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Dendrogeomorphological determination of the frequency of rockfalls at Solà d'Andorra (Andorra Principality): sampling strategies and completeness of the record

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A major challenge in the quantitative analysis of risk of rockfalls is to get the frequency of the events. Dendrochronology has proved its efficacy to date several types of mass movements, including rockfalls. We applied this technique to the study of the Solà d'Andorra (Eastern Pyrenees, Andorra), a rock slope with high relief and with a face length greater to a thousand meters. This site is especially interesting for a dendrogeomorphological analysis: a) rockfall risk is obvious because a town is located at the lowest part of the slope; b) a dense forest is available at the talus slope formed at the base of the cliff (forest density ranges from 900 to 2700 trees/Ha); c) there exists a historic record of rockfalls events, which allowed a comparison with the results obtained from tree-rings.

Broad-leaved species (*Quercus robur*, *Quercus pubencens*, *Quercus ilex*) form the 99% of the forest colonizing the talus slope. The practical absence of coniferous trees (which amount only the 1%) prevented the use of reaction wood or resin ducts for dating. Dating was carried out in most of the cases using wound scars visible on the stem surface. Results were obtained with a seasonal resolution (dormant and growth season).

Three sampling strategies have been applied in successive steps, representing each

one a more detailed work. Several gullies cut the rock slope and feed talus cones. The first strategy consisted in sampling a stripe of forest at the apex of some cones. Each sampling stripe was arranged parallel to the contour lines and comprises a forest band of 15 to 20 m of width. All the rockfall events witnessed by local inhabitants were also detected by tree-ring analysis. Nevertheless, the presence of treeless tracks in some of the talus apex suggested the probable missing of some rockfall events.

The second strategy we applied was to sample in several stripes across a same talus slope at increasing distances from the cliff face. Results obtained using this latter method confirmed that some events were not recorded at the upper part of the talus. These data show also the change of the rockfall frequency slope down the talus and allowed a rough estimation of the run out of rockfall events. A question that remained unsolved was whether the width of the sampled stripes was sufficient to get a complete record of the rockfalls which hit the trees located on the talus slope. The third strategy was addressed to clarify this question; it involved the sampling of all the trees showing injuries in one of the talus cones. The results of this latter approach indicate that, for a forest with a average tree diameter (DBH) of about10 cm, the width of the sampling stripes should not be less than 15 m if the forest density is of 2000 trees/Ha or less than 20 m if the density is less than 1000 trees/Ha.