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Research paper

Defining optimal sample size, sampling design and thresholds for dendrogeomorphic landslide reconstructions

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ABSTRACT

Trees affected by mass movements record the evidence of geomorphic disturbance in their growth-ring series, and thereby provide a precise geochronological tool for the reconstruction of past process activity. At the tree scale, identification of past mass movements was typically based on the presence of growth anomalies and focused on the presence of scars, tilted or buried trunks, as well as on apex decapitation. In terms of sampling strategy, however, clear guidelines have been largely missing. Most previous work was based either on the sampling of visibly disturbed trees irrespective of their position at the study site or on the systematic sampling of trees evenly distributed along transects. Based on a dense dataset of 323 trees growing on an active landslide body, this study aims at defining guidelines for future tree-ring sampling of landslides. Using random extractions of trees and iterative mapping, we investigate subsets of the full tree-ring sample to define optimal sampling strategy, sample depth and trees for the development of frequency maps of landslide reactivations. We demonstrate that (i) the sampling of 50–100 trees can be sufficient to obtain satisfactory results on landslide frequency without including noise to the dendrogeomorphic record; (ii) increasing growth disturbance thresholds should be adjusted to sample size and are preferable to fixed values; (iii) an even distribution of sampled trees is crucial to increase the reliability of frequency maps, even more so if the reconstruction is based on small sample sizes; and that (iv) the selection of the most frequently disturbed trees is key to reduce uncertainties in the frequency maps. The optimization of sample sizes and the adjustment of sampling strategy will not only facilitate fieldwork and render analyses and interpretation more reliable, but will also ultimately allow reconstruction of time series of past mass movements with reasonable temporal efforts and excellent cost-benefit ratios.

1. Introduction

Dendrochronology is one of the most accurate and precise dating methods in geochronology (Stahle et al., 2003), and has also been demonstrated to represent a valuable recorder of mass movement activity (Alestalo, 1971; Stoffel et al., 2010, 2013; Stoffel and Corona, 2014). Growth-ring series of disturbed trees have been used widely for the reconstruction of time series of various types of geomorphic (e.g., McAuliffe et al., 2006; Stoffel et al., 2008, 2012; Bollschweiler et al., 2009; Lopez Saez et al., 2012a,b; Osterkamp et al., 2012), hydrologic (St. George and Nielsen, 2002; Ballesteros et al., 2011a,b; Stoffel and Wilford, 2012), and geologic (Jacoby et al., 1988; Salzer and Hughes, 2007; Baillie, 2008; Bekker, 2010; Stoffel et al., 2005, 2011; Corona et al., 2012) processes. In addition, dendrogeomorphic data has been demonstrated to permit an accurate mapping of both past events and return periods (e.g. Stoffel et al., 2005; Corona et al., 2010; Lopez Saez et al., 2012b).

Recent advances in dendrogeomorphic research have demonstrated that an appropriate sampling design and size (Schneuwly-Bollschweiler et al., 2013; Trappmann et al., 2013) is indeed key to improve reliability as well as traceability of results, even more so if data is used for hazard assessments and disaster risk reduction. To date, sampling strategies focused typically on trees with visible growth defects and related growth disturbances (GD) in the tree-ring record. Guidelines for the tree-ring sampling of tilted or

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buried trunks, impact scars or trees with decapitated apices were defined at the tree scale (Stoffel and Bollschweiler, 2008) and different types and intensities of reactions have been given different weight in reconstructions (see Stoffel and Corona, 2014 for a recent review). In addition, recent work has shown quite clearly that tree selection as well as an adequate mixture of tree species and age classes are in fact fundamental for the reconstruction of well-balanced and minimally biased time series of past mass-movement activity (Trappmann and Stoffel, 2013; Stoffel et al., 2013; Corona et al., 2012).

Yet, at the slope scale, no clear rules exist as of today on how and where to realize tree-ring sampling (in terms of sampling design) and on how many samples to take (i.e. sample size). A vast majority of past studies was based on either random sampling of trees with visible growth defects (Stoffel et al., 2010; Corona et al., 2010) or on the systematic sampling along transects (Schneuwly and Stoffel, 2008; Trappmann and Stoffel, 2013; Schläppy et al., 2013). In addition, the influence of the spatial distribution of sampled trees on the quantity and quality of mass-movement reconstructions has never been tested objectively, but has, at best, been considered as a subjective exclusion criterion in past work (Lopez Saez et al., 2012b, 2013; Schneuwly-Bollschweiler et al., 2013).

As a logical consequence of largely differing sample design and size, considerably varying thresholds have been suggested in the past to distinguish signal (events) from noise (non-events). Some authors have dated past mass-movement activity based on one single GD in just one tree, whereas others only accepted event years where 40% of all trees sampled showed GD (Butler et al., 1987; Butler and Sawyer, 2008). Differences in thresholds will not only yield substantially different times series of events, but have also given rise to repeated and contentious discussions on the value, accuracy and completeness of dendrogeomorphic dating and, thus, call quite clearly for the definition of more objective standards and guidelines on how and where to sample and on how to interpret results.

In this paper, we therefore propose a more objective means for the determination of the best sampling design and the definition of optimal sample sizes and thresholds. Based on an event chronology derived from a large set of trees affected by landslide reactivations in the southern French Alps, we (i) test different subsets of trees and (ii) calibrate thresholds for sample size and index values (i.e. percentage of responses relative to the number of trees alive in a given year) to obtain optimal signal-to-noise ratios in reconstructions. We then (iii) characterize the optimal spatial configuration of trees to be sampled on the landslide body using random bootstrap extraction. In a final step, we (iv) characterize trees (in terms of age, number of GD, frequency of GD) involved in each optimal subset so as to facilitate the selection of optimal trees in future reconstructions.

2. Study site

The Pra Bellon landslide (44°25′ N., 6°37′ E., Fig. 1a) is located in the Riou-Bourdoux catchment, a tributary of the Ubaye River located on the N-facing slopes of the Barcelonnette basin (Alpes de Haute-Provence, France). The Riou-Bourdoux catchment has been

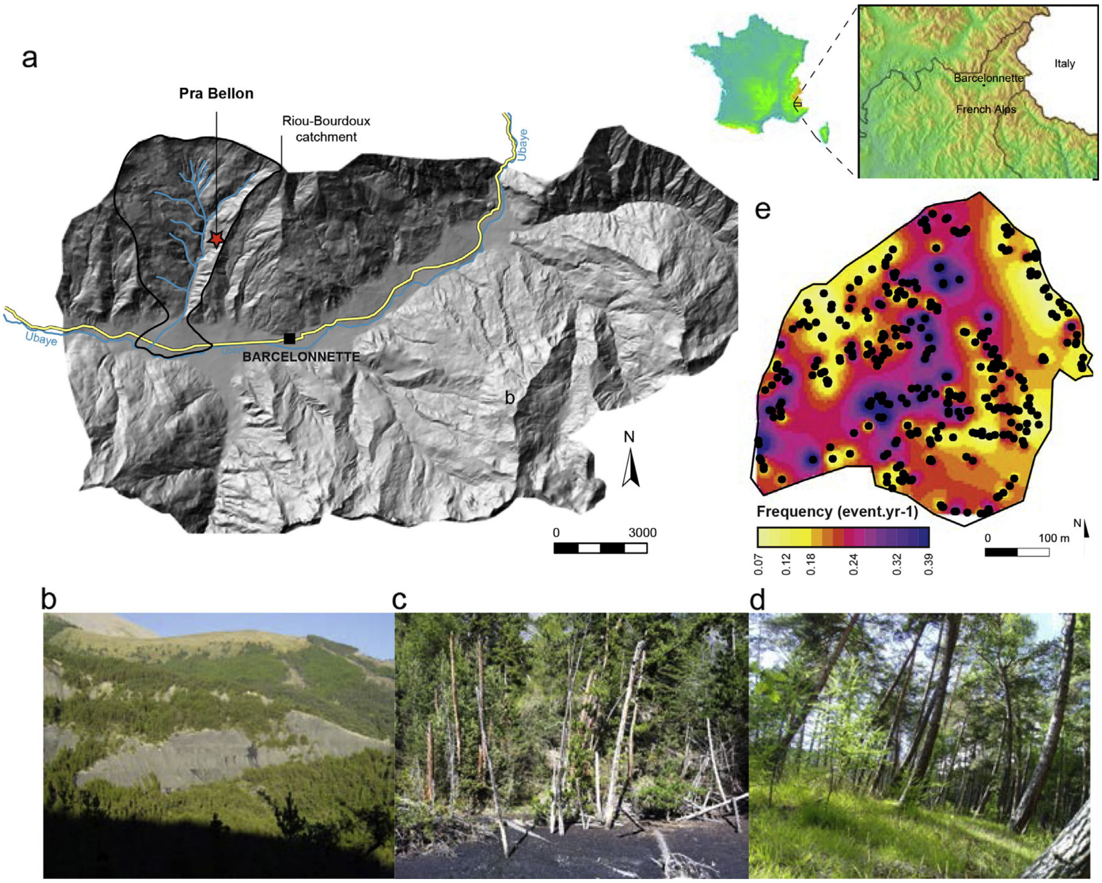

Fig. 1. (a) The Pra Bellon landslide is located in the Ubaye valley (southern French Alps), near the village of Saint-Pons. (b) View of the two mains scarps (SC1 and SC2) of the landslide body. (c) Buried and (d) tilted Mountain pine (*Pinus uncinata*) trees were used to reconstruct past landslide activity. (e) Interpolated frequency maps for the sampled area of the Pra Bellon landslide computed from growth disturbances observed in 323 trees.