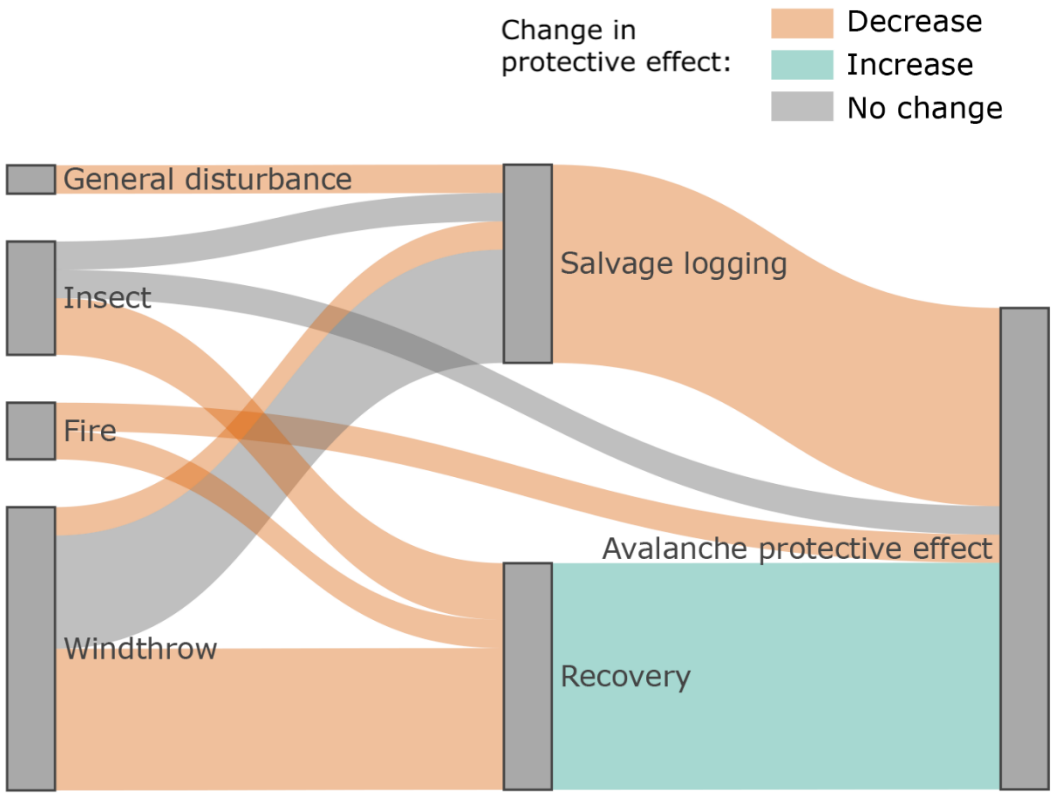
Regeneration cuts and thinning show varying effects under different climate scenarios…

- e.g., positive effects under no climate change
- but negative impacts increase as climate change intensifies

Interactions between climate change an anthropogenic influences are complex!

Teich et al. 2024

Natural disturbances: what does science say?

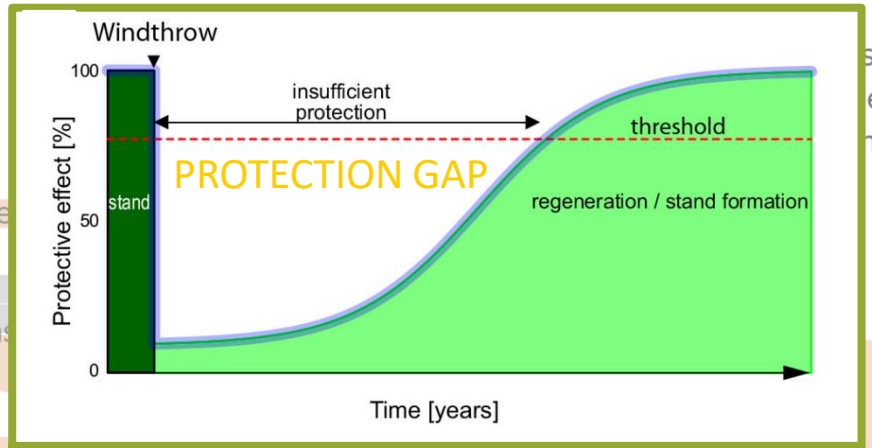


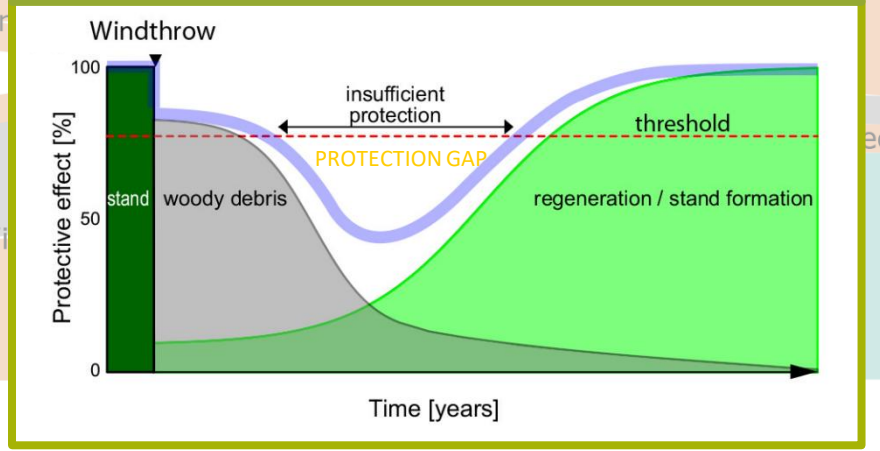
18 publications:

- natural disturbances often decrease protective effects
- management decisions influence post-disturbance protective effect

Teich et al. 2024

Natural disturbances: what does science say?





18 publications:

- natural disturbances often decrease protective effects
- management decisions influence post-disturbance protective effect

Post-disturbance management is key.

Figures: Wohlgemuth et al., 2017 (adapted)


Where do we grow from here?

Closing the gaps.

Empirical data and site-specific assessments

…investigate effects of compound events

…enhance and couple modeling approaches

…enhance and couple modeling approaches

Observation-based approaches

Process-based approaches

…enhance and couple modeling approaches

Observation-based approaches

Process-based approaches

Closing the gaps.

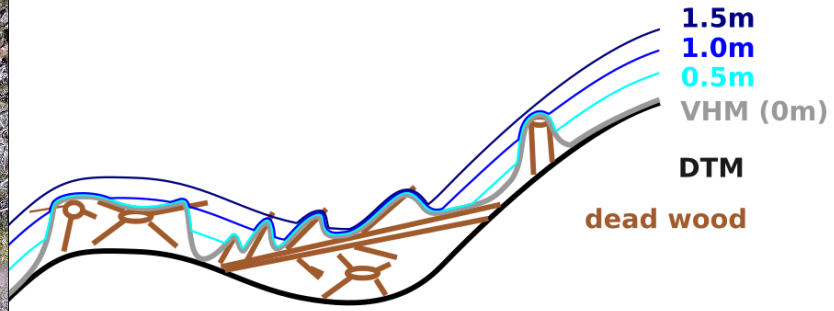
…decision support tools for prioritization

Interreg Alpine Space

Co-funded by the European Union

MOSAIC

Which protective effect against avalanches has a windthrow area, if „filled“ with snow?

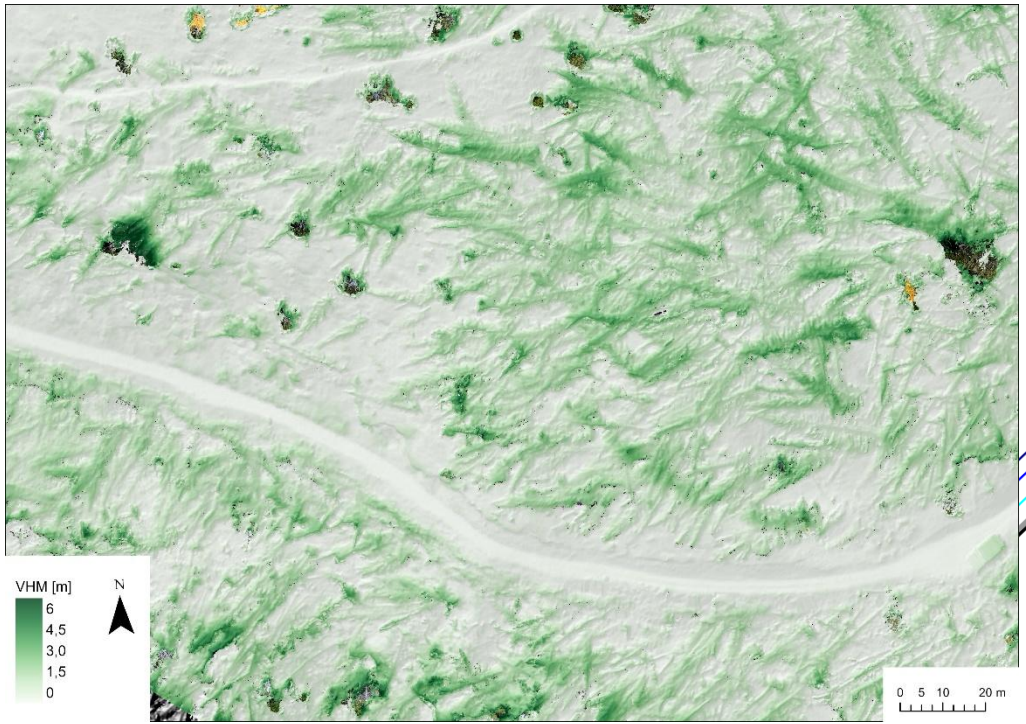


Bührle et al. 2025

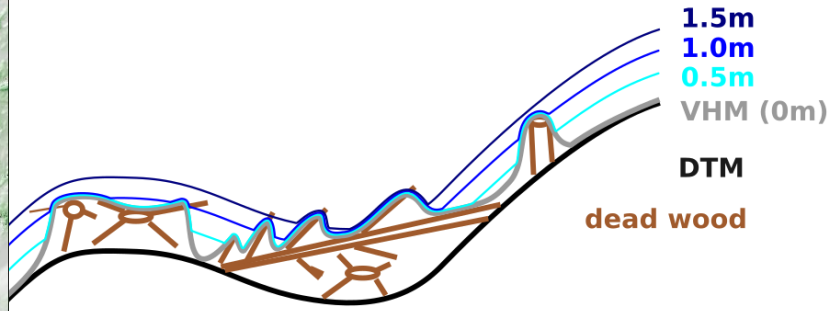
…decision support tools for prioritization

Interreg Alpine Space — Co-funded by the European Union

MOSAIC



- Vegetation height model (VHM) from drone photogrammetry

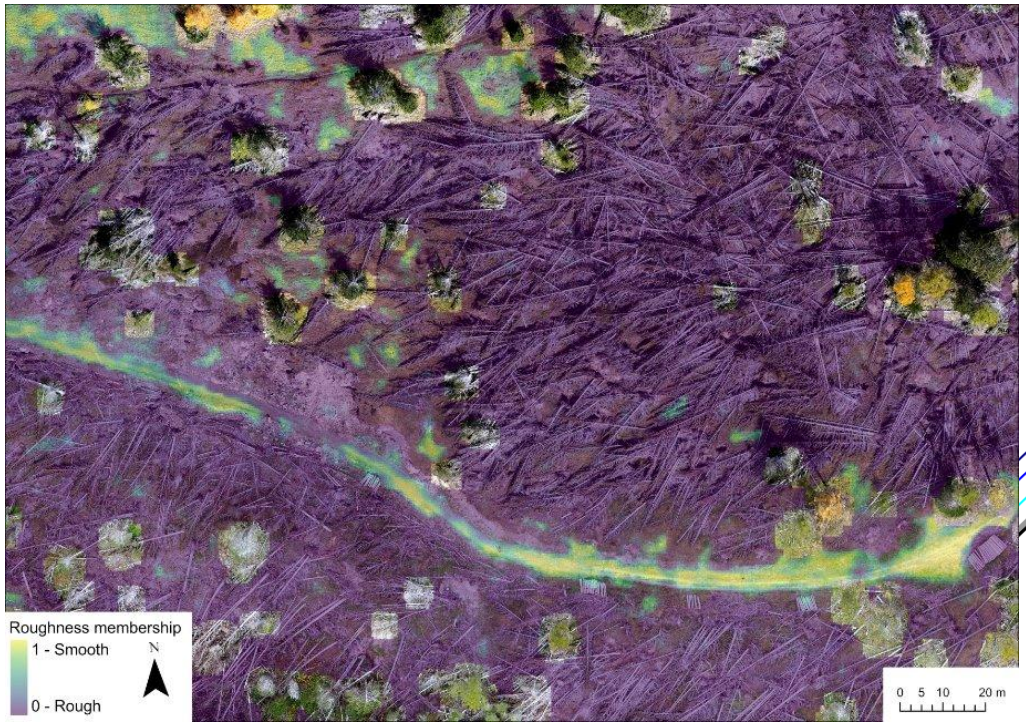


Bührle et al. 2025

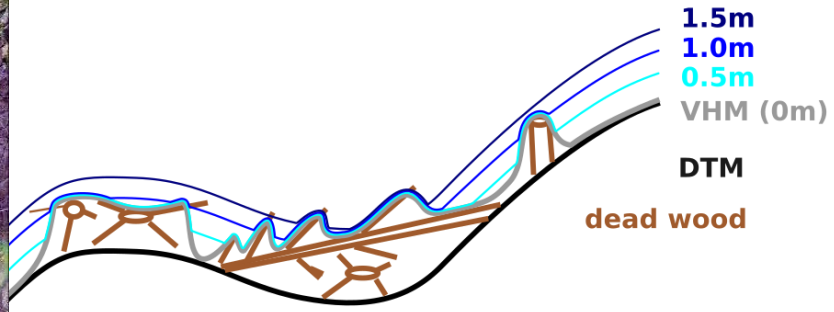
…decision support tools for prioritization

Interreg Alpine Space — Co-funded by the European Union

MOSAIC



- Roughness membership (no snow)

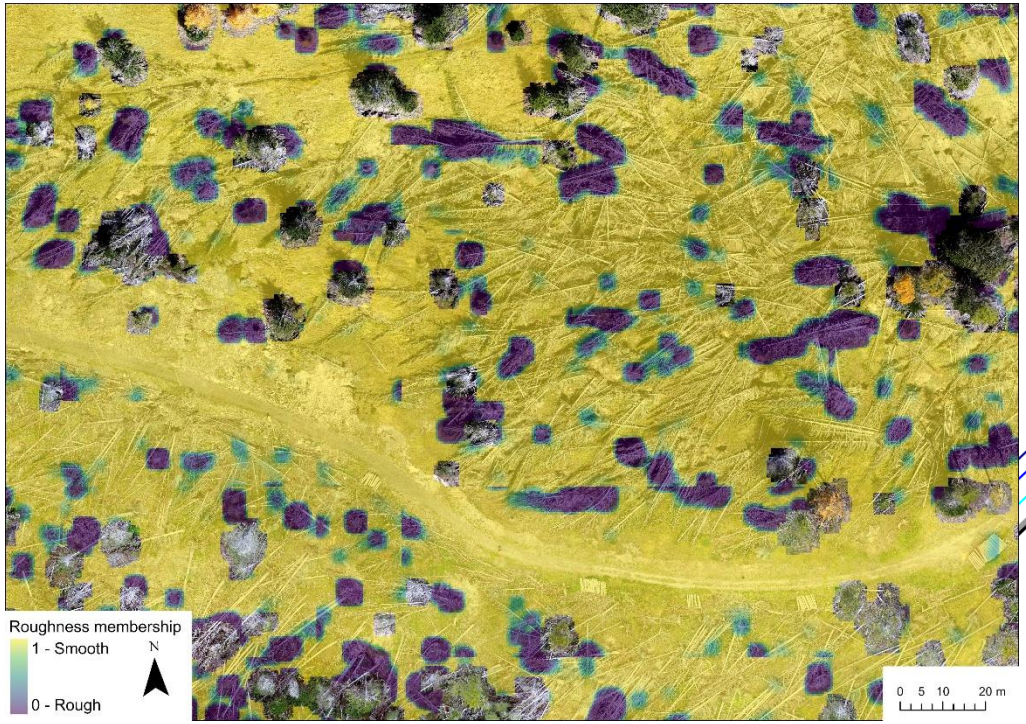


Bührle et al. 2025

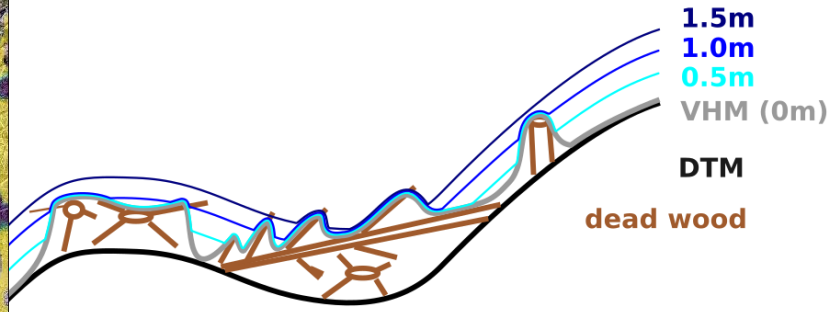
…decision support tools for prioritization

Interreg Alpine Space — Co-funded by the European Union

MOSAIC



- Roughness membership (1,5 m snow depth ≈ 10-year return period)

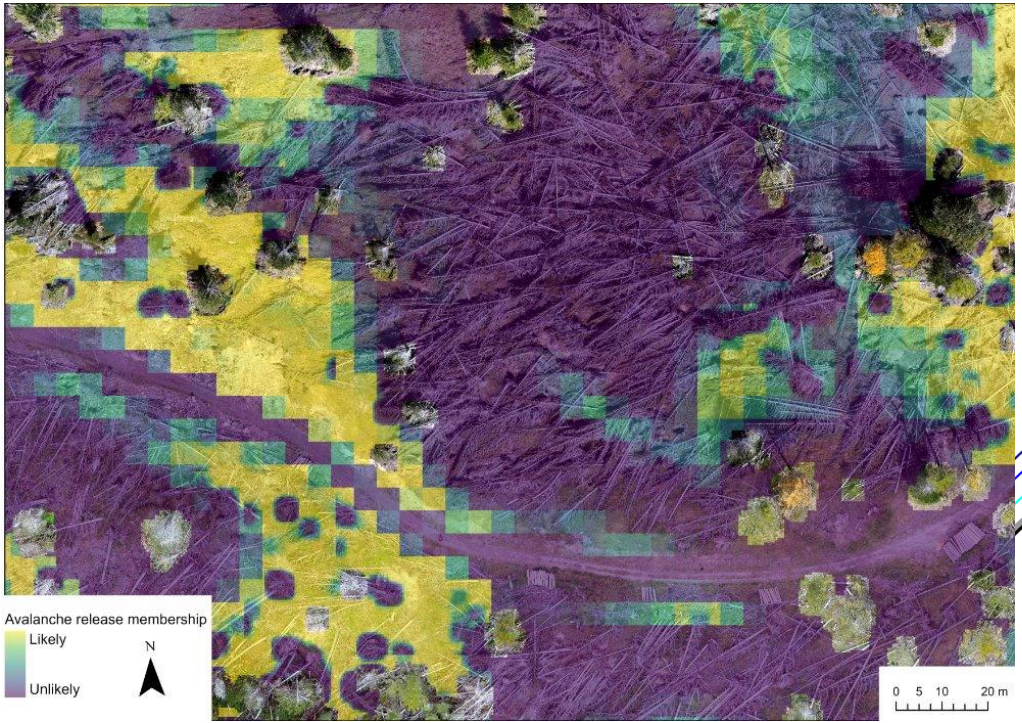


Bührle et al. 2025

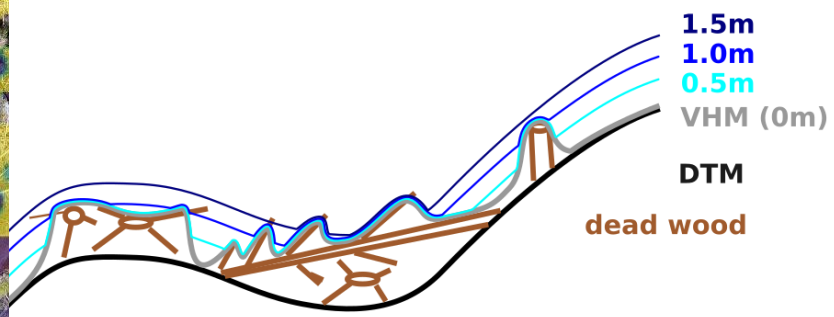
…decision support tools for prioritization

Interreg Co-funded by the European Union
Alpine Space

MOSAIC



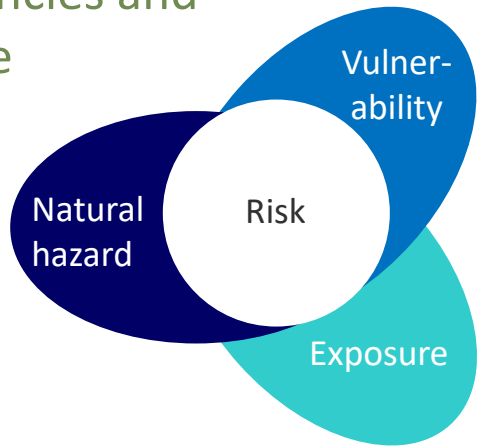
- Avalanche release membership / probability (1,5 m snow depth ≈ 10-year return period)



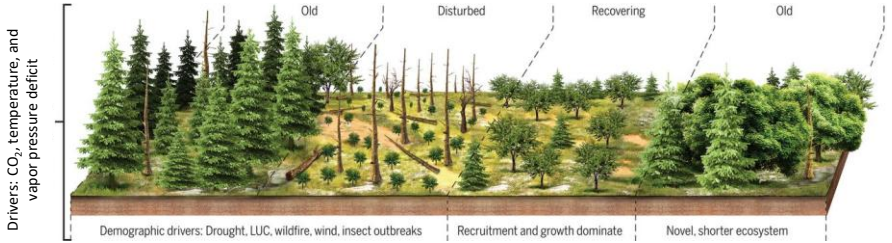
Bührle et al. 2025

Take home messages

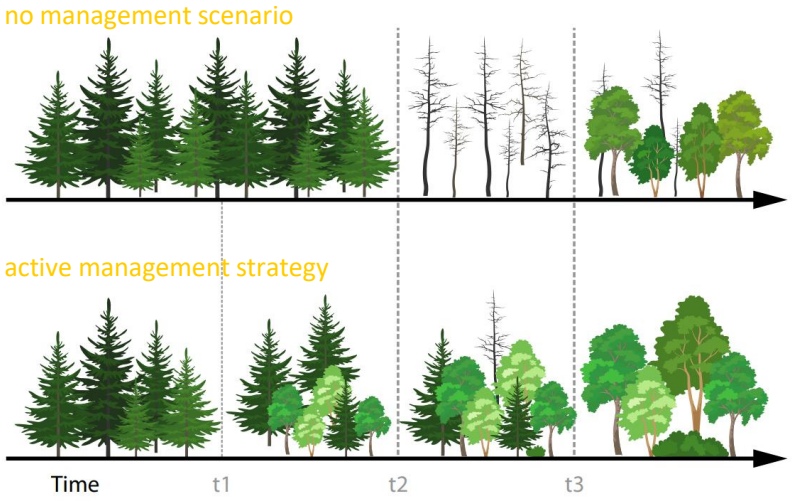
- forests change constantly
  - global change and especially disturbances determine and accelerate forest pathways
  - as do management decisions
- avalanche frequencies and intensities change
- society changes



Conceptual diagram of the components of forest dynamics and the disturbances that drive them



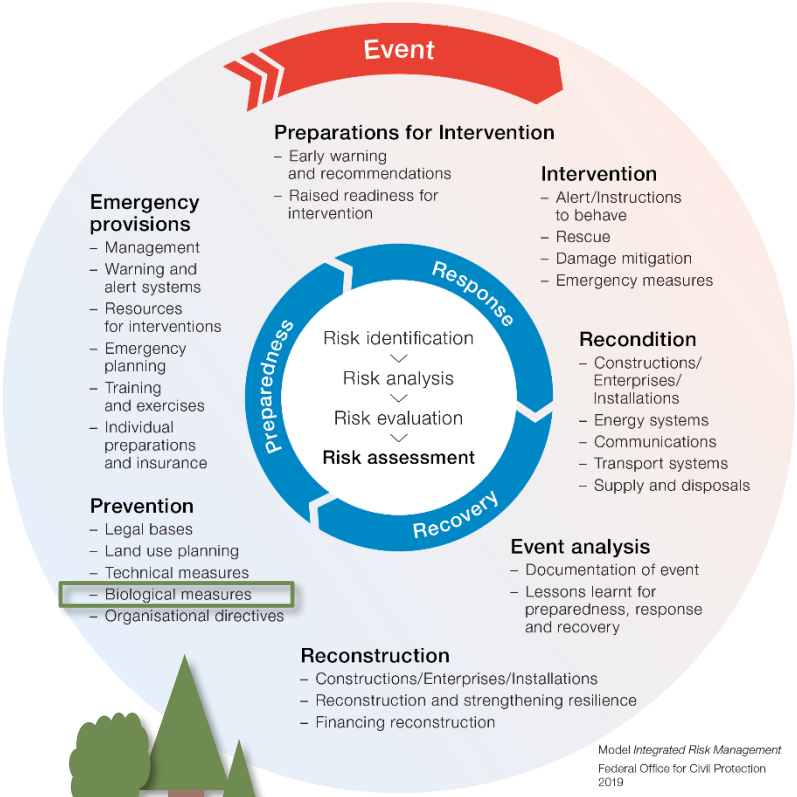
Possible pathways of forest development under climate change



Figures: McDowell et al. 2020; Jandl et al., 2019

BFW
BILDUNG
FORSCHUNG
WALD

Take home messages



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

Brang et al. 2001

References

Supported by the OeAD (Project number BG 01/2023)
the National Science Fund of Bulgaria (Project KP-06-Austria/4/2023)
and the Interreg Alpine Programme, co-funded by the European Union (Grant number ASP0100014)

Accastello, C., Poratelli, F., Renner, K., Cocuccioni, S., D'Amboise, C.J.L., Teich, M., 2022. 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.

Bebi, P., Bast, A., Helzel, K., Schmucki, G., Brozova, N., Bühler, Y., 2021. 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.

Bebi, P., Kienast, F., Schönenberger, W., 2001. Assessing structures in mountain forests as a basis for investigating the forests' dynamics and protective function. Forest Ecology and Management, 145, 3–14

Bebi, P., Kulakowski, D., Rixen, C., 2009. Snow avalanche disturbances in forest ecosystems—State of research and implications for management. Forest Ecology and Management, 257(9), 1883–92.

Bottero, A., Moos, C., Stritih, A., Teich, M., 2024.. Editorial: Impacts of global change on protective forests in mountain areas. Frontiers in Forests and Global Change, 7, 1375285.

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

Bührle, L., Baggio, T., Adams, M., Winiwarter, L., Lingua, E., Stoffel, A., Marke, T., Bebi, P., Teich, M., 2025. Assessment of protective effect of wind-disturbed forest against snow avalanches. EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-17290.

D'Amboise, C.J.L., Neuhauser, M., Teich, M., Huber, A., Kofler, A., Perzl, F. et al., 2022. Flow-Py v1.0: a customizable, open-source simulation tool to estimate runout and intensity of gravitational mass flows. Geosci Model Dev., 15(6), 2423–2439.

Huber, A., Saxer, L., Spannring, P., Hesselbach, C., Neuhauser, M., D'Amboise, C.J.L., Teich, M., 2024. Regional-scale avalanche modeling with com4FlowPy—potential and limitations for considering avalanche-forest interaction along the avalanche track. Proceedings, International Snow Science Workshop, Tromsø, Norway, 2024, 587-594.

Imbeck, H., 1987. Schneeprofile im Wald. Winterbericht EISLF 1885/86, Eidg. Institut für Schnee- und Lawinenforschung (EISLF), Davos, 50, 177-183.

Jandl, R., Spathelf, P., Bolte, A., Prescott, C.E., 2019. Forest adaptation to climate change—is non-management an option? Annals of Forest Science, 76, 48.

McDowell, N. G., Allen, C. D., Anderson-Teixeira, K., Aukema, B. H., Bond-Lamberty, B., Chini, L., ... & Xu, C., 2020. Pervasive shifts in forest dynamics in a changing world. Science, 368(6494), eaaz9463.

Moos, C., Bebi, P., Schwarz, M., Stoffel, M., Sudmeier-Rieux, K., Dorren, L., 2018. Ecosystem-based disaster risk reduction in mountains. Earth-Science Rev., 177, 497–513.

Oesterle, F., Tonnel, M., Wirbel, A., Fischer, J.-T., 2022. avaframe/AvaFrame: Version 1.3 (1.3). Zenodo. https://doi.org/10.5281/ZENODO.7189007

Panayotov, M., Markov, K., Tsvetanov, N., Huber, A., Hesselbach, C., Teich, 2024. Avalanche hazard mapping using the Avalanche Terrain Exposure Scale (ATES) in the high mountain ranges of Bulgaria. Proceedings, International Snow Science Workshop, Tromsø, Norway, 2024, 1660-1667.

Perzl, F., Bono, A., Garbarino, M., Motta, R., 2021. 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.

Perzl, F., Kleemayr, K., 2020. Assessment of forest protection effects and functions for natural hazard processes. GreenRisks4Alps Report D.T.1.3.2.

Perzl, F., Rössel, M., Kleemayr, K., 2019. 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. Unpublished.

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

Schneebeli, M., Meyer-Grass, M., 1993. Avalanche starting zones below the timber line—structure of forest. Proceedings of the International Snow Science Workshop, Breckenridge, Colorado, 4–8 October 1992, 176–181.

Teich, M., Perzl, F., Fuchs, S., Papathoma-Köhle, M., Scheidl, C., 2021. Schutzfunktion und Schutzwirkung des Waldes: Schutzgüter, Risikoanalyse und Bewertung. In: Freudenschuß, A., Markart, G., Scheidl, C., Schadauer, K., Hrsg. Schutzwald in Österreich - Wissensstand und Forschungsbedarf. Bundesforschungszentrum für Wald, Wien: 8-10.

Teich, M.; Stritih, A.; Bottero, A.; Moos, C., 2024. Global change impacts on avalanche protective forests — current knowledge and future research directions. Proceedings, International Snow Science Workshop, Tromsø, Norway, 2024, 553-561.

Wohlgemuth, T., Schwitter, R., Bebi, P., Sutter, F., Brang, P., 2017. Post-windthrow management in protection forests of the Swiss Alps. European Journal of Forest Research, 136(5–6), 1029–1040.

BFW BUNDES FORSCHUNGS ZENTRUM FÜR WALD

Thank you for listening!

Michaela Teich

Austrian Research Centre for Forests (BFW)
Department of Natural Hazards

Hofburg, Rennweg 1, 6020 Innsbruck

michaela.teich@bfw.gv.at
www.bfw.gv.at

Follow us

- www.facebook.com/BundesforschungszentrumWald
- www.instagram.com/bundesforschungszentrum_wald
- www.youtube.com/waldforschung
- www.linkedin.com/company/bundesforschungszentrum-wald-bfw