Landslides in cultural landscapes: legacy effects of land-use in a centennial perspective

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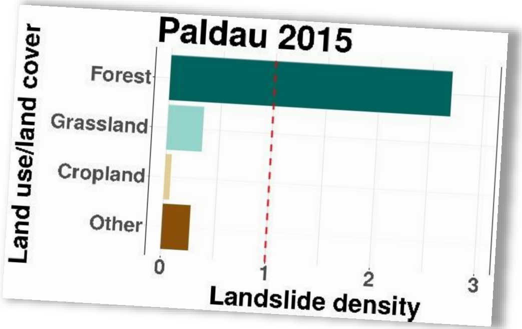
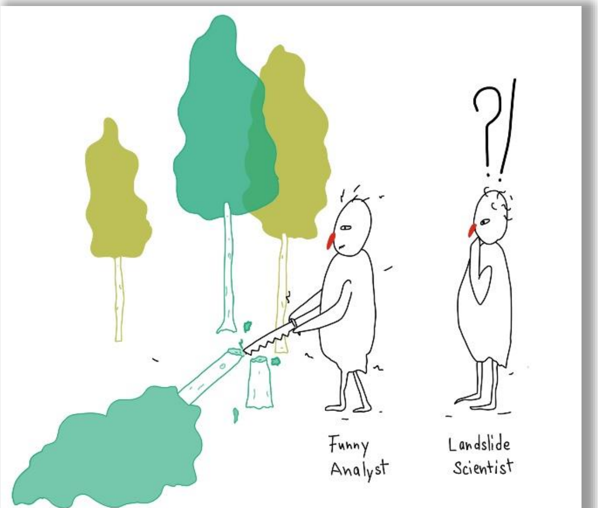
High landslide density under recently forested areas!

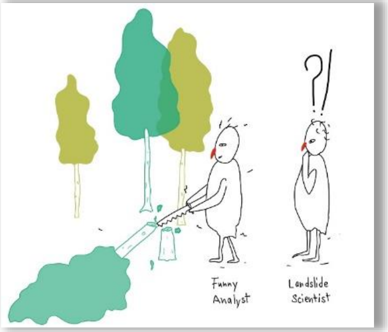
… considering historical LiDAR-derived inventory





Cutting down trees?

- Looking back into the land-use/land-cover since the 18th century
- Investigated three time points (1820, 1960, 2015)
- Modelling landslides with land-use legacies and local topography
- 2 study areas in Austria (Waidhofen & Paldau)



What does the model tell us?

----> Visit our PICO at screen PICO1.12 ☺

Landslides in cultural landscapes: legacy effects of land-use in a centennial perspective

Knevels et al.

Navigation

[click for more information]

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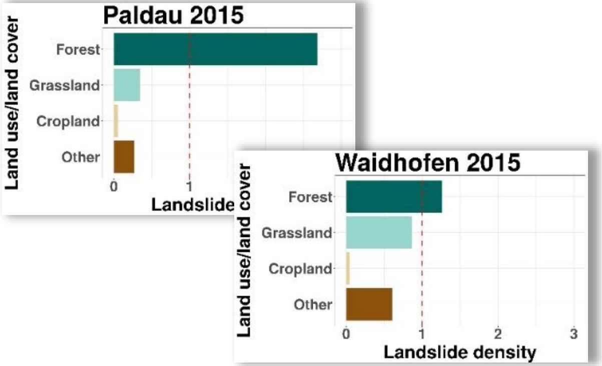
LiDAR-derived inventories often show a surprisingly high landslide density particularly in forested areas. This apparent contradiction underlines the need to better understand the factors explaining landslide occurrence in cultural landscapes. We hypothesize that land-use legacies may be a previously-neglected explanatory factor.

The **objective** of this study was to assess relationships between landslide occurrence and land-use legacies (until 1820) while also accounting for geomorphological and lithological conditions as possible confounders.



Study Area and Data

- Study areas Paldau and Waidhofen located in the alpine fringe region, Austria

- Input data …
  - LiDAR DTM (1 x1 m resolution) and its derivatives
  - Lithology and soils
  - Land-use legacy (1820 – 1960 – 2015):
    - Biomass removal
    - [Soil compaction]
    - Mean distance to forest border
    - Land-use/land-cover change: current forest, deforestation, afforestation

- Historical landslide inventory based on LiDAR DTM
  - Different polygons for landslide body and scarp

- Sampling design (trivial area, spatial auto correlation, scarp points)
- Landslide susceptibility modelling using generalized additive model (GAM)

Model performance

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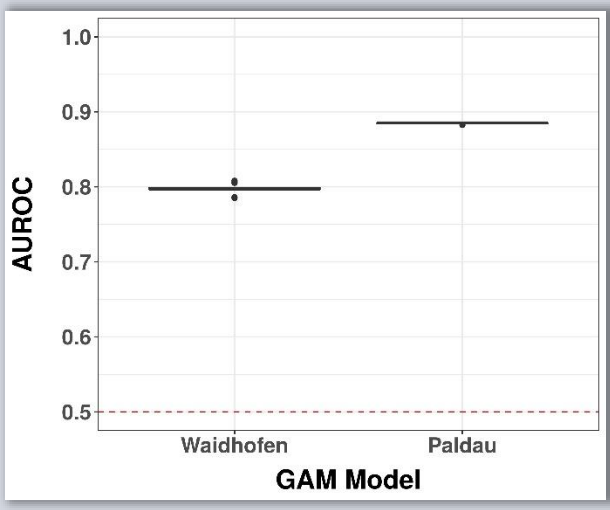
- Assessment using the area under the ROC curve (AUROC) estimated by 5-fold spatial cross-validation with 100 repetitions
- Paldau: 0.89 median AUROC
- Waidhofen: 0.80 median AUROC



- Sampling design (trivial area, spatial auto correlation, scarp points)
- Landslide susceptibility modelling using generalized additive model (GAM)

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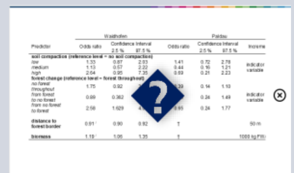
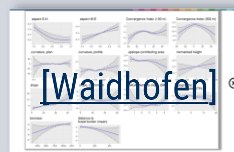
Explanatory power of predictors

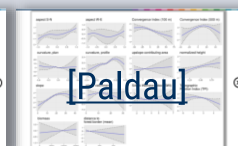
- Mean decrease in deviance explained

- Odds ratios of land-use legacy variables (and other)



- Component smooth functions of numerical variables


[Waidhofen]


[Paldau]

- Sampling design (trivial area, spatial auto correlation, scarp points)
- Landslide susceptibility modelling using generalized additive model (GAM)

Key findings

- **Waidhofen:**
  - Afforested areas have a 2.4-times higher chance of landslide occurrence than not afforested areas.
  - The chance of landslide occurrence in current forest areas is 0.6-times less than in current non-forest areas.
  - Areas with a higher mean distance to the forest border show a lower chance of landslide occurrence (50 m: 0.94 | 100 m 0.87 | 300 m: 0.52).
  - Areas with a higher biomass removal show a higher chance of landslide occurrence (from 4000 kg FW/ha: 1000: 1.23 | 4000: 2.3 | 8000: 5.35).

- Sampling design (trivial area, spatial auto correlation, scarp points)
- Landslide susceptibility modelling using generalized additive model (GAM)

Key findings

- **Paldau:**
  - Deforested areas have a 2.2-times higher chance of landslide occurrence than not deforested areas.
  - The chance of landslide occurrence in current forest areas is 4.7-times higher than in current non-forest areas.

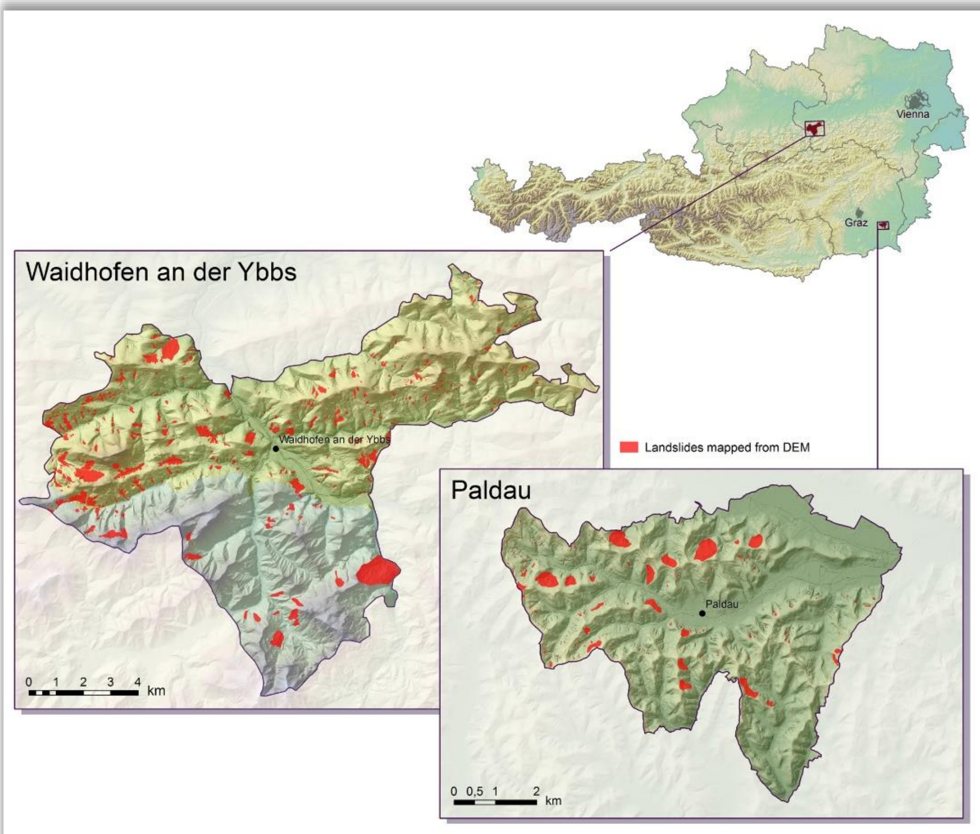
Conclusion

- Integration of land-use legacy as predictors enhances the model fit
  - BUT slope is the most important variable

- Each study must be modelled and explained individually due to different underlying cultural landscape change

- Bias in historical inventory ("landslides in forest areas") can not be completely eliminated -> implementation of land-use in modelling with care!

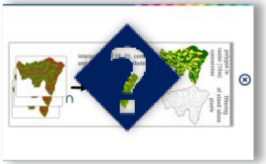
- Result has the potential to assess implications of future land-use change for landslide occurrences


Vienna
Graz
Waidhofen an der Ybbs
Waidhofen an der Ybbs
0 1 2 3 4 km
Landslides mapped from DEM
Paldau
Paldau
0 0,5 1 2 km

Terrain attributes	Land-use/land-cover	Social-ecological indicator	Other
Aspect (N-S, W-E)	Land-use/land-cover change classes	Biomass removal	Lithological units
Convergence Index (100m, 500m)	*current forest area*	[Soil compaction]	Total pore volume
Curvature (plan, profile)	*deforestation*		Water conductivity
Normalized height	*afforestation*		
SAGA Wetness Index	Mean distance to forest border		
Slope			
Slope, catchment			
Topographic Position Index			
Upslope contributing area			

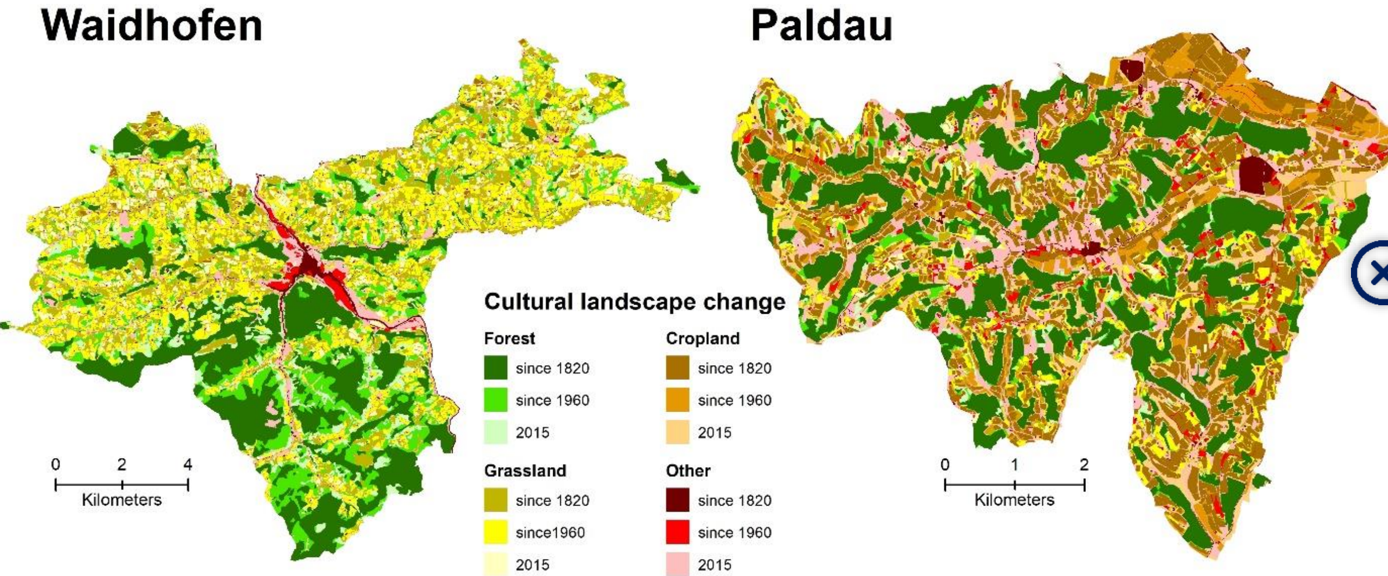
- GIS vector database for 1820, 1960, and 2015
  - Land-use/land-cover: Forest, cropland, grazing land, and other land
  - archival sources and statistical publications
    - 1820: Franciscan Cadastre
    - 1960: aerial photographs
    - 2015: InVeKoS data combined with aerial orthophotos
    - yields and livestock information
  - Digitized at scale 1:1000
  - Positional error estimates: 1820: 3-5 m; 1960: 5-10 m; 2015: < 3 m

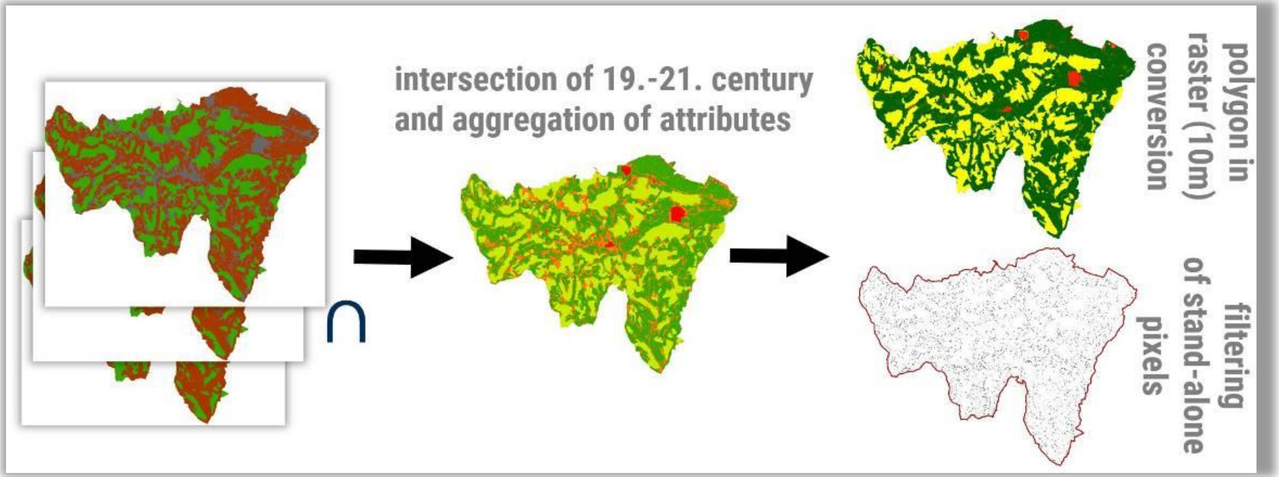
[Cultural landscape change map]



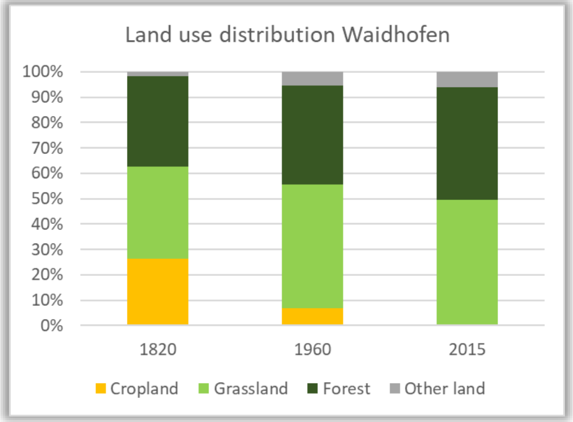
[Creation of legacy rasters]

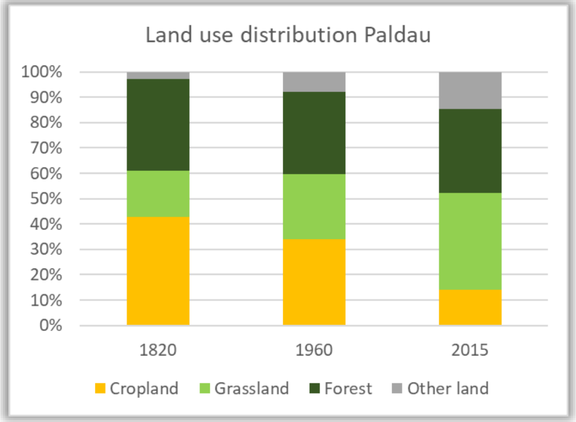
[Change statistics]

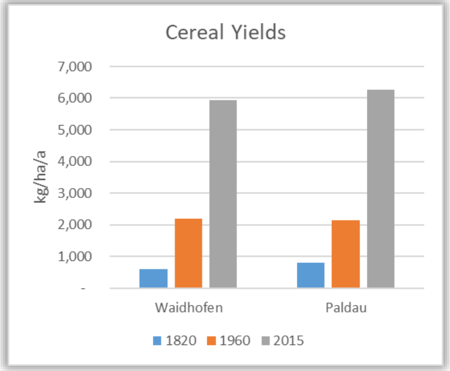

Waidhofen
Paldau
Cultural landscape change
Forest
since 1820
since 1960
2015
Cropland
since 1820
since 1960
2015
Grassland
since 1820
since1960
2015
Other
since 1820
since 1960
2015
0 2 4
Kilometers
0 1 2
Kilometers

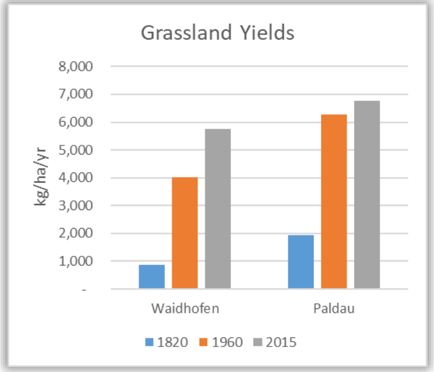

intersection of 19.-21. century
and aggregation of attributes
∩
polygon in
raster (10m)
conversion
filtering
of stand-alone
pixels

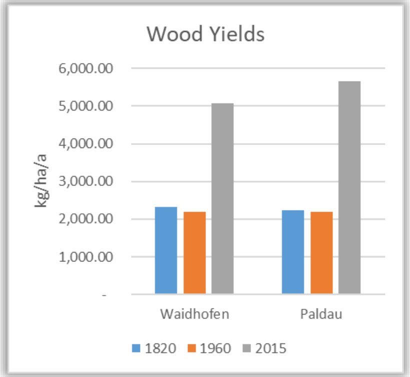
Study Area and Data

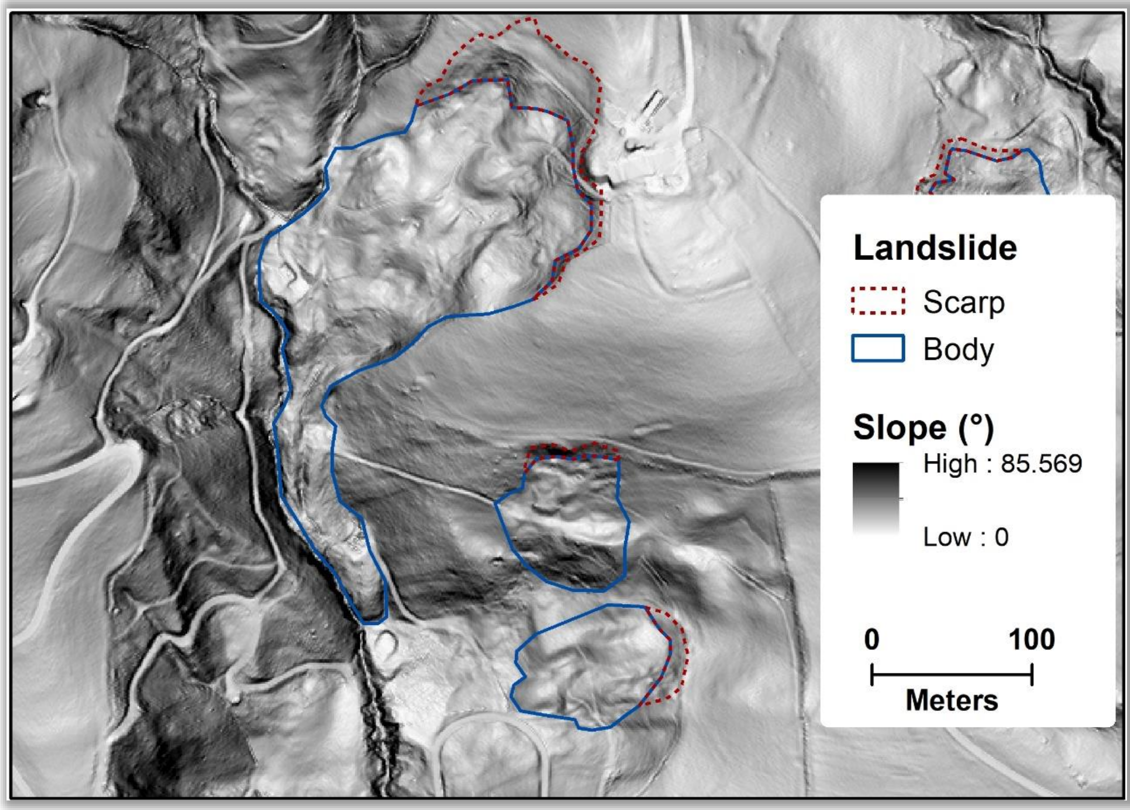




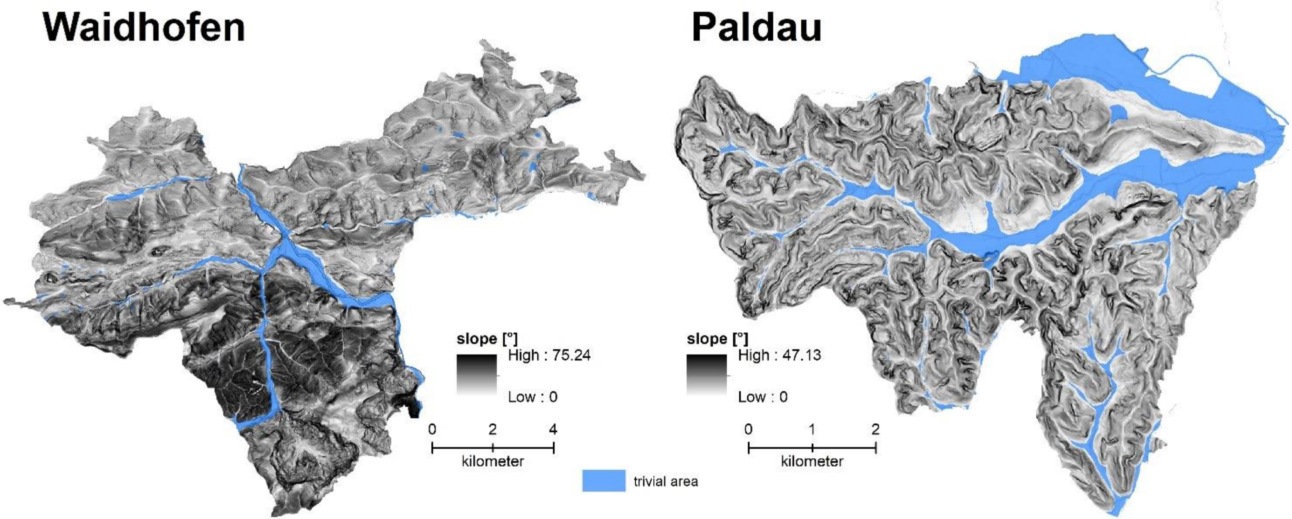




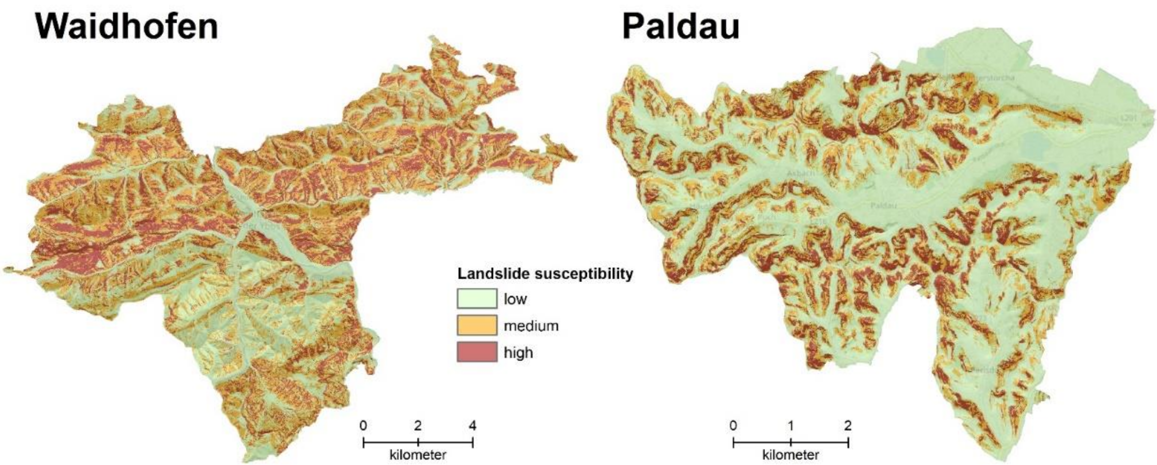



Landslide
Scarp
Body
Slope (°)
High : 85.569
Low : 0
0
100
Meters

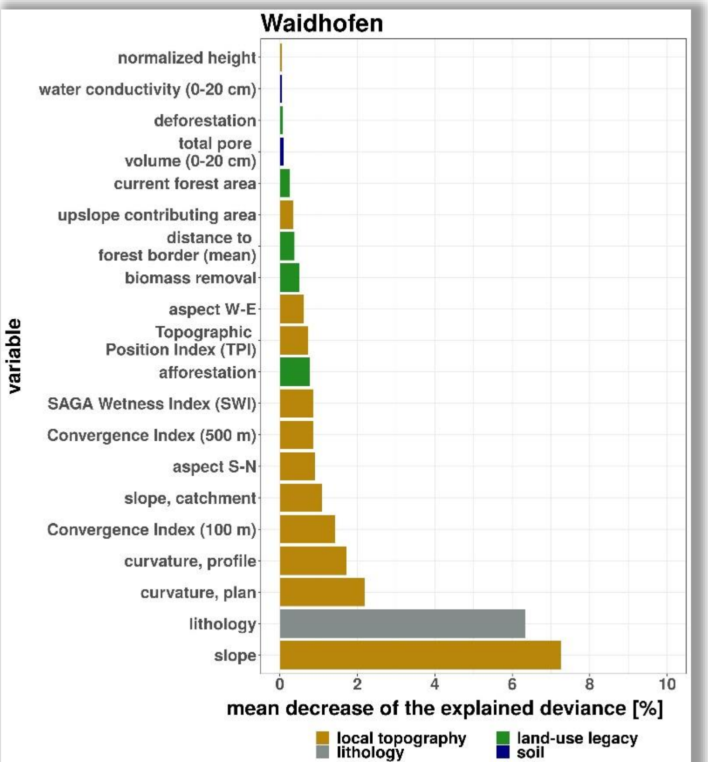
- Landslide presence samples are located in the landslide scarp
- Landslide body is masked for landslide absence samples
- Reduction of spatial auto-correlation effects by using minimum distance constraint of 50 m between sampling points
- Masking of so-called trivial area by using the lithological unit of alluvial deposits to reduce bias in modelled relationships

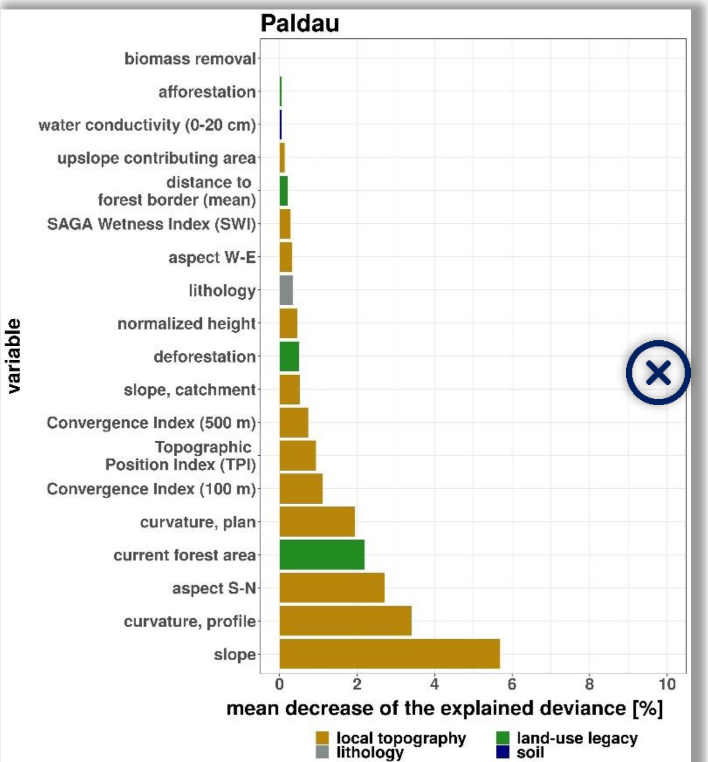


- Inventory ~ local topography + land-use legacy + lithology + soil
- Landslide susceptibility classification:
  - low susceptibility class contains 5 % of the observed landslides
  - medium susceptibility class contains 25 % of the observed landslides
  - high susceptibility class contains 70 % of the observed landslides
- Proportion of the high susceptibility class area: Waidhofen: 23.52 % | Paldau: 13.07 %



Method and Results





Predictor	Waidhofen Odds ratio	Waidhofen Confidence Interval 2.5 %	Waidhofen Confidence Interval 97.5 %	Paldau Odds ratio	Paldau Confidence Interval 2.5 %	Paldau Confidence Interval 97.5 %	Increment
Current forest area (reference level = current non-forest area)							
	0.60*	0.41	0.90	4.71***	2.87	7.71	indicator variable
Deforestation (reference level = no deforestation)							
	0.81	0.52	1.26	2.25**	1.30	3.87	indicator variable
Afforestation (reference level = no afforestation)							
	2.42***	1.59	3.68	0.76	0.37	1.55	indicator variable
Mean distance to forest border (reference value = 0 m)							
	0.94*	0.92	0.97	1.00	1.00	1.00	50
	0.87*	0.85	0.90	1.00	1.00	1.00	100
	0.52*	0.48	0.57	1.00	1.00	1.00	300
Biomass removal (reference value= 4000 kg FW/ha)							
	1.23***	1.12	1.36	1.00	1.00	1.00	1000
	2.31***	1.67	3.19	1.00	1.00	1.00	4000
	5.35***	3.83	7.48	1.00	1.00	1.00	8000

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.*

[Odds ratios lithology]

Waidhofen

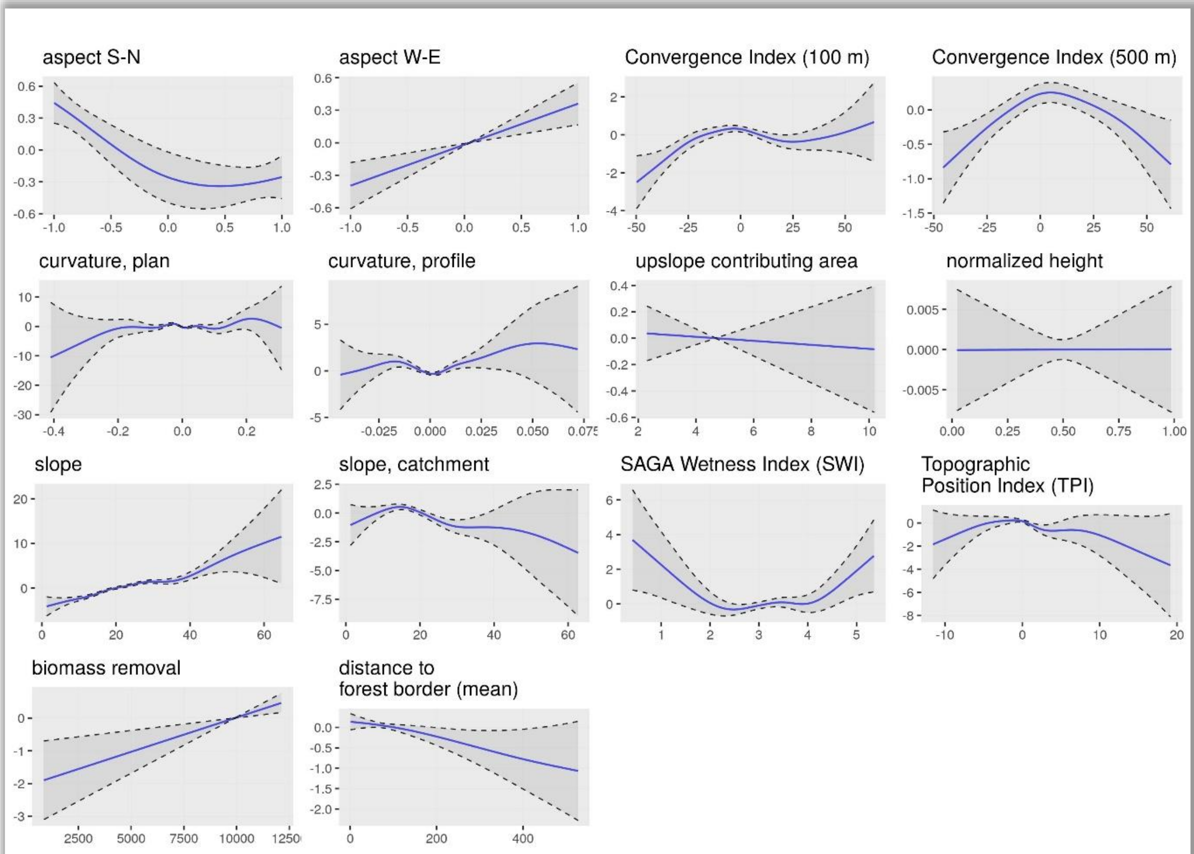
Predictor	Odds ratio	Confidence Interval 2.5 %	Confidence Interval 97.5 %	Increment
Lithological unit (reference level = Oberostalpine Lime)				
*Talus & glacial deposit****	36.91	13.08	104.11	indicator variable
*Inneralpine Neogen****	132.81	32.53	542.23	
*Klippen Zone****	66.66	31.53	140.91	
*Flysch Zone****	13.30	7. 27	24.34	
*Oberostalpine Marl****	7.07	4.00	12.51	

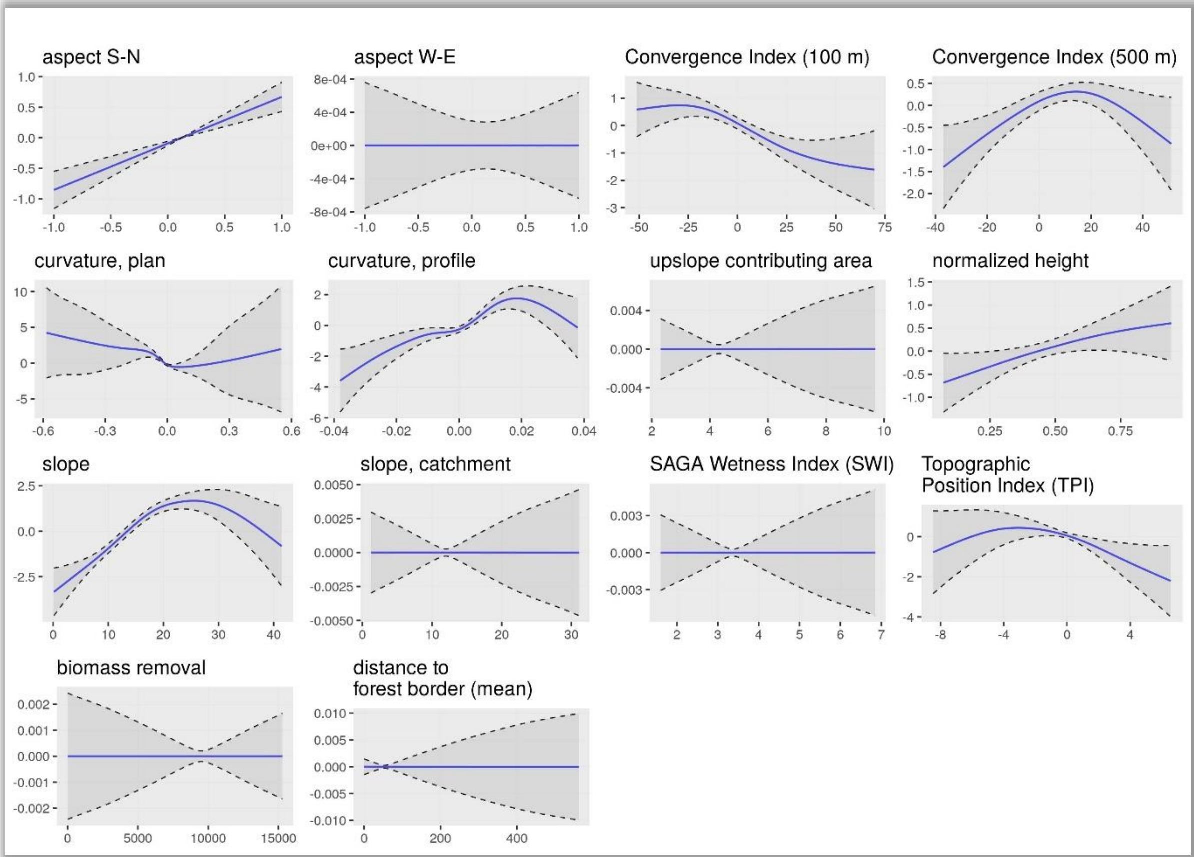
*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.*

Paldau

Predictor	Odds ratio	Confidence Interval 2.5 %	Confidence Interval 97.5 %	Increment
Lithological unit (reference level = Tertiary)				
Quaternary Rutschhang, tertiary Clay Marl	0.86	0.55	1.35	indicator variable
Quaternary High Terraces & Higher Terraces	0	0	Inf	

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.*


aspect S-N
aspect W-E
Convergence Index (100 m)
Convergence Index (500 m)
curvature, plan
curvature, profile
upslope contributing area
normalized height
slope
slope, catchment
SAGA Wetness Index (SWI)
Topographic
Position Index (TPI)
biomass removal
distance to
forest border (mean)


aspect S-N
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Convergence Index (100 m)
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curvature, plan
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