Catena 118 (2014) 41–54

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Differing responses to extreme rainfall events in headwater areas recorded by wood anatomy in roots (Gorce Mountains, Poland)

Dominika Wrońska-Wałach

Institute of Geography and Spatial Management, Jagiellonian University, Department of Geomorphology, Poland

ARTICLE INFO

Article history:
Received 30 May 2013
Received in revised form 17 January 2014
Accepted 28 January 2014
Available online 28 February 2014

Keywords:
Headwater area
Triggering events
Exposed roots
Earlywood and latewood anatomy

ABSTRACT

Local, short-lasting downpour is typically observed more frequently in headwater areas than in overall catchments. Headwater systems act as buffers and serve as starting points for stream channels. Therefore, recognition of the magnitude and frequency of their transformation is important for the understanding of the functioning of entire mountain catchments. Despite numerous studies on extreme events, the headwater areas are still poorly recognised. There are a number of steep forest-covered headwater areas in the Gorce Mountains, a range of flysch-type mountains that form part of the Polish Carpathians, which have not yet been studied in relation to this issue. Therefore, the main aim of this study was to determine the nature of geomorphic activity acting within different parts of the headwater areas. In order to date extreme geomorphic events precisely, a dendrogeomorphic approach was performed based on anatomical changes in exposed roots. A total of 59 spruce *Picea abies* L. Karst roots were sampled. Besides the reduction in tracheid lumen area in earlywood that is traditionally used, a recently developed approach using an abrupt change in the amount of latewood as an indication of the moment when geomorphic activity takes place was also taken into consideration. Data from exposed roots were compared to rainfall data. The results showed that the headwater areas experienced a variety of geomorphic processes. The timing of processes was assessed for the years 1944 to 2001. The main difference between the roots can be observed between the upper and lower parts of the headwater area. In the upper part of the headwater area, anatomical changes within the roots were observed when heavy rainfall events occurred, i.e. in 1958, 1970, 1971, 1972, and 1985. Roots in the lower part of the headwater area had become exposed during continuous rainfalls in 1997 and 2001. This research provides a fundamental review of dendrogeomorphological methodology applied to the identification of extreme geomorphic events acting within headwater areas.

Contents

E-mail address: dominika.wronska-walach@uj.edu.pl.

http://dx.doi.org/10.1016/j.catena.2014.01.016
0341-8162/

1. Introduction

Extreme geomorphic events in the flysch-type mountains have been examined many times and by a number of different researchers (Ellen and Wieczorek, 1988; Froehlich and Starkel, 1995; Gil and Starkel, 1979; Jacobson et al., 1989; Kotarba, 1998; Nemčok, 1982; Šilhán and Pánek, 2010; Starkel, 1979, 1996, 2002). Such events typically follow the magnitude–frequency relationship in that they are episodic but their magnitude may be very high. They tend to scour channels, transform the headwater areas and produce abrupt changes in mountain relief (Benda, 1990; Crozier, 1986; Dietrich and Dunne, 1978; Kelsey, 1980; Ziętara, 1968). These kinds of events are mainly induced by rainfall. Starkel (1979, 1996, 2002) classified rainfalls into three different types. Each of these rainfall types possesses different levels of geomorphic effectiveness and is characterised by a different threshold value: i) local, short-lasting downpours are morphologically effective in small catchments, tend to produce debris flows and mudflows, amount to 30–120 mm and have an intensity of 1–3 mm/min, ii) continuous rain is morphologically effective when precipitation does not exceed 3–12 mm/h and reaches a quantity of between 150 and 400 mm over a period of 2–5 days, and iii) rainy seasons occur when precipitation during the summer months reaches 200–500 mm.

Local, short-lasting downpours are typically observed more frequently in headwater systems than in overall catchments. Those remote areas are located in the upper parts of mountain catchments (Gomi et al., 2002; Montgomery and Dietrich, 1988). Gomi et al. (2002) highlighted the fact that headwater areas, understood as zero-order basins, make a hydrological contribution to first-order and second-order channel discharge. Furthermore, there exists a very close relationship between hydrological and geomorphic processes within headwater areas where water input exerts a significant influence on hillslope and channel conditions (Sidle et al., 2000). For this reason, an understanding of the functioning of headwater systems is crucial to the understanding of systems covering entire mountain catchments.

Much previous research concerning the activity of headwater areas was carried out post factum, based on geomorphological mapping in the field (Crozier, 1986; Ellen and Wieczorek, 1988; Jacobson et al., 1989). Application of this method does not allow one to determine the frequency of morphogenetic processes and does not allow one to assess the role of the particular events in the headwater system. Information gathered could refer to different geomorphological events which tend to cluster during consecutive years (Starkel, 2006). In addition, Starkel (2012) emphasised that many worldwide correlations of rainfall data with their geomorphic consequences were based on data obtained from a distant (even exceeding 15 km distant) recording station and were thus not sufficiently reliable to draw conclusions. Headwater areas are usually poorly instrumented therefore, studies which are located in such areas close to a meteorological station (less than 1 km) are of great interest for the understanding of how such areas function.

Dendrogeomorphological methods are currently used to reconstruct a variety of geomorphic processes (Alestalo, 1971; Bollschweiler et al., 2007; Carrara and Carroll, 1979; Pelfini and Santilli, 2008; Stoffel, 2006; Zielonka et al., 2008). Changes in root structure caused by a sudden or continuous exposure to the atmosphere have proven to be a helpful tool in geomorphology (Gärtner, 2003, 2006, 2007; Gärtner et al., 2001; Schweingruber, 1996).

Measurements of gradual changes taking place within roots are used to calculate soil and sheet erosion (Bodoque et al., 2005, 2011; Buchwał, 2008; Corona et al., 2011; Pelfini and Santilli, 2006; Pérez-Rodríques et al., 2007; Rubíales et al., 2008; Saez et al., 2011; Wrońska-Wałach, 2009). Dendrogeomorphological methods are being tested in different conditions for their accuracy and usefulness in dating and quantifying of soil erosion (Ballesteros-Cánovas et al., 2013; Corona et al., 2011; Saez et al., 2011). Ballesteros-Cánovas et al. (2013) emphasised the importance of precise measurements of microtopography around roots in the quantifying of erosion rates by using dendrogeomorphological methods and proved that dendrogeomorphological analysis is helpful for the reconstruction of extreme events and erosion in badlands. Furthermore, changes in cell structure in the roots of various tree species are used to reconstruct the frequency of extreme events acting in different environments (Hitz et al., 2008; Malik, 2008; Malik and Matyja, 2008). Nevertheless, there still exists a data deficit relating to the potential benefits of the application of dendrogeomorphological analysis to the evaluation of the role of extreme geomorphic events in headwater areas in midsize mountain ecosystems.

Data obtained from such analysis yield insight into the role of different rainfall events in the development of headwater areas in midsize mountains. Moreover, the type of data obtained by analysing exposed roots can be crucial to the understanding of:

- geomorphological processes affecting different parts of headwater areas
- various geomorphic processes overlapping with different types of precipitation
- the role of headwater areas as buffer zones between slopes and channel systems.

The aim of the study was to connect various anatomical responses of exposed spruce (*Picea abies* L. Karst) roots to geomorphic processes at three levels of magnitude–frequency (M–F) relationships: episodic but with high magnitude, moderate M–F and continuous. Subsequently, based on that link, a description was made of geomorphic activity in an area which is located close (less than 1 km) to the meteorological station and thus could exhibit a reliable relationship between rainfall and different geomorphic processes within the headwater area.

2. Study area

Fieldwork was carried out in the Gorce Mountains (Polish flysch-type Carpathians). The Gorce Mountains are built of a lithostratigraphic unit in the flysch called the Magura nappe. With an elevation of 1200–1300 m a.s.l. and a slope gradient of more than 20°, they are representative of midsize mountains (Klimaszewski, 1972; Starkel, 1996).

The study area is located within the Gorce National Park on the southern edge of the Gorce Mountains and features a number of steep forest-covered headwater catchments (Fig. 1). The headwaters in this area exhibit fresh signs of contemporary geomorphic activity. The Olszowy headwater area, featuring a well-preserved semi-natural forest, was selected for analysis (Fig. 1).

In the study headwater area landforms indicative of a past landslide occur such as 20–50 m high headwalls, sloping at 30–45°, displaced blocks, and a distinct toe (Fig. 1-B). The headwater taken into consideration has a drainage basin area of 0.62 km^2, a drainage density of about 7.03 km/km^2, and mean slope of 25–30°. The most diverse area is the upper part of the headwater catchment where small gully-type valleys, rills, rock veneers (a thin accumulation of rock clasts that partially or fully covers a surface or hillslope), torrential chutes, and small landslide scars can be found close to one another. Further down the headwater area one comes across a landslide toe which is dissected by ravine-type and V-shaped valleys.

The Olszowy headwater area is covered by subalpine spruce forest in its terminal phase of development (Chwistek, 2001). The density of Norway spruce (*P. abies*) is similar throughout the entire study area and ranges from 7.1 to 8.0 trees/100 m^2 (Loch et al., 2001).

The climate of the Gorce Mountains is characterised by the presence of several climate zones. Mean annual temperature in the altitudinal profile ranges from 6 to 7 °C in the foothills to about 3 °C on mountain ridges (Hess, 1965). Average annual precipitation ranges from 750 to 800 mm at lower elevations to 1200 mm on the upper part of the ridge. The maximum monthly precipitation is in July and August. Four different plots were chosen for further analysis.

The first plot analysed is located in the upper part of the headwater area and starts above the landslide niche, close to a man-made forest