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Response of anatomical structures in tree roots to an erosion event on the southeastern Tibetan Plateau

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ABSTRACT

Exposed roots have been used in dendrogeomorphology to determine erosion rates. However, few studies have focused on the changes in ring width and in the anatomical properties of hardwood roots exposed by soil erosion at a macroscopic and microscopic level. In this study, we identified the ring width and the anatomical response of hardwood root to a denudation event and applied these anatomical findings to the reconstruction and quantification of soil erosion rates. A total of 136 cross sections (54 from buried roots and 79 from exposed roots of 25 trees) were sampled in the study area. Measurements of the widths of the growth rings, the average vessel area in earlywood, the average vessel area per ring, and the vessel number per ring were performed with WinDENDRO and ImageJ. Our results show that the analysis of vessel features is a useful tool to identify soil erosion events recorded during the life of a tree. A sharp decrease of nearly 50% in the vessel area of earlywood was an important signature indicating the exposure of tree roots caused by denudation. Soil erosion rates derived from exposed roots varied between 1.04 and 3.61 mm y^{-1} in the southeastern Tibetan Plateau.

1. Introduction

Soil erosion has been an extremely serious environmental problem of public concern throughout the world since the 1930s (Held and Clawson, 1965; Arts and Church, 1982; Verheijen et al., 2012). Assessing the impacts of climatic and land use changes on rates of soil erosion induced by water is the objective of many national and international research projects (Williams et al., 1996; Poesen et al., 2003; Nearing et al., 2004; Boardman et al., 2009; Bilotta et al., 2012). Conventionally, soil erosion has been quantified using a variety of approaches, ranging from reconstruction to direct measurements. These approaches have included runoff plot studies (Horton, 1938; Zhang et al., 1996; Morgan, 2005), erosion pin measurements (Couper et al., 2002), isotopic dating (^{137}Cs, ^{210}Pb) (Walling and He, 1999; Walling and Quine, 2006; Benmansour et al., 2013), high-precision remote sensing (Stojic et al., 1998; Thoma et al., 2005; Prasuhn et al., 2013), reservoir sedimentation investigations, and riverine-suspended sediment monitoring (Brazier, 2004). These approaches have traditionally produced the rates of soil erosion. However, these methods address the problem of quantifying soil erosion from different perspectives; thus, they involve a series of biases. Generally, direct measurements over one single area may be expensive, and they cannot be used to estimate soil erosion dynamics at millennial and centennial timescales. Over the last several decades, the quantification of soil erosion losses has remained elusive in many countries (Toy et al., 2002; Bilotta et al., 2012).

As an alternative to the traditional methods used to determine soil erosion, dendrogeomorphology (Alestalo, 1971; Shroder, 1980; Stoffel and Bollschweiler, 2008; Chartier et al., 2009) represents an effective tool to determine recent and long-term rates of soil erosion against datable exposed roots. This tool is one of the most accurate nonsystematic sources of data for dating events with annual or even seasonal precision over several centuries (Corona et al., 2011). Dendrogeomorphology uses different characteristic sequences of tree rings and other measurements as indicators to characterise geomorphological processes from spatial and temporal standpoints (Wiles et al., 1996). This method determines how active geomorphological processes affecting tree growth are reflected in variations in width measurements of growth rings in the tree morphology (Eardley and Viavant, 1967; Danzer, 1996; Perez-Rodriguez et al., 2007; Rubiales et al., 2007) and in certain anatomical properties of wood (Gärtner et al., 2001; Wimmer, 2002; Hitz et al., 2008a; Rubiales et al., 2008; Chartier et al., 2009; Ohashi et al., 2009; Luo et al., 2011).

Previously, studies using dendrogeomorphic methods primarily focused on the stem and, to a lesser extent, on roots, concentrating on variations in ring width or structural changes in roots at a macroscopic level (Carrara, 1979). More recently, microscopic approaches and equations have been introduced, allowing for the year of exposure to be determined based on changes in the anatomical structure of roots. For example, in broadleaved trees, the characteristic feature indicating exposure is a 50% reduction in fibre sizes, which is similar to the tracheid size reduction in earlywood of coniferous roots (Sahling et al., 2003;

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Ballesteros, 2008; Hitz et al., 2008a,b). Moreover, the existing microscopic approaches and proposed equations (Gärtner, 2007) have been checked for accuracy against other systematically measured rates of erosion at the same sites (Corona et al., 2011). The advantage of using exposed roots compared with common erosion measurement techniques is that the area's erosion rates, as well as its variations in erosion rate, can be determined from a spatial and a temporal point of view, especially in regions lacking detailed historical records (Bodoque et al., 2005). Additionally, the equations used in these studies are limited to the analysis of roots still in contact with the soil surface (Gärtner, 2007). Corona et al. (2011) proposed two hypotheses to verify the accuracy of these equations. Their results showed that erosion rates obtained with the two hypotheses did not show significant differences compared with those found using the equations of Gärtner (2007), allowing for the quantification of erosion rates over time with relatively high precision.

However, previous studies have largely been conducted in alpine environments (particularly, North American mountain chains and the European Alps), primarily focused on softwood (e.g., larch, spruce, and pine) and, to a lesser extent, on hardwood (e.g., ash, poplar, and oak) (Stoffel and Bollschweiler, 2008; Ballesteros et al., 2013). Saez et al. (2011) used 48 exposed roots of *Scots pine* to reconstruct the soil erosion dynamics in the Alps and found that the average medium-term soil erosion rates varied between 1.8 and 13.8 mm y^{-1}. Corona et al. (2011) dated continuous denudation rates using *Pinus sylvestris* in the French Alps. Hitz et al. (2008a,b,c) reconstructed the erosional processes of two mountain torrents (in Swiss alpine areas) through the root ring dating of hardwood (European ash) that had been exposed for the first time. However, no such studies have been conducted focusing on hardwood (e.g., *Eucalyptus camaldulensis*), which is widely distributed in the southeastern Tibetan Plateau, China.

In this study, our aims are as follows: (i) to identify the ring width and the anatomical response of *Eucalyptus camaldulensis* root resulting from a denudation event to estimate the first year of exposure and (ii) to apply these anatomical findings to the reconstruction and quantification of slope erosion rates on catchment area of gully head, using roots of *Eucalyptus camaldulensis* that are partly exposed and still living. This work represents the first attempt to study soil erosion using a dendrogeomorphological technique involving anatomical indicators in the Tibetan Plateau area.

2. Materials and methods

2.1. Study area

The study area is located in the southeastern Tibetan Plateau (Longchuanjiang watershed, dry-hot valley of Jinsha River, China, 25°41′ N–25°50′ N, 101°49′ E–101°53′ E), at 1178-1207 m altitude (Fig. 1). The mean annual precipitation is 615.1 mm, of which approximately 90% falls during the growing period (from May until October); and the mean annual temperature is 21.8 °C. At the sampling site, the tree population consists exclusively of *Eucalyptus camaldulensis* and has not been farmed for at least 30 years. Site one is mainly dominated by an artificial *Eucalyptus* forest. In the inhibition of *Eucalyptus camaldulensis*` oil, herbs and shrubs are difficult to survive; only a few *Eucalyptus camaldulensis* leaves are scattered on the soil surface. Soil erosion by water has been concentrated on the catchment area of the gully head. In site two, the erosion process has caused relatively little soil loss because of high cover of herbs and shrubs. Site three with bare land is close to the village and is severely disturbed by anthropogenic activities. The local soils are classified as Vertisols under the

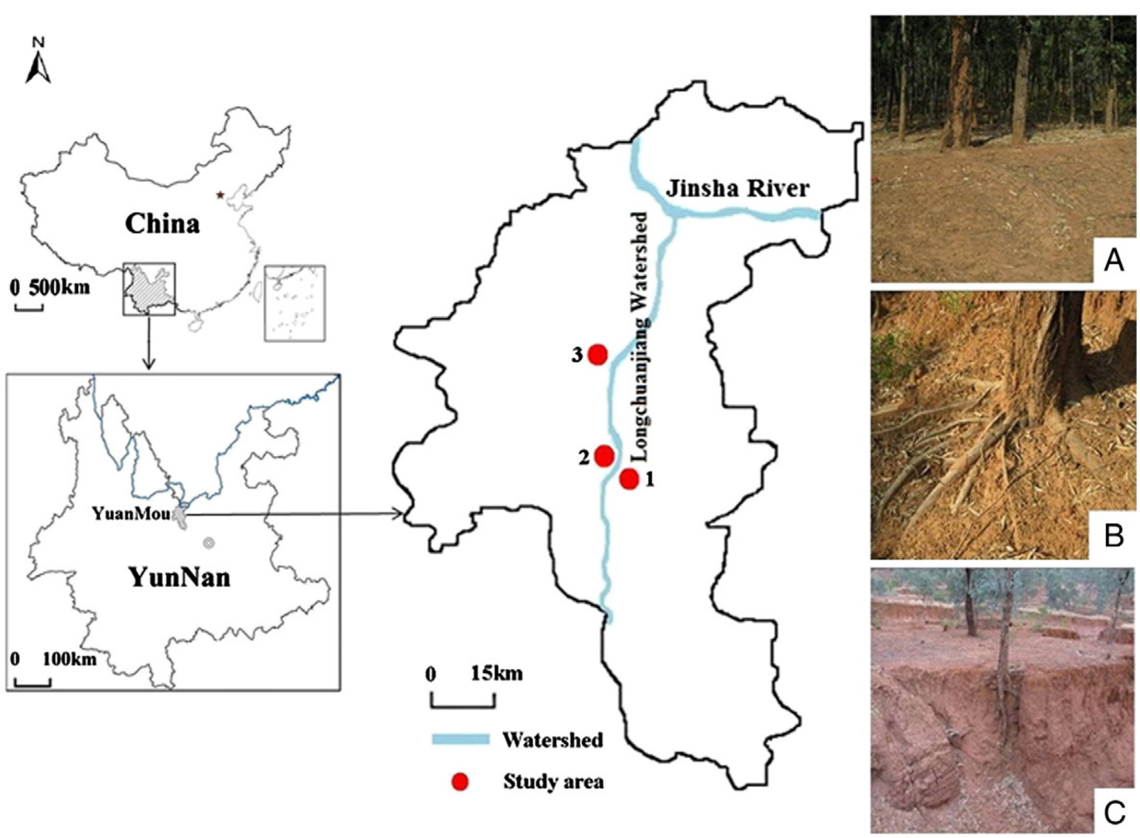

Fig. 1. Study area and sampled sites.