RISK Summer School 2024

Mountain forests as a Nature-Based Solution for protection against natural hazards

Sylvain DUPIRE, INRAE - UR LESSEM, Grenoble

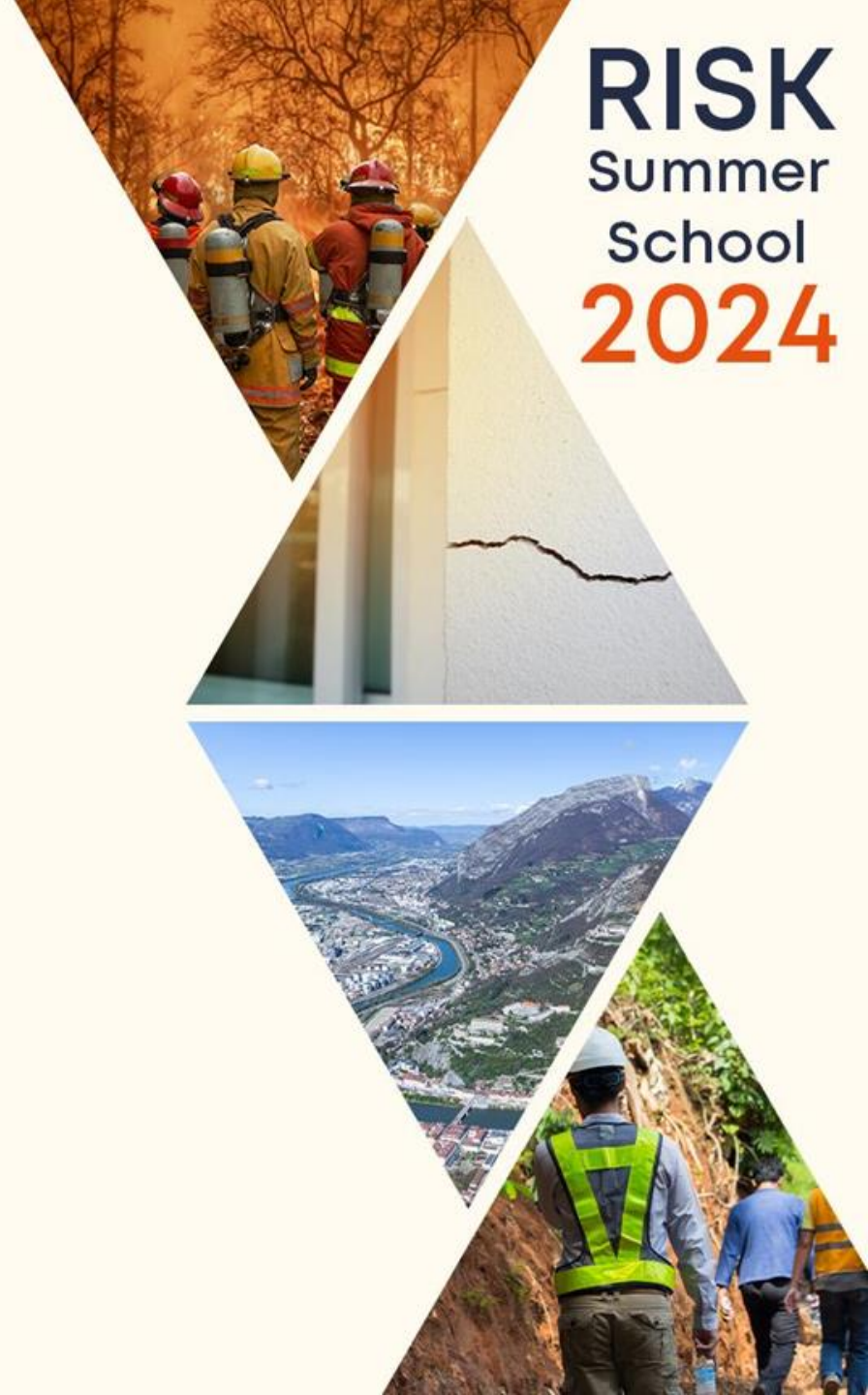
INRAE LESSEM

Presentation outline

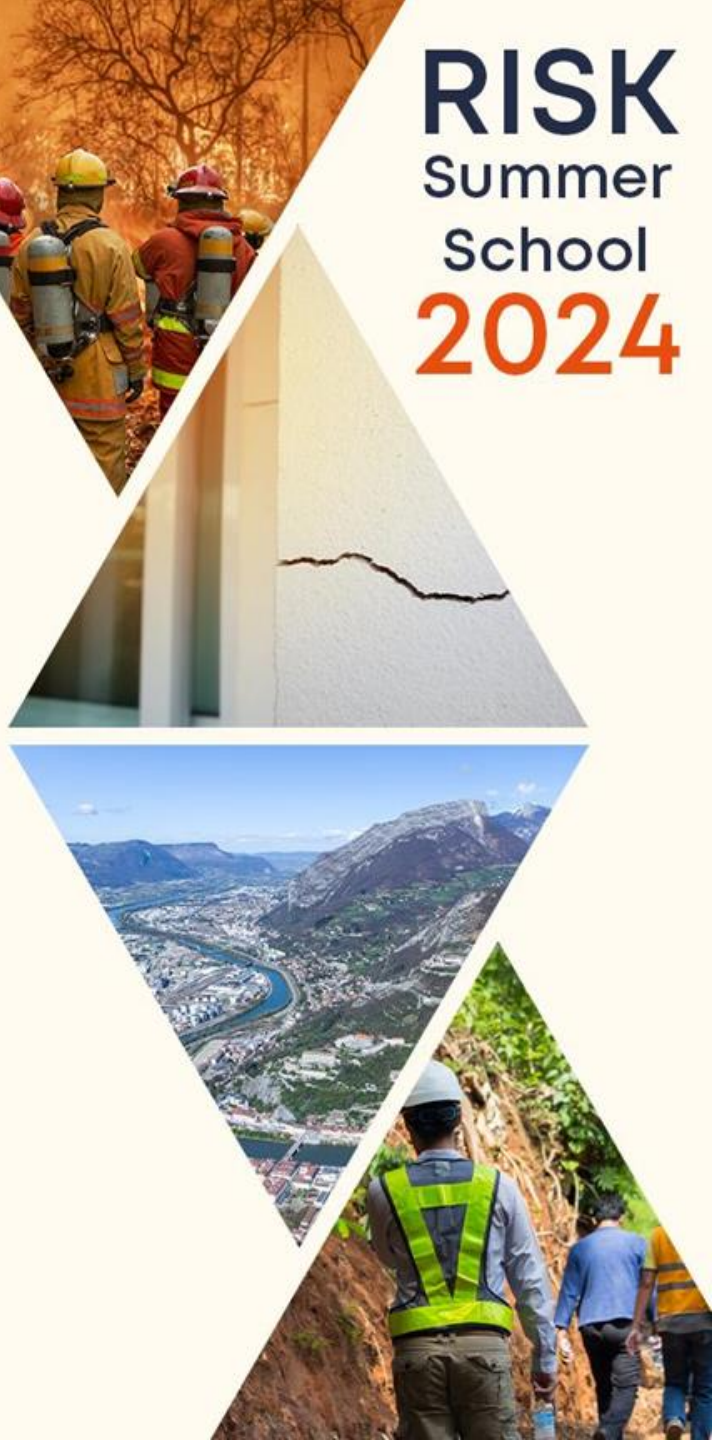
1. Context

2. How forests mitigate rockfalls

3. A efficient but vulnerable NBS due to Climate Changes



Presentation outline



1. Context

2. How forests mitigate rockfalls

3. An efficient but vulnerable NBS due to Climate Changes

Context

Using forests to mitigate gravitational natural hazards

RISK Summer School 2024

France - 19th century: only 10% of forests remained in the Alps due to intense agricultural and demographic pressure.

1882 : creation of the "Mountain Land Restoration" (“Restauration des Terrains de Montagne” RTM) service by the National Water and Forests Administration.

- The **decline of forests** is responsible for an increase in the severity and frequency of natural hazards (floods, landslides, erosion, etc.)
- **Reforestation** is an effective and sustainable way to mitigate these hazards.

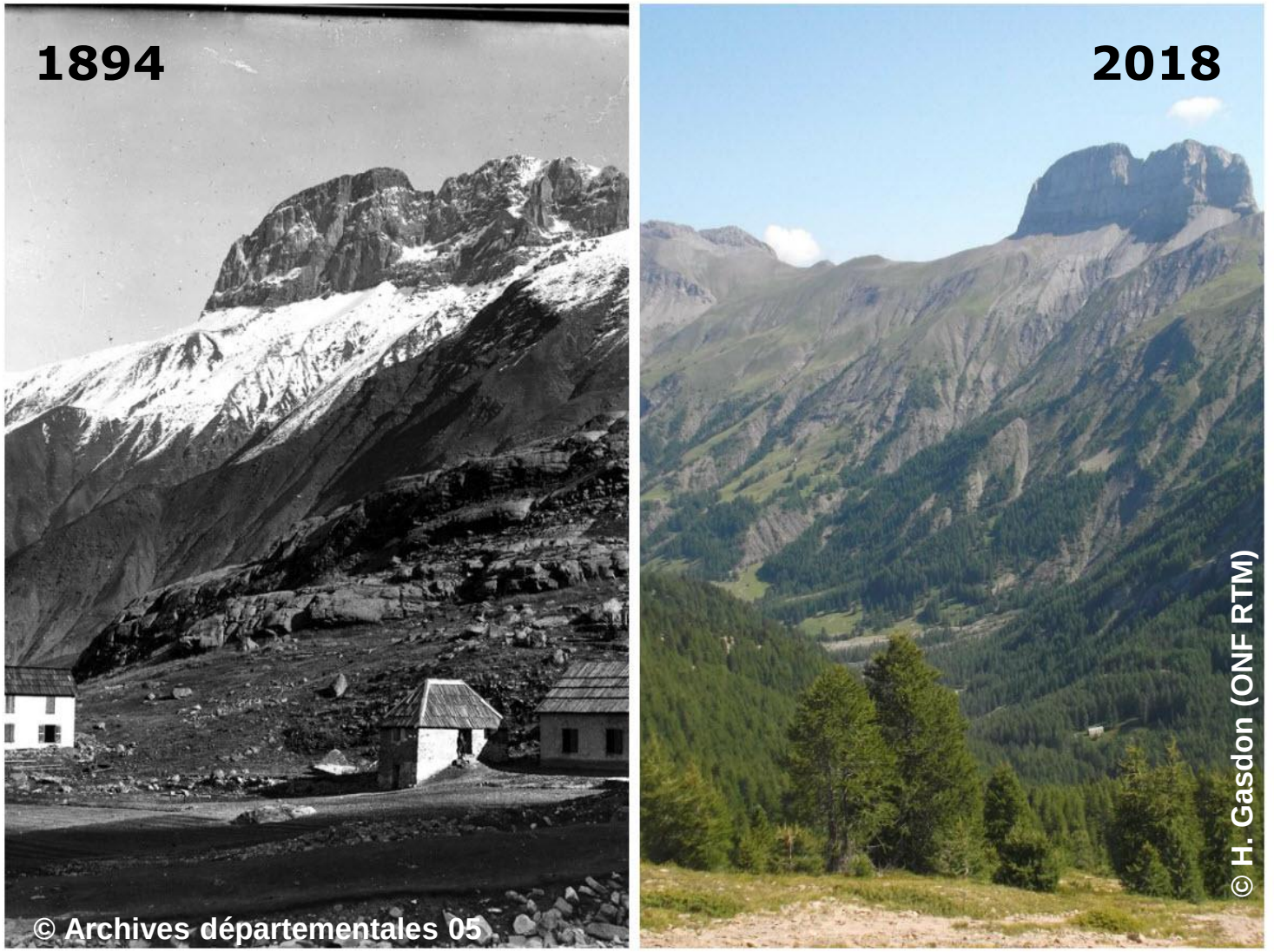
➡ The French State acquired 390 000 ha, with 250 000 ha reforested, forming the RTM state-owned forests (Forêts domaniale RTM).

Context

Using forests to mitigate gravitational natural hazards

RISK Summer School 2024

Flash floods



Laverq forest barracks (05 - Ubaye)

Context

Using forests to mitigate gravitational natural hazards

RISK Summer School 2024

Erosion

Monospecific planted forest for flood and erosion control of black marls in the French Southern Alps.

Context

Using forests to mitigate gravitational natural hazards

RISK Summer School 2024

Avalanche

Plantation in clusters in avalanche starting areas (Haute-Savoie)

Context

Using forests to mitigate gravitational natural hazards

Rockfalls

1911

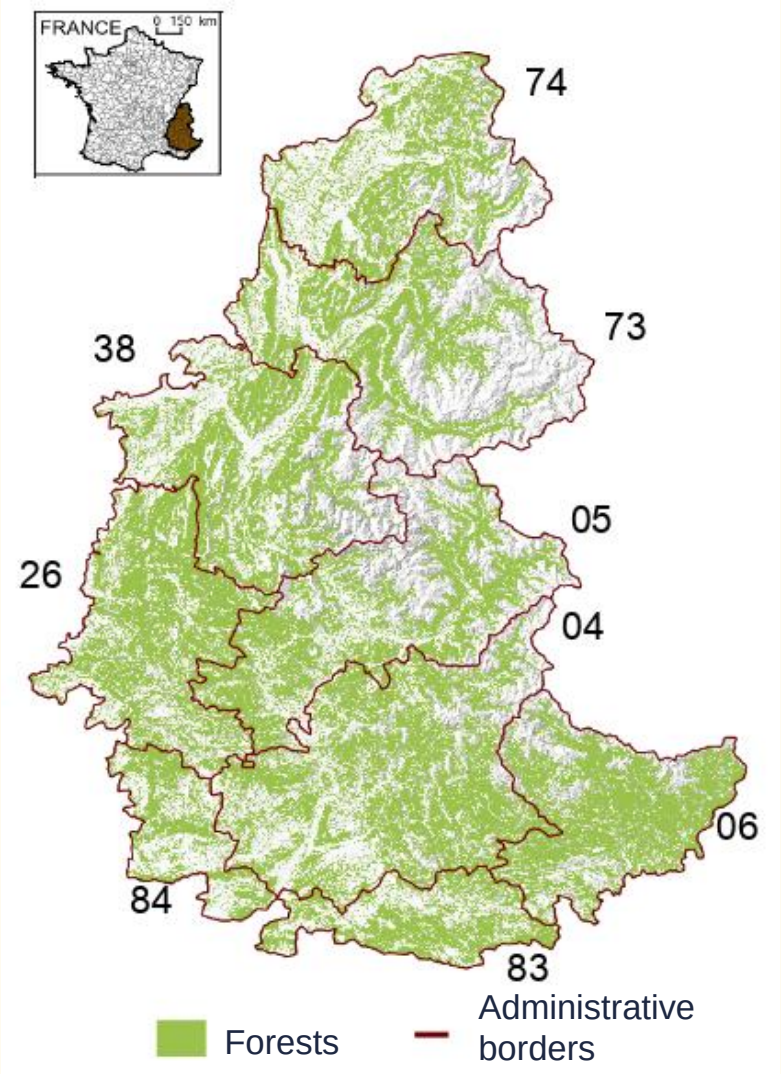
2017

No planting is done to protect against this hazard; it is generally a result of agricultural abandonment.

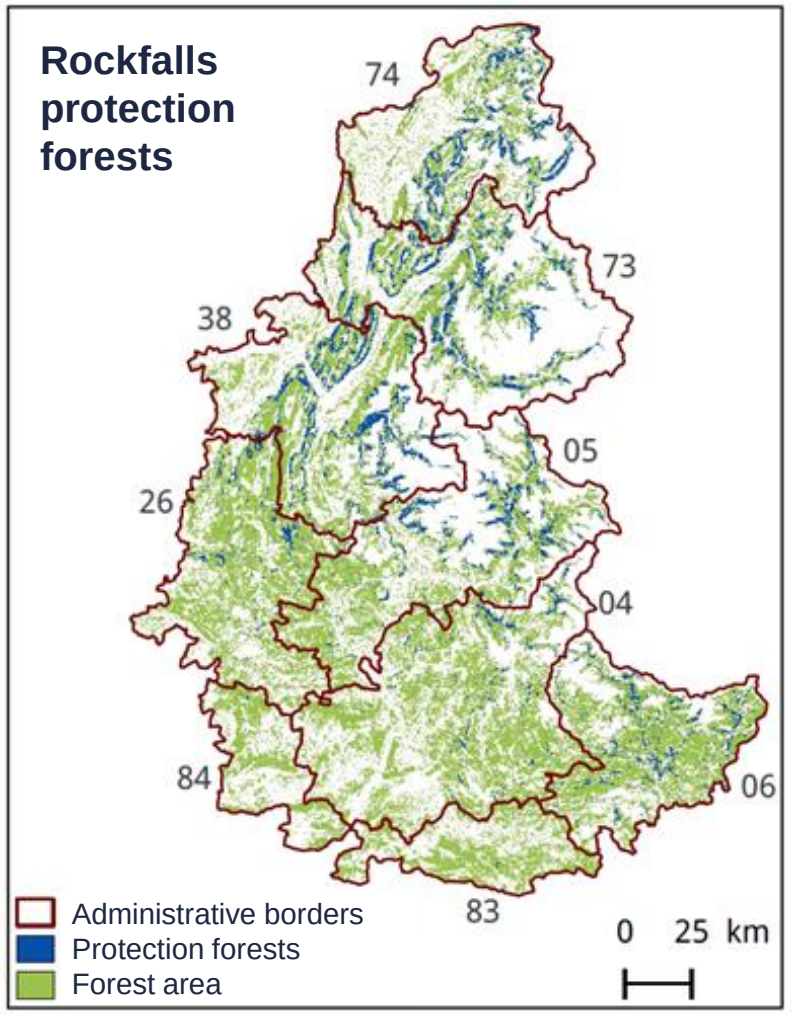
Context

RISK Summer School 2024

Nowadays forests are quite widespread in the French Alps



2 120 000 ha of forests (50% of the area)



300 000 ha of protection forests against rockfalls (14%)

60% in the Northern Alps

32% above 800m elevation in the Southern Alps

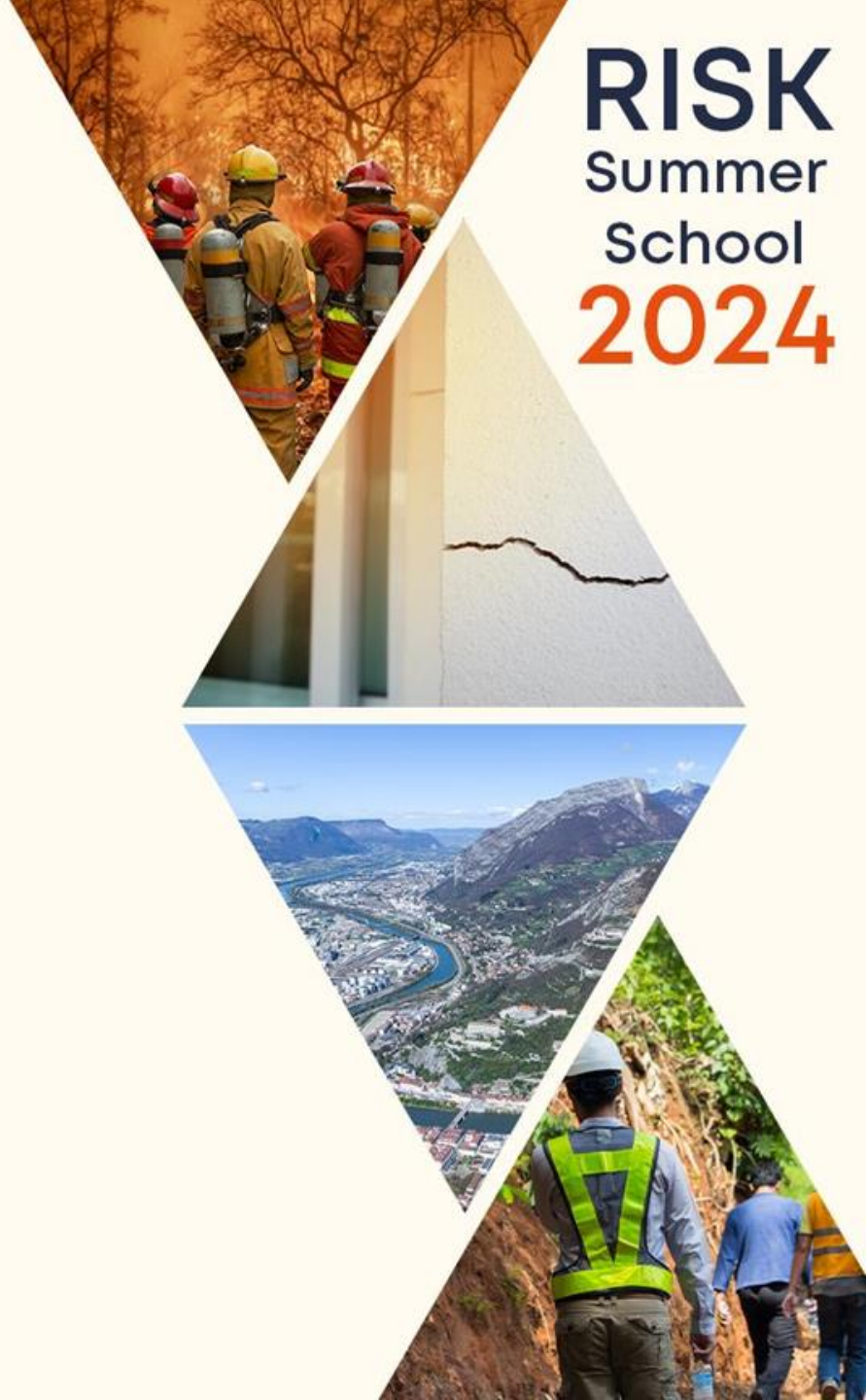
Dupire S., Toe D., Barré J-B., Bourrier F., Berger F. Harmonized mapping of forests with a protection function against rockfalls over European Alpine countries. *Applied Geography.* Vol 120, 102221

Presentation outline

1. Context

2. **How forests mitigate rockfalls**

3. An efficient but vulnerable NBS due to Climate Changes



RISK Summer School 2024

How forests mitigate rockfalls

Importance of on-site experiments : rocks releases on a forested slope

Topography ?
Soil ?

Rock ?

Trees ?

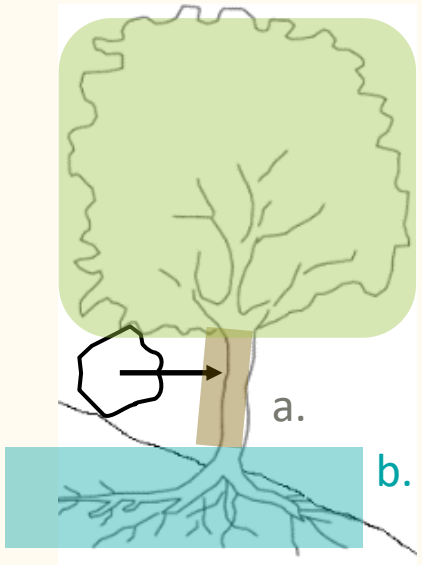
Dorren, L. K. A., Berger, F., & Putters, U. S. (2006). Real-size experiments and 3-D simulation of rockfall on forested and non-forested slopes. *Natural hazards and earth system sciences*, *6*(1), 145-153.

I. Olmedo, F. Bourrier, D. Bertrand et al. (2020) Dynamic analysis of wooden rockfall protection structures subjected to impact loading using a discrete element model, EJE E, 24:9, 1430-1449

How forests mitigate rockfalls

Importance of on-site experiments : rocks releases on a specific tree

a. trunk



b. roots

Influence of the impact on the rock's kinematics (speed, change of direction…)

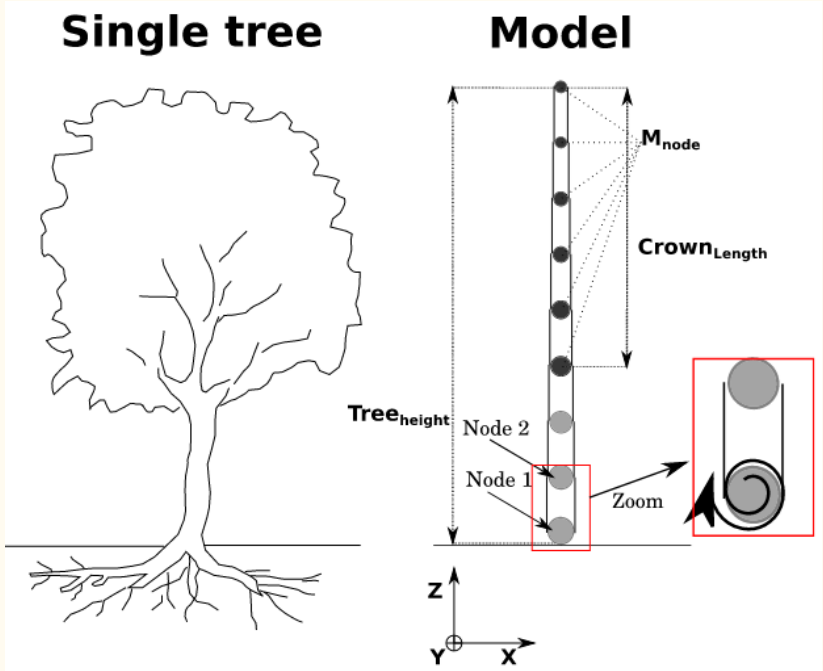
How each compartment contribute to the reduction of a rock's energy ?

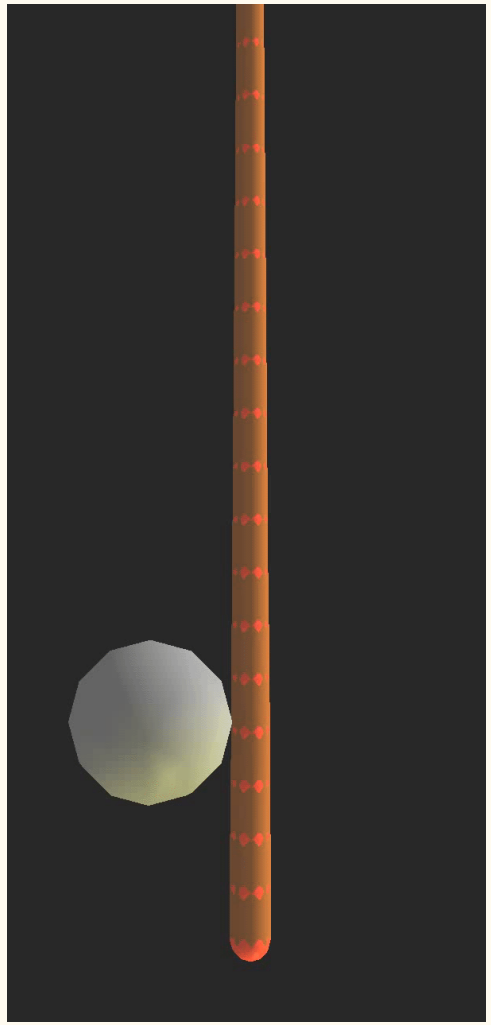
Moos, C et al (2019). Assessing the effect of invasive tree species on rockfall risk–The case of Ailanthus altissima Ecological engineering, *131*, 63-72.

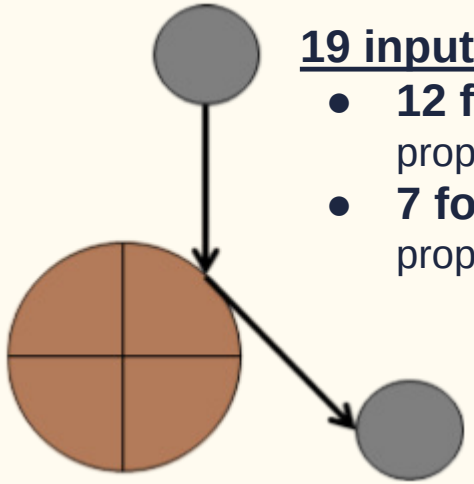
How forests mitigate rockfalls

Modelling rock impacts on trees : which variables matters ?

Yade-DEM







19 inputs parameters :

- **12 for the tree** (size and mechanical properties)
- **7 for the rock** (size, mechanical properties, kinematic)

4 outputs parameters :

- Kinetic energy reduction
- Variation of rotational speed
- Block deviation (vertical and horizontal)

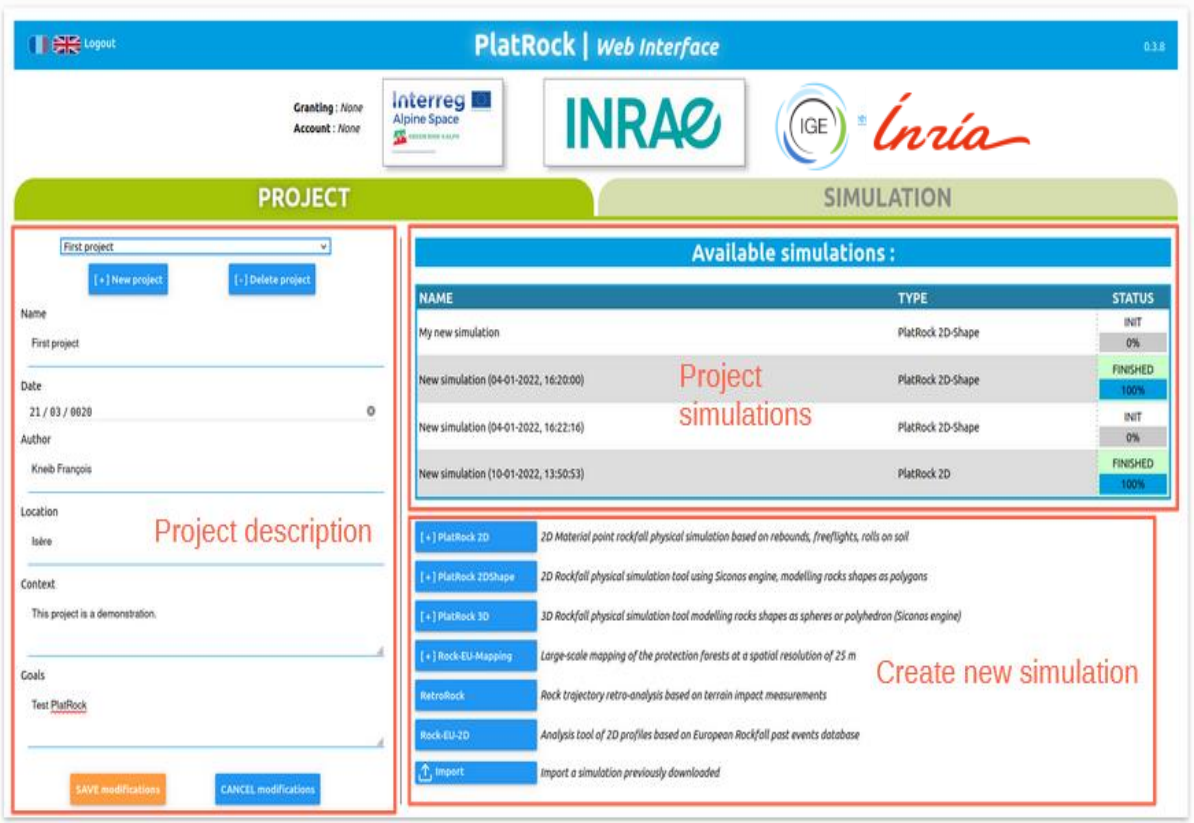
7 variables are sufficient to accurately describe the impact:

- Diameter / Height / Density of the tree
- Speed of the rock
- Volume of the block
- Eccentricity and height of the impact

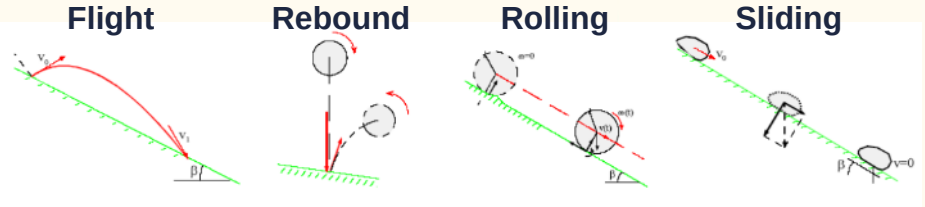
Toe, D., Bourrier, F., Olmedo, I. *et al.* Analysis of the effect of trees on block propagation using a DEM model: implications for rockfall modelling. *Landslides* **14,** 1603–1614 (2017).

How forests mitigate rockfalls

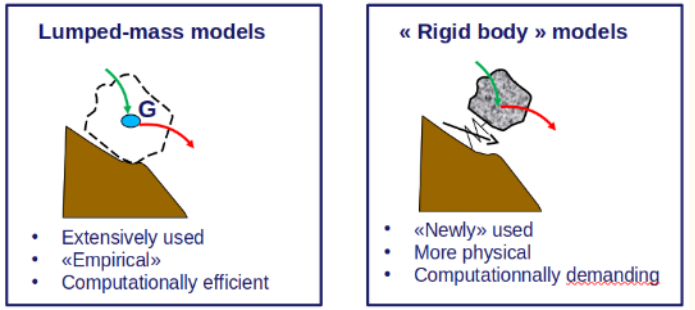
Modelling rockfalls on a slope taking into account a forest: www.platrock.org



Modelled rock trajectory phases



Rock modelling options

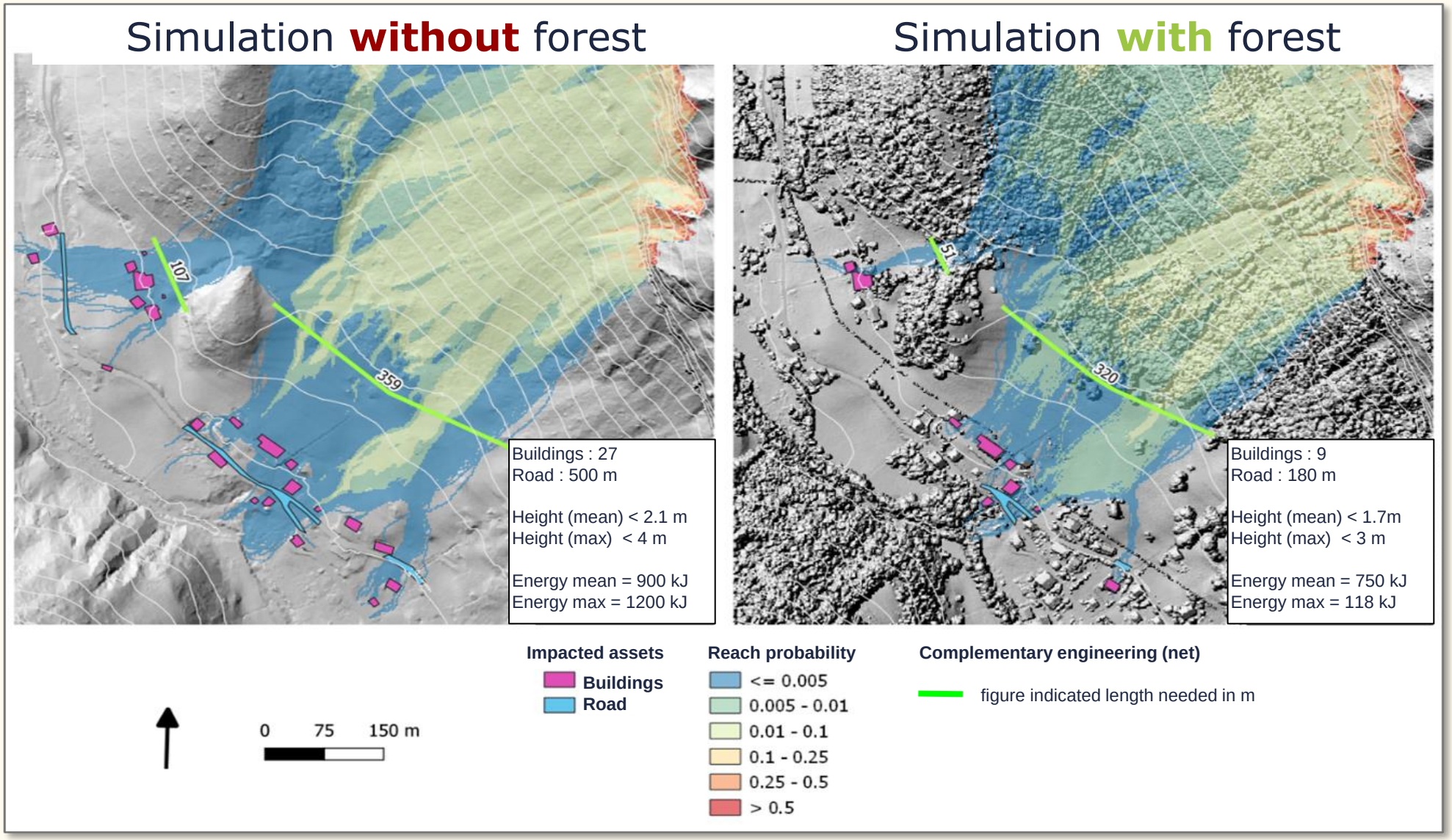


Dimensional modelling options

Rock / tree interaction

How forests mitigate rockfalls

Modelling rockfalls on a slope taking into account a forest: www.platrock.org



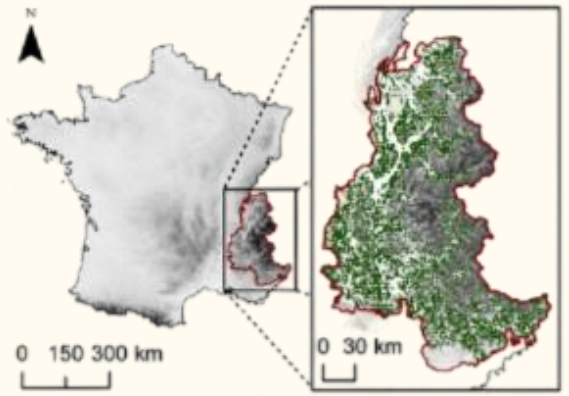
In this particular case :

- **Rockfall risk on human assets is divided by ~ 3 thanks to the forest**
- **Complementary engineering fences could be smallest while taking into account the protective effect of forest (reduction of length and height)**

How forests mitigate rockfalls

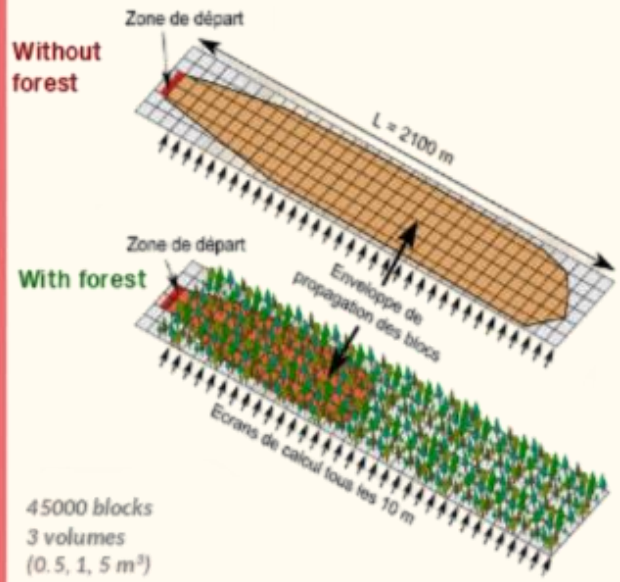
Quantifying the protective effect of forest against rockfalls

Data



4438 Forest plots from NFI
- Structure &composition
- Slope & topography

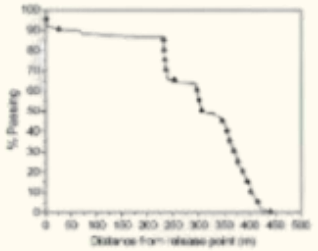
Rockfall simulations



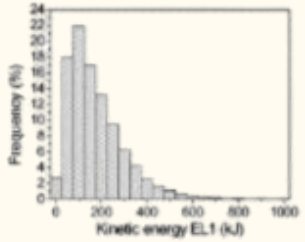
45000 blocks
3 volumes
(0.5, 1, 5 m³)

Results

Stop distances



Kinetic energy



Calculation of protective effect indicators

$$Ind(x) = 100.\left(1 - \frac{V(x)_{with\ forest}}{V(x)_{without\ forest}}\right)$$

100 : 🙂
0 : ☹

x *distance from release area*

V *variable compared between simulation with and without forest*

Indicator of frequency reduction	X	Indicator of intensity reduction	=	Indicator combining frequency and intensity reduction
BARI(x) : BARier effect Index		MIRI(x) : Maximum Intensity Reduction Index		ORPI(x) : Overall Rockfall Protection Index
V: number of blocks reaching x		V: quantile95 of the kinetic energy reaching x		V: sum of all kinetic energies reaching x

Dupire S., Bourrier F., Monnet J.-M., et al. Novel quantitative indicators to characterize the protective effect of mountain forests against rockfall. Ecological Indicators. Vol 67 pp 98-107

How forests mitigate rockfalls

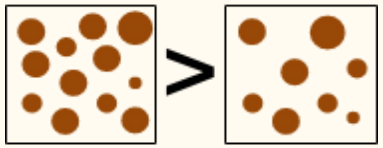
The main effects of the forest

1 "Barrier" effect

A part of the rocks are directly stopped in the forest

f(impact probability)

number and size of trees

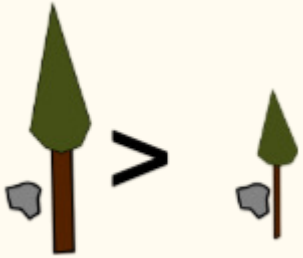


2 "Buffer" effect

The rock's kinetic energy is reduced with each impact against a tree

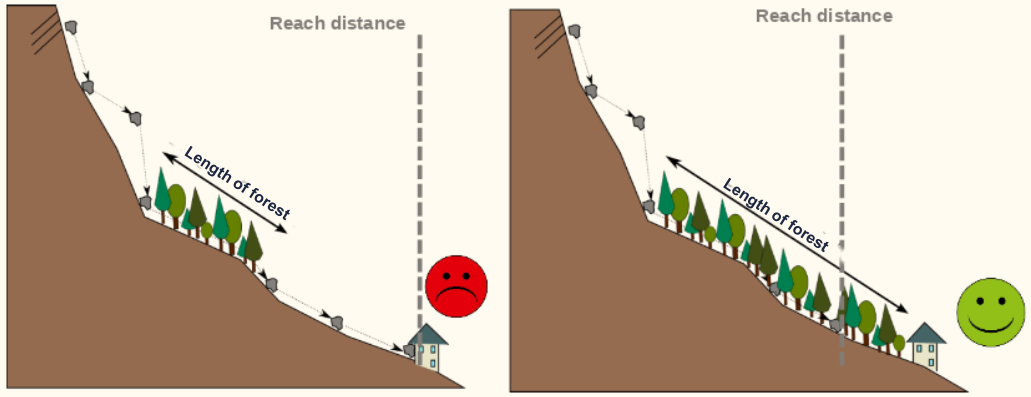
f(tree size)

tree diameter



3 "Cumulative" effect

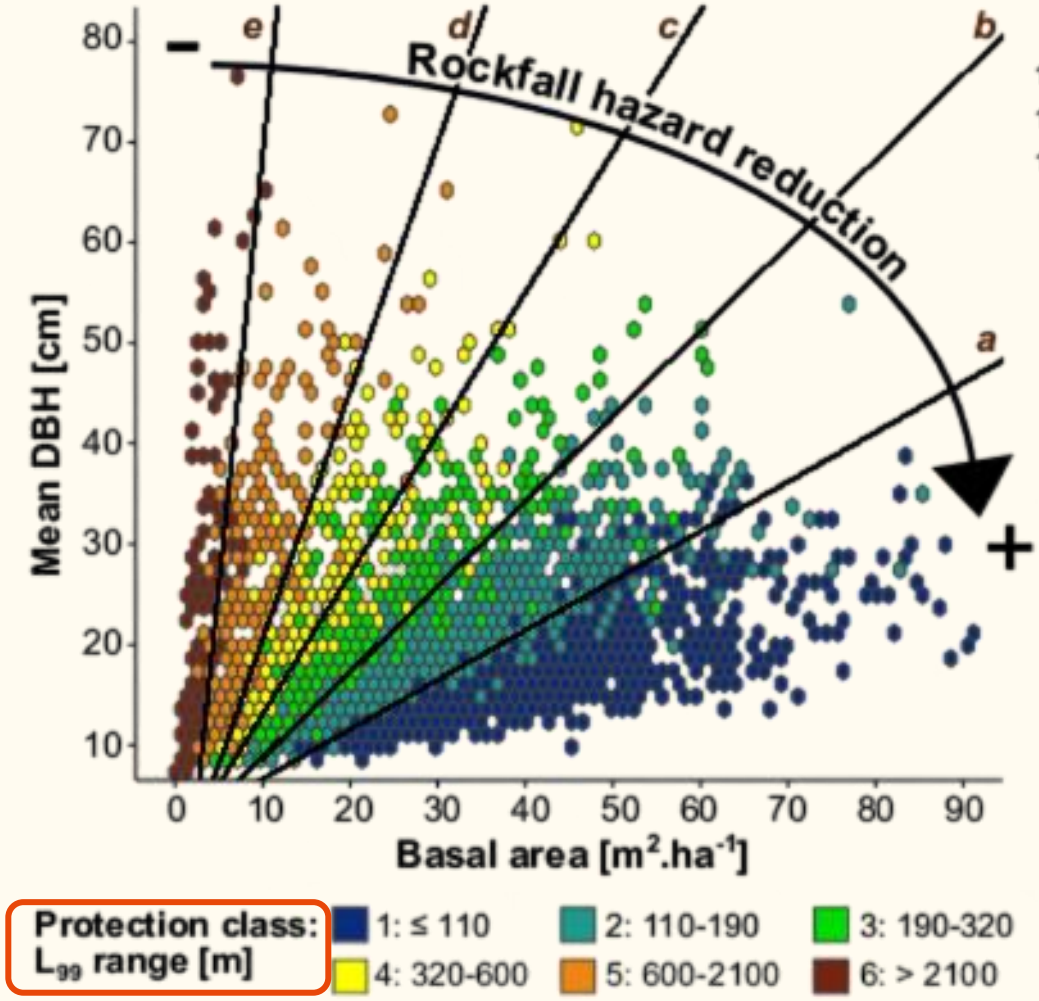
The longer the forest length on the slope, greater the effects



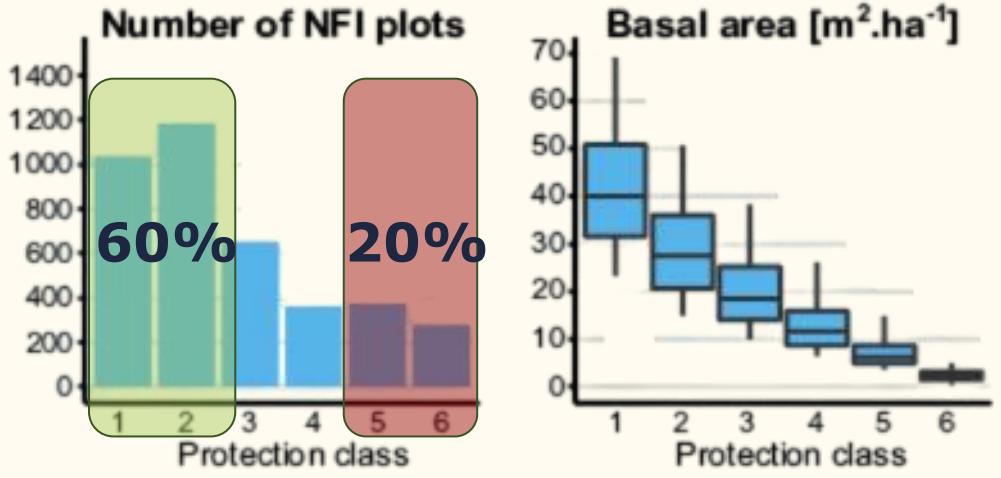
Dupire S., Bourrier F., Monnet J.-M., et al. The protective effect of forests against rockfalls across the French Alps: Influence of forest diversity. Forest Ecology and Management - Vol 382 pp 269-279

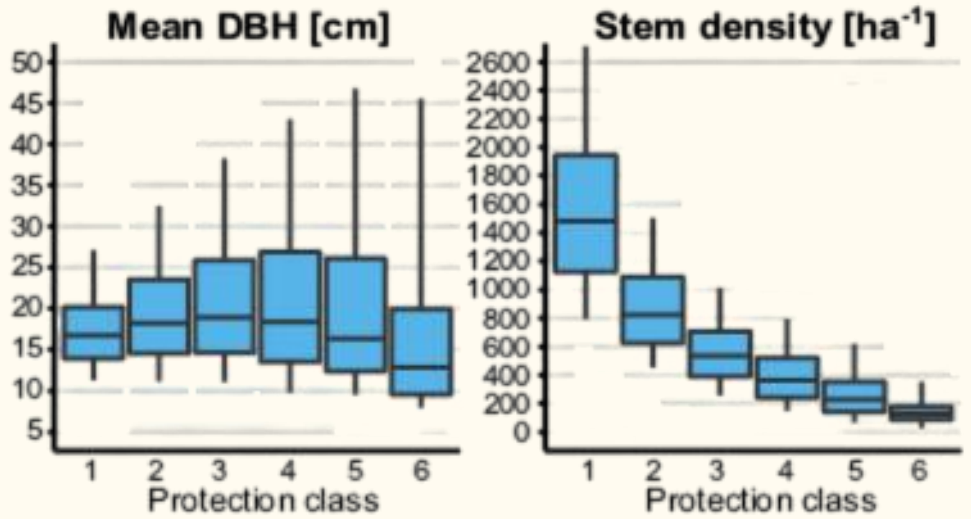
How forests mitigate rockfalls

How effective are French Alpine forests ?



Length of forest needed to reach ORPI=99





60% reach a high protective effect :

99% of hazard reduction after only 190m of forested slope

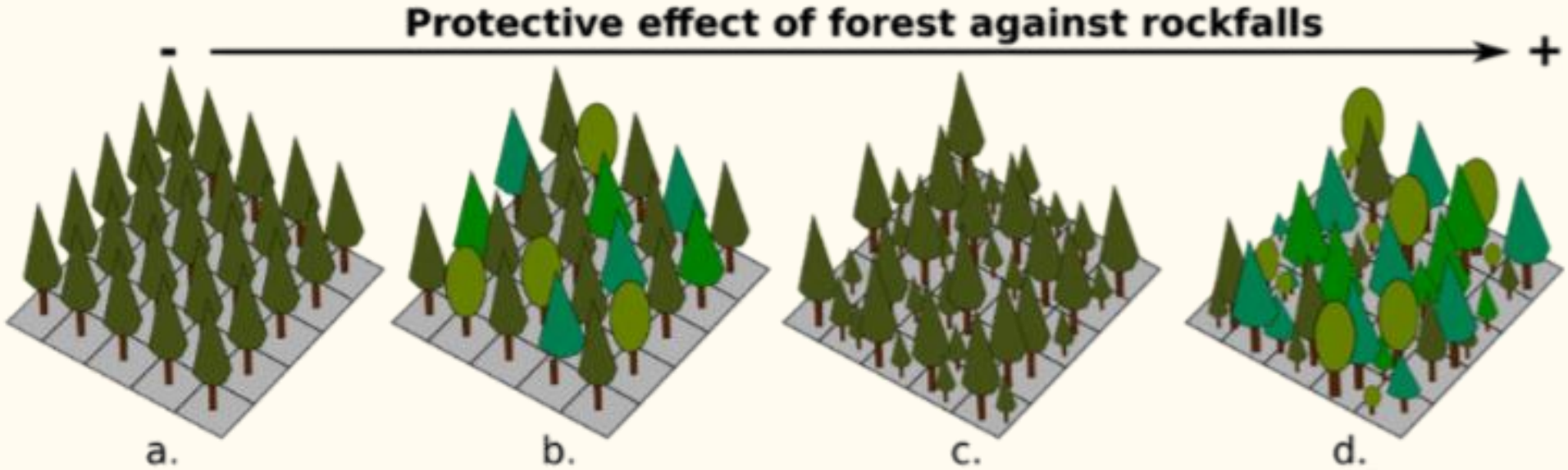
20% have a low protective effect :

600 m of forested slope are not sufficient to reach 99% of hazard reduction

Dupire S., Bourrier F., Monnet J.-M., et al. The protective effect of forests against rockfalls across the French Alps: Influence of forest diversity. Forest Ecology and Management - Vol 382 pp 269-279

How forests mitigate rockfalls

Which forest offers the best protection ?



a.	b.	c.	d.
Monospecific conifer - Regular structure (evenaged)	Mixed forest - Regular structure (evenaged)	Monospecific conifer - Irregular structure (unevenaged)	Mixed forest - Irregular structure (unevenaged)

Increasing the overall diversity (e.g. in both structure and composition) in a forest stand enhances the protective capacity.

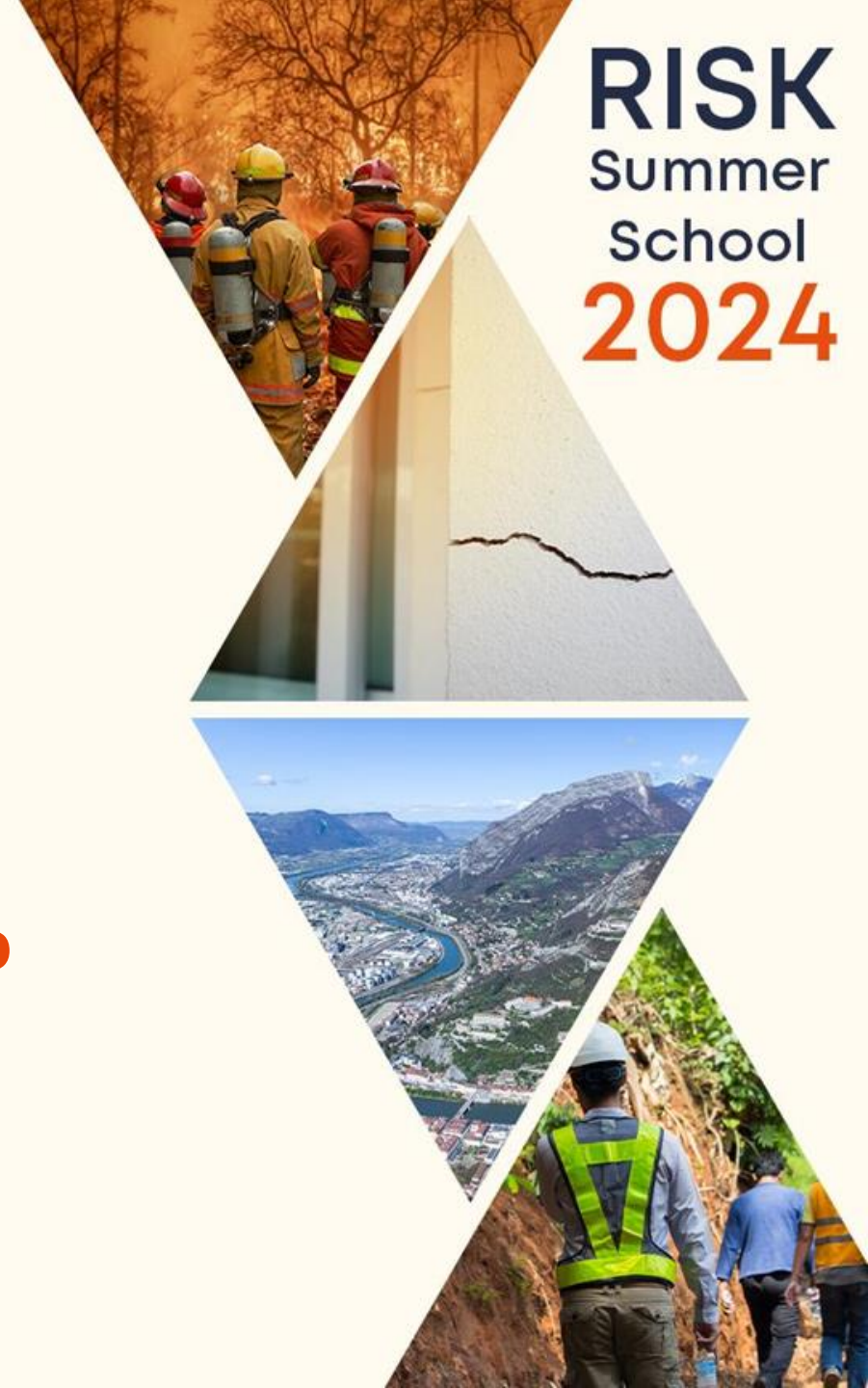
Dupire S., Bourrier F., Monnet J.-M., et al. The protective effect of forests against rockfalls across the French Alps: Influence of forest diversity. Forest Ecology and Management - Vol 382 pp 269-279

Presentation outline

1. Context

2. How forests mitigate rockfalls

3. **An efficient but vulnerable NBS due to Climate Changes**



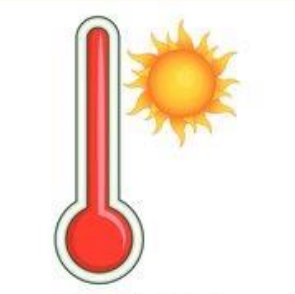
RISK Summer School 2024

An efficient but vulnerable NBS

Climate change increases the probability of disturbances in forest

Pests

Storm

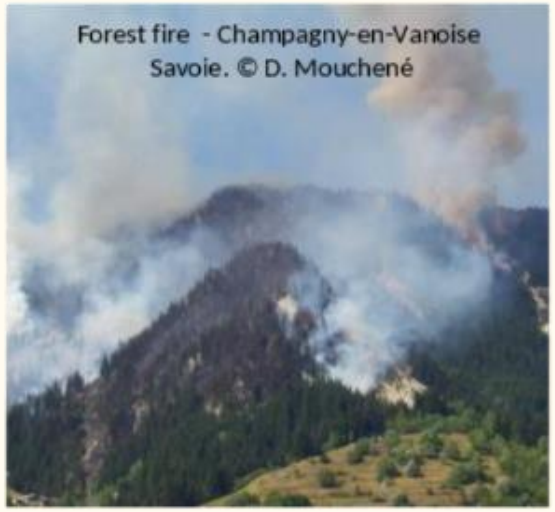


Drought

An efficient but vulnerable NBS

Climate change increases the probability of disturbances in forest

Summer 2003

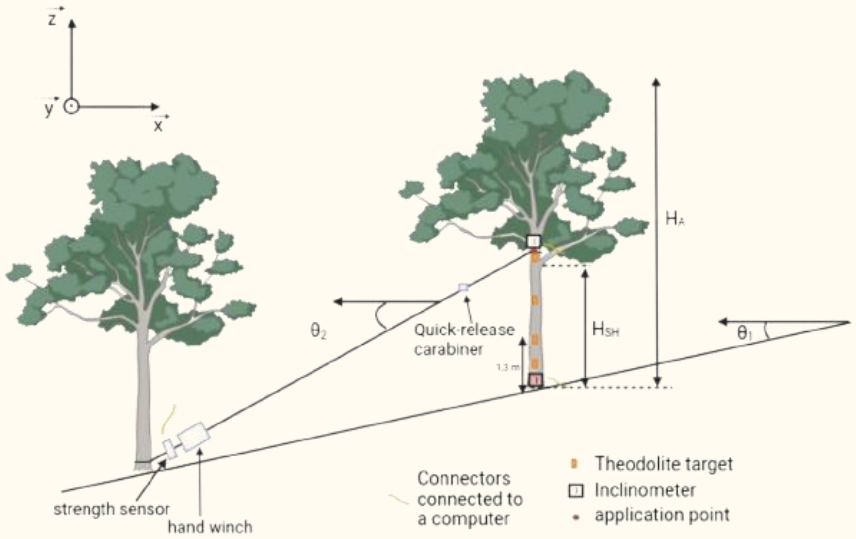


Summer 2022

An efficient but vulnerable NBS

Which impact of a disturbance on the mechanical properties of trees ?

Pull & Release experiments

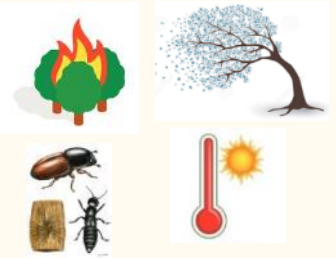


Direct measurements during pulling :

- **Root stiffness**
- **Trunk elasticity**

Indirect measurements of mass distribution (trunk + crown) during release

Comparison of mechanical parameters between disturbed and healthy trees

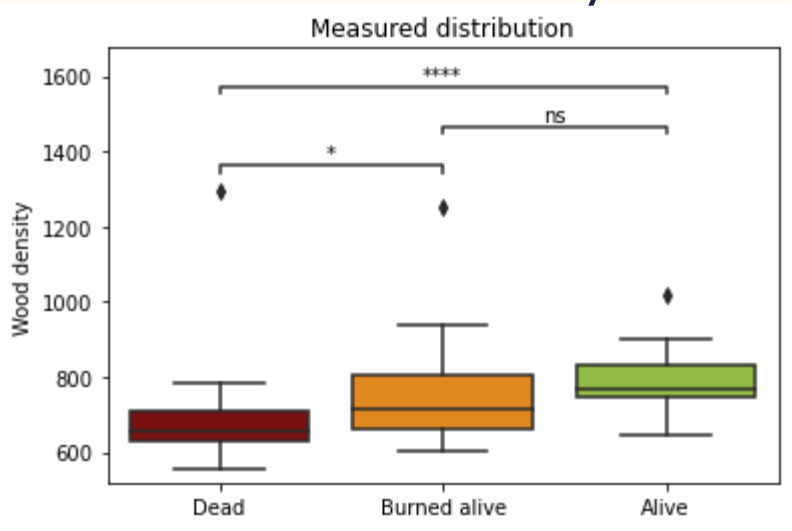


An efficient but vulnerable NBS

Which impact of a disturbance on the mechanical properties of trees ?

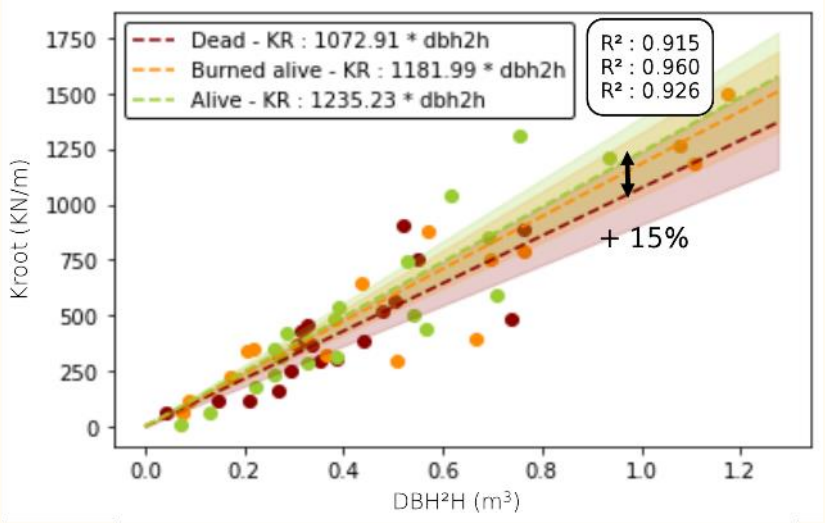
Fire influence (Villargondran fire, Summer 2022 : 69 trees, only Larch)

Wood density*



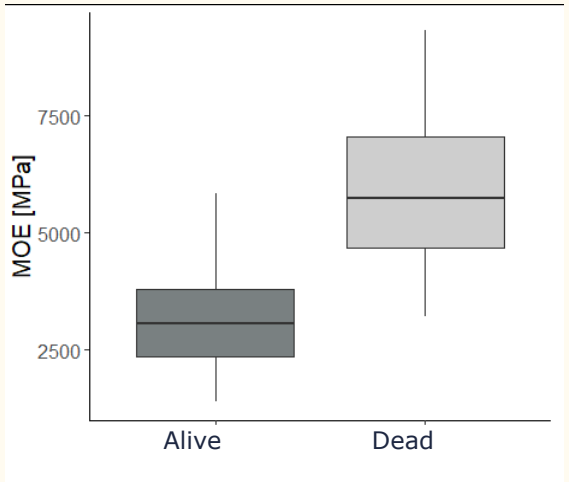
Decrease of density after fire
Less mass to oppose the rock

Root stiffness*



Decrease of root stiffness after fire
Easier to uproot the tree

Trunk elasticity*



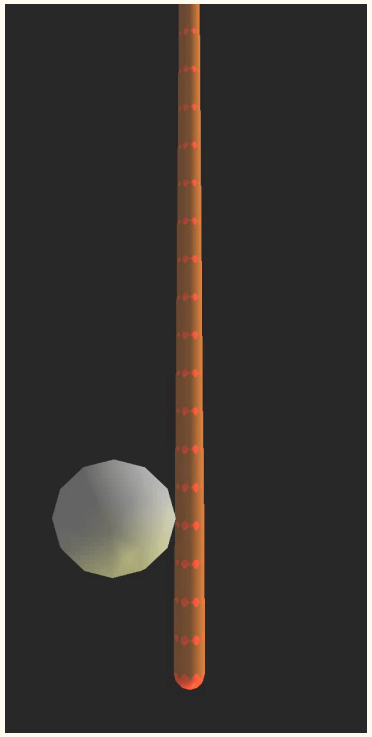
Increase of trunk elasticity after fire
Harder to break the trunk

*2 years after fire

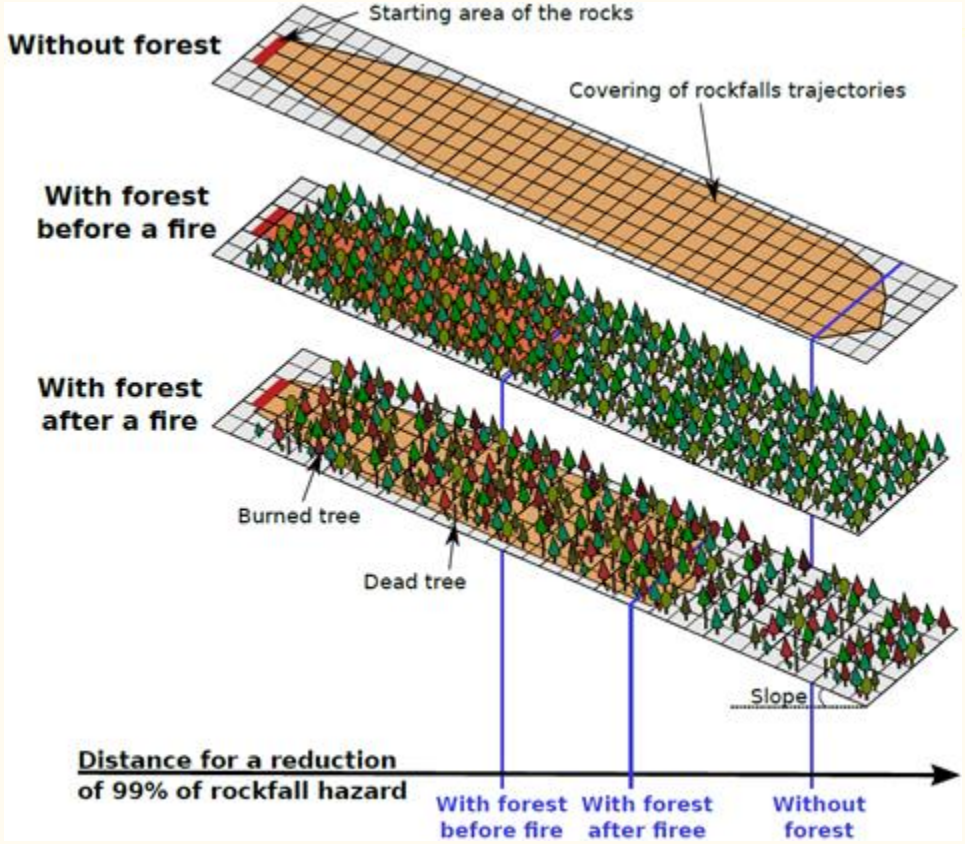
An efficient but vulnerable NBS

Which impact of a disturbance on the protective effect ?

Fire influence, next steps



Impact simulations with mechanical properties that change before/after disturbance



Rockfall simulations with different responses according to the “state of the tree”
Comparison of protective effect indicators before/after disturbances

Thank you for your attention

RISK Summer School 2024