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Short- and long-term studies of sediment dynamics in a small humid mountain Mediterranean basin with badlands

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ABSTRACT

Badland landscapes are the main sediment sources in the Vallcebre area (Eastern Pyrenees, Catalonia, Spain). Short-term studies (up to 3-years long) carried out between 1980 and 1994 were used to estimate the rates of both denudation on bare surfaces and sediment production at the plot scale, to analyse the seasonal dynamics of bedrock weathering and regolith behaviour, and to study the relationships between geomorphic activity and herbaceous plant colonisation. Since 1990, stream flow and suspended sediment loads have been monitored using three gauging stations equipped with infrared backscattering turbidimeters, ultrasonic beam attenuation solids sensors and automatic water samplers. The combination of the two different approaches has been useful for a better perception of the dynamics of the badland systems and to assess the long-term contribution of these areas to the basin sediment loads. Badland erosion at the event scale for a period of 15 years was simulated with the KINEROS2 model and allowed the long-term comparison between badland erosion and sediment yield at the small basin scale. Badlands are the main source of sediment in the basin for most of the events, but infrequent runoff events cause the removal of sediment stores and the activation of other sediment sources. The analysis of the uncertainty of sediment yield measurements for a range of record durations demonstrated that long records are needed for obtaining acceptable results due to the high interannual variability. Relatively low-cost short-term geomorphic observations may provide information useful for assessing the long-term sediment production in these basins with badland areas only if the observations are used to implement a model able to simulate long-term observations.

1. Introduction

Badlands have received increasing attention in the scientific literature (Gallart et al., in press), particularly as source areas of sediments (e.g. Clotet et al., 1988; Benito et al., 1992; Cantón et al., 2001; Mathys et al., 2003; Garcia-Ruiz et al., 2008; Nadal-Romero and Regüés, 2010). Although these landforms are considered characteristic of dry environments, they also occur in wetter areas where high-topographic gradients, bedrock weakness and high-intensity rainstorms, which are rather frequent in Mediterranean environments, coexist (Gallart et al., in press). Humid badlands (in the sense of Gallart et al., 2002a) develop in areas, usually mountainous, with annual precipitation exceeding 700 mm and with frequent summer rainstorms. Erosion rates in these humid badlands are typically higher than in dry ones (Gallart et al., 2002a). Furthermore, erosion rates in humid badland areas are several orders of magnitude higher than in the vegetated surrounding areas (Descroix and Mathys, 2003; Gallart et al., 2005a; Garcia-Ruiz et al., 2008). Nevertheless, erosion rate measurements depend both on the method used (Sirvent et al., 1997) and the spatial scale of observation (Nadal-Romero et al., 2011) as discoupling features within hillslopes and between hillslsopes and channels may occur (Harvey, 2002). Moreover, measurements may vary significantly from one year to another (Descroix and Mathys, 2003; Gallart et al., 2005a). We thus believe that higher attention should be paid to the comparison of erosion rates obtained by diverse methods and to analyse the uncertainty associated with measurements taking into account their temporal variability.

The badlands of Vallcebre (Eastern Pyrenees, Catalonia, Spain) have been the subject of several studies since 1982 (Clotet et al., 1983). Since 1989, runoff and sediment yield have been permanently measured in a set of small basins that include some badlands (Balasch et al., 1992). The purpose of this paper is to revisit some of the main findings obtained during the last 30 years and to compare them with updated results. Badland erosion rates were simulated for a 15-year period and compared with monitored sediment loads at the small basin scale. Special attention has been paid to compare erosion rates estimated with other methods (erosion pins, small erosion plots and natural sediment traps) taking into account the uncertainties

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associated with the temporal variability of erosion and sediment transport events.

2. Characteristics of the study area

The Vallcebre research basins are located at the headwaters of the Llobregat River, on the southern-eastern of the Pyrenees (Catalonia, NE Spain) at latitude 42° 12′ N and longitude 1° 49′ E. Altitude ranges from 1100 to 1700 m a.s.l. The research area consists of two basin clusters, whose centres are 2.5 km apart. The main cluster (Fig. 1, Cal Rodó basin, 4.17 km^2) was sub-divided into three sub-basins, whereas the smaller cluster (Cal Parisa basin, 0.32 km^2) consists of two sub-basins of similar size.

The basins lie in sedimentary rocks. Bedrock corresponds to a Cretaceous–Palaeocene continental formation dominated by red smectite-rich mudstones susceptible to mass movements and erosion (Feist and Colombo, 1983). As a consequence, some small, intensely eroded badlands with little or no soil cover are present in the basins, usually well connected to the drainage network (Figs. 2 and 3). Elsewhere, silty-loamy soils (Rubio et al., 2008) are covered by pasture and *Pinus sylvestris* forests, most of them spontaneously growing on old terraced agricultural fields after land abandonment (Poyatos et al., 2003; Delgado et al., 2010). Forest now covers 60% of the Cal Rodó basin. The rest of the catchment is largely covered by pasture, with smaller areas of Mediterranean bushes on slopes with thinner soils (Latron et al., 2009).

Climate is humid Mediterranean, with a marked water deficit in summer. Mean annual temperature at 1260 m a.s.l. is 9.1 °C and long-term (1983–2006) mean annual precipitation is 862 ± 206 mm, with 90 rainy days per year on average. Snowfall accounted for less than 5% of the precipitation in volume over the record period. The Mediterranean influence is evident in the area, leading to high inter- and intra-annual rainfall variability. Rainfall characteristics (frequency, volume and intensity) were strongly dependent on the season, with large rainfall events of low or moderate intensity occurring in autumn and spring, and short intense downpours in summer. Winter is the season with least precipitation. The long-term (1989–2006) mean annual reference evapotranspiration, calculated by the Hargreaves–Samani method (Hargreaves and Samani, 1982) is 823 ± 26 mm.

Investigations in the Vallcebre research basins started in 1989, with the objective of better understanding the hydrological functioning of Mediterranean mountain basins. A complete overview of general hydrological findings in the Vallcebre research area can be found in several papers (Llorens and Gallart, 1992; Llorens et al., 1992; Gallart et al., 1994, 1997, 2002b, 2005b; Latron and Gallart, 2007, 2008; Latron et al., 2008, 2009, 2010). In addition to results on sediment dynamics and transport discussed in the present paper, findings on rainfall–runoff modelling (Anderton et al., 2002a,b; Gallart et al., 2007, 2008) and forest water balance analyses at the plot scale (Llorens, 1997; Llorens et al., 1997a, 2003; Poyatos et al., 2005, 2008; Llorens et al., 2010) were also obtained.

3. Methods

At Vallcebre two different methods and spatial and temporal scales were used to investigate the hydrological and erosional responses of badlands: experimental short-term (up to 3 years) investigations of processes and erosion rates on small elements of badland areas, and long-term monitoring of water discharge and sediment loads in gauging stations at the outlets of small basins (Table 1). Furthermore, the erosion model KINEROS2 (Woolhiser et al., 1990) was used to estimate the long-term (15 years) sediment production from the badlands at the Ca l'Isard sub-basin.

In order to make clearer the spatial scales involved, erosion rates are indicated in kg m^{-2} for small scale values obtained in badland areas, and in Mg ha^{-1} for basin-scale measurements or for badlands upscaled to the basin area, taking into account the relative badland area in the basin.

3.1. Short-term experiments on badlands

As part of a geomorphological study, areal denudation in badland hillslopes was measured during 1982–1984 at the La Barrumba area (Figs. 1 and 2) using a rectangular array of 6 erosion pins. In the same area, sediment production from a small badland hillslope and an elementary basin (37.5 m^2) were monitored during 1982 using large plastic bags provided with small orifices that allowed the drainage of water (Clotet et al., 1983; Clotet and Gallart, 1986).

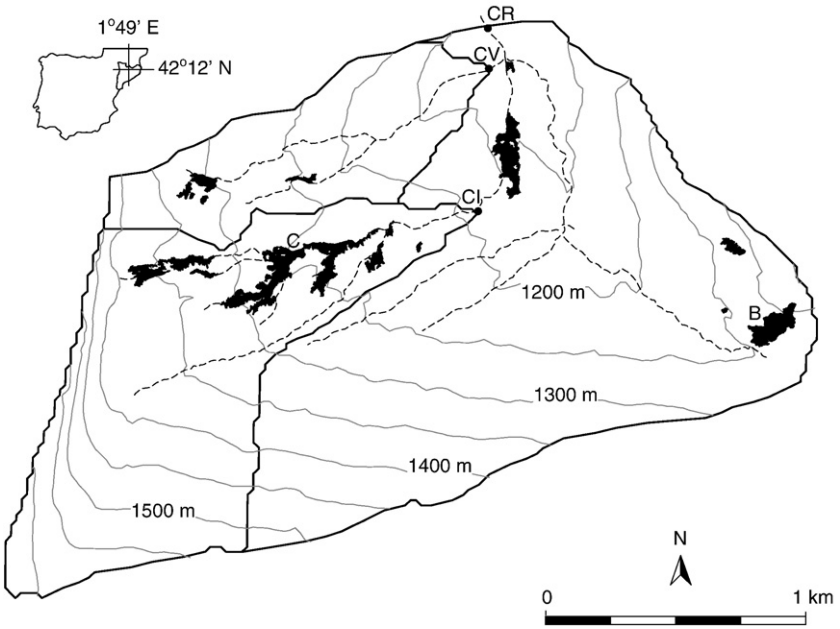

Fig. 1. Simplified map of the Vallcebre research basins. Grey lines: contours (50 m spacing); solid lines: sub-basin divides; dashed lines: drainage net; CR: Cal Rodó gauging station; CV: Can Vila gauging station; CI: Ca l'Isard gauging station. B: La Barrumba badlands. C: El Carot macro-plot. Badlands are shown in black.