

Dear Editor and Reviewers,

We sincerely thank you for your constructive and thoughtful comments on our manuscript. We greatly appreciate the time and effort invested in the review. We would also like to thank the Editor for the continuous effort in identifying suitable reviewers and guiding the manuscript through the review process.

A detailed point-by-point response to all reviewer comments is provided below. The indicated line numbers refer to the revised manuscript with marked changes. In addition to the changes made in response to the reviews, we made some minor corrections and updates to the manuscript that are unrelated to the reviewer comments:

- We corrected an error in Eq. (2), where $\mathbf{\hat{q}}$ and $\mathbf{u}$ had been mixed up.
- We updated the reference to Bührle et al. (2026), which was previously cited as a preprint and has since been formally published.
- We updated the Code and Data Availability statement. The original manuscript stated that the code would be published upon acceptance. The code has since been published and the statement has been revised accordingly.
- We corrected some grammar and typos (lines 19, 177, 252, 376)

The detailed responses to Reviewer 1 and Reviewer 2 follow below.

Reviewer 1

1. All figures could be improved. In the maps, some symbols are difficult to distinguish and would benefit from being thicker or more visible.

Answer: We have revised all figures with particular attention to the visibility of map symbols. We have increased the size of markers, use stronger outlines and apply higher-contrast colours. For the standing trees, which are currently shown to scale according to their DBH, we have added a clearly indicated scaling factor to make them more visible while preserving the relative differences in tree size (Figures 3, 4 and A1).

2. Lines 257–259: I appreciate that tree species is discussed first, but I would also suggest mentioning height above the ground, which is closely related to ground contact. This variable is especially interesting, though also challenging, because it may change during the first years after tree fall, for example as branches break. In addition, slope exposure could be worth considering: does a south-facing slope versus a north-facing slope make a difference? This may also be linked to differences in temperature and humidity.

Answer: We agree that height above ground is a potentially relevant factor that is often associated with, but not identical to, direct ground contact. We have expanded the discussion accordingly (lines 268–275). Although studies addressing a direct relationship between height above ground and decay rate are scarce, distance to the ground may affect local moisture conditions and accessibility for microbial colonisation, particularly at low heights and where dense vegetation, such as shrubs, tall herbs or grasses, surrounds the dead stems. This has, for example, been discussed and tested by Perez et al. (2022), who included sample distance to ground as a potential predictor of deadwood decay. While they did not find a significant effect, they noted that this variable was measured only at the time of sampling, although it is temporally variable, and that multi-year averages may better represent the conditions experienced by a log throughout the decay process. This is particularly relevant for our context, as branches may break and the stem may settle closer to the ground over time, potentially increasing moisture availability and contact with decomposer communities and thereby accelerating decay.

We have also added slope exposure as a relevant but complex site factor (lines 275–279). As correctly pointed out by the referee, exposure can influence both temperature and moisture, which may have opposing effects on decay rates. South-facing slopes may favour decay through higher temperatures and longer biologically active periods. However, they may also lead to faster drying of stems, potentially constraining decomposition, whereas north-facing slopes may favour decay through higher humidity and more favourable conditions for fungal activity (Bardelli et al., 2018).

References

- Bardelli, T., Ascher-Jenull, J., Burkia Stocker, E., Fornasier, F., Arfaioli, P., Fravolini, G., Alves Medeiros, L. R., Egli, M., Pietramellara, G., Insam, H., & Gómez-Brandón, M. (2018). Impact of slope exposure on chemical and microbiological properties of Norway spruce deadwood and underlying soil during early stages of decomposition in the Italian Alps. *Catena*, 167, 100–115. <https://doi.org/10.1016/j.catena.2018.04.031>
- Perez, S. B., Fraterrigo, J. M., & Dalling, J. W. (2022). Interspecific wood trait variation predicts decreased carbon residence time in changing forests. *Functional Ecology*, 36, 674–685. <https://doi.org/10.1111/1365-2435.13936>

Reviewer 2

1. Tree falls sometimes occur induced by rockfalls when a falling block fells a fresh stem. The original rockfall then loses parts of its kinetic energy and transfers it to the tree stem. How does this effect change the situation for the simulation and the hazard situation?

Answer: We agree that rockfall may represent an additional mobilisation mechanism. Unfortunately, observations of sliding deadwood events are scarce, and we are not aware of documented long-distance sliding events directly triggered by a rockfall felling a tree. The process is nevertheless plausible. As discussed in Sect. 6.1, mobilisation alone is not sufficient: low-friction conditions, steep terrain, and a suitable decay stage must coincide. A rockfall may therefore fell a healthy tree without causing substantial subsequent sliding, whereas impact on a sufficiently predisposed snag could provide the required mobilisation. Compared to the already mentioned mobilisation mechanisms, the transferred momentum would alter the initial condition/motion of the stem, but these triggering mechanics are not resolved by the present model, which idealises the initial conditions and focuses on runout after mobilisation, as discussed in the limitations section of the discussion. We clarify this point in the revised manuscript and explicitly include rockfall as a possible mobilisation mechanism. We renamed Sect. 6.5 to “Model limitations and remaining uncertainties” and discuss this aspect there together with the possible influence of branches raised in Comment 6 (lines 427-445). These two mechanisms remain plausible but cannot presently be evaluated systematically from the available observations.

2. Dead wood or also freshly cut trees are not only a danger but provide a certain protection from rockfalls till a certain degree of degradation. You already cited the work of Ammann (2006). Some more findings are to be found in e.g. <https://theses.hal.science/tel-05373164>

Answer: Thank you for pointing us to this very interesting work. In the revised manuscript, we have included the findings of Olmedo (2015) in the discussion on forest management recommendations (lines 386-389). In particular, the thesis provides a useful basis for our proposed measure of selectively felling and securing potentially hazardous trees across the slope, showing how such felled-tree structures can be configured to retain or enhance their protective effect against rockfall while preventing subsequent downslope mobilisation.

3. L36: could you add a short reference to section 2 that the reader knows that you will present the tree fall events in this section more closely?

Answer: Yes, thank you, we have added this reference (lines 38-39).

4. L122 : Can you add the orientation of the two tangential directions? I would have expected only one direction in parallel to the relative motion.

Answer: We have clarified the definition of the local contact frame in the revised manuscript (lines 126-131). The two tangential directions are mutually orthogonal and span the local tangent plane, while their absolute orientation within this plane is arbitrary for the isotropic spatial Coulomb friction law. During sliding, the resulting tangential contact force acts opposite to the relative tangential contact velocity within this plane.

5. L137+196: Have you checked the influence of a possible partial elastic restitution component? How large is it or is it really negligible? I can imagine that the impact of a rigid rock block into the ground is fully plastic but how does a stem react that – especially with a length of 25m – has a certain degree of bending flexibility?

Answer: Thank you for raising this interesting point. We agree that a long stem may exhibit substantial flexural deformation during impact and that this could influence its subsequent motion. Unfortunately, addressing this with the present model is not straightforward. The assumption of a normal restitution coefficient of zero was directly adopted from the underlying rockfall formulation. In the present nonsmooth rigid-body framework, Newton's impact law is a kinematic impact law relating the pre- and post-impact relative normal velocities. It is not a constitutive representation of the stem's flexural deformation. Simply increasing the restitution coefficient while retaining the stem as a rigid body would therefore not represent this flexural response and could instead introduce artificial rebound or bouncing behaviour. A more physically meaningful treatment could involve representing the sliding log as a deformable body capable of bending, storing strain energy, and subsequently releasing or dissipating part of this energy. Implementing such a formulation would require a substantial extension of the present rigid-body model and is unfortunately beyond the scope of this study.

Based on these considerations, in the revised manuscript, we have removed the reference to negligible elastic deformation from the description of the restitution coefficient, as this wording is misleading. Instead, we discuss stem flexibility explicitly as a limitation of the rigid-body formulation (lines 410-412). In the original manuscript, this limitation is discussed only with respect to the inability of the stem to break. We extend this discussion to note that long stems may also bend and temporarily store strain energy during impact, which may subsequently be dissipated or released again and thereby influence the post-impact translational and rotational motion.

6. It is mentioned several times in the article that the tree stem has no bark and branches. How do you reckon the influence of branches to enable the stem sliding downwards? The branches could act like skids of a slide? Further, the branches might keep the stem in the air preventing getting stuck in microtopographic ground?

Answer: This is an interesting thought. The idea that branches may keep parts of the log above the ground and thereby help it overcome small-scale roughness and obstacles is plausible. At the same time, branches introduce competing effects. We expect this mechanism to compete with the exceptionally low sliding resistance of a smooth, branchless, barkless and wet stem. In addition, branches may increase resistance through interlocking with terrain or obstacles (standing trees, deadwood), or even by penetrating soft ground. Given these competing effects, the influence of branches is therefore likely to depend strongly on terrain roughness, obstacles, forest density and branch or crown architecture.

Especially in forested terrain, one may expect branches to increase resistance due to the surrounding standing trees. For the events investigated here, we therefore still consider the very low sliding friction of smooth, barkless and wet stems to be the dominant factor. In these specific case studies, terrain roughness and discrete obstacles along the main sliding paths also appear to have played a secondary role compared with the low-friction ground contact. This does not prove that branch loss generally increases mobility, but it supports this interpretation for the presented events. At other sites with more pronounced roughness or obstacles, the balance between these effects may be different.

The effect may also depend on tree phenotype. More horizontally oriented branches and wider crowns could increase the likelihood of interlocking with rough terrain, whereas slender crowns with more downward-oriented or hanging branches may interact less strongly with the ground when the stem moves crown-first. Even within Norway spruce, the species observed in the

presented events, substantially different crown types occur, ranging from strongly hypotonic “comb” types to strongly amphitonic “plate” types, with corresponding differences in second-order branch orientation (Geburek et al., 2008). We therefore expect the net influence of branches to be both site- and tree-specific. Since all observed events in our study involved branchless stems, this provides an indication that branch loss may be relevant, but not sufficient evidence to establish a general causal relationship. In the revised manuscript, we have therefore added this discussion to Sect. 6.5 (lines 431-438), which, similarly to Comment 1, addresses plausible mechanisms that cannot be fully assessed from the available observations.

7. L180-182: Please, be careful, you are not directly calculating the probability. Here, you determine the relative frequency. Only, if N_{tot} is large enough, the relative frequency approaches the probability. To determine the necessary N_{tot} you have to consider variance/standard deviation etc. Currently, your simulations are more a random test/spot sample.

***Answer:** We have corrected the terminology (introduced in line 185) in the revised manuscript and refer to the quantity as the relative frequency, or equivalently an estimate of the corresponding reach probability for a finite number of simulations, rather than as the exact probability itself.*

8. g. L285: the blank after the degree-sign is missing a couple of times in the manuscript.

***Answer:** We have added the correct blank spaces in the revised manuscript.*

9. L249-297: This finding could be very important for the whole rockfall simulation “world”. A forest is not fully randomly distributed in the terrain but follows certain topographical laws. Could this be a significant improvement for current models?

***Answer:** Thank you for highlighting this potentially broader implication. Our results suggest that the spatial correlation between forest structure and terrain-controlled preferential process paths may also be relevant for rockfall modelling, as rocks, similarly to sliding deadwood, tend to follow preferential paths controlled by the terrain. We have added a cautious statement on this aspect to the discussion of the revised manuscript (lines 327-331), as further research is required before drawing general conclusions. This represents an interesting direction for future work, particularly as increasingly detailed forest data and established methods for detecting individual tree locations and forest structure now provide the basis for systematically assessing this effect. For elongated deadwood objects, this effect plays an even more important role, since once the stem is deflected by a tree, it cannot simply pass around subsequent trees alternately on the left and right.*

10. L327: Stem impacts into net not only depend on the danger that a stem might slip through the mesh of the primary net. Moreover, they load the impact area more than a normal block due to the concentrated front area.

***Answer:** Thank you for this addition. We have expanded the discussion of impacts on rockfall barriers in the revised manuscript (lines 354-356) to note that approximately longitudinal impacts may concentrate the load over a relatively small frontal area and therefore produce a more localised loading of the net than typical block impacts.*

11. Have you studied the influence of the DEM resolution on the sliding performance of the investigated trees? Especially, because you do expect the friction coefficient to be dependent on the DEM resolution.

Answer: *We have not systematically investigated the influence of DEM resolution on the sliding behaviour in the present study. However, a short sensitivity test for the Gruobenwald case study showed that the relative reach frequency of the national road increased from 9.1% for the 0.5 m DEM to 9.5% for a 2 m DEM and 18% for a 5 m DEM when using the same friction coefficient of 0.25. This supports our expectation that runout and reach can increase with decreasing DEM resolution because progressively more microtopographic roughness is smoothed out. We have added these results to the revised manuscript to illustrate the potential magnitude of this effect (lines 256-259), but refrained from deriving a general relationship between DEM resolution and sliding behaviour, as the sensitivity is expected to depend strongly on the roughness present at a given site. For Gruobenwald specifically, the results suggest that the loss of relevant terrain detail occurs between 2 and 5 m resolution, while a 2 m DEM still reproduces the 0.5 m result closely.*

References

- Geburek, T., Robitschek, K., and Milasowszky, N.: A tree of many faces: Why are there different crown types in Norway spruce (*Picea abies* [L.] Karst.)?, *Flora – Morphology, Distribution, Functional Ecology of Plants*, 203, 126–133, 2008. <https://doi.org/10.1016/j.flora.2007.01.003>
- Olmedo Manich, I.: Felled trees as rockfall protection devices : Experimental and numerical studies for design purposes, *Theses, INSA de Lyon*, 2015. <https://doi.org/10.70675/b09b0561z2d0fz4887z8171zbed7af26793d>