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Sediment budget of the Mediterranean Lower Tordera River (NE Iberian Peninsula)

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Abstract The objective is to construct the sediment budget of the Mediterranean Lower Tordera River, recently affected by intensive gravel mining. During the relatively dry study period, mean annual sediment transit (mostly bed load) at the upper section was 30 000 tonnes, while 21 500 tonnes passed the downstream section, close to river mouth. An average of 8500 tonnes of sediment per year accumulated in the active channel. Net deposition has been the consequence of small floods (<20 $m^3 s^{-1}$), which entered the system, but did not reach the lower sections. The tendency towards river bed aggradation favours the progressive recovery of its former channel profile prior to gravel mining.

Key words bed load; flow regime; river bed; sediment budget; suspended sediment

INTRODUCTION

A sediment budget is an accounting of the sources and deposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin (Reid & Dunne, 1996). Almost no sediment budgets based on direct field measurements and focused on a single large river reach have been developed in a Mediterranean climate catchment (e.g. Shick & Lekach 1993; Batalla *et al.*, 1995).

The Tordera basin is located in the northern part of Catalan Coastal Ranges (Fig. 1) with a drainage area of 894 km^2. Plutonic rocks mainly compose bedrock. Climate is classified as sub-humid Mediterranean. Annual rainfall ranges from 1100 mm on summit areas to 600 mm in the lower parts. Vegetation covers most of the catchment area. Mean annual water yield (period 1967–1987) is 178 hm^3 (7 $l\ s^{-1}\ km^{-2}$).

The river study site is located in the lower part of the river, covering an 11 km perennial to ephemeral reach. At the upper section (Fogars de Tordera) the total water yield for the study period (1997–1999) was 184 hm^3, with a mean annual water yield of 74 hm^3, well below the mean (175 hm^3) (Fig. 2). Mean annual discharge was 2.2 $m^3 s^{-1}$. At the lower section (Blanes bridge) total water yield for the study period was 156 hm^3, yielding a mean annual water contribution of 62 hm^3. Mean annual discharge was 1.9 $m^3 s^{-1}$. Water does not flow during the late spring and summer months. The river bed is composed mainly of coarse sand and fine gravels (D_{50} = 4.5 mm in the upper section to 2.27 mm in the lower ones). Around 5 × 10^6 tonnes of sand and gravel were extracted until mining was prohibited in 1987. This means >100

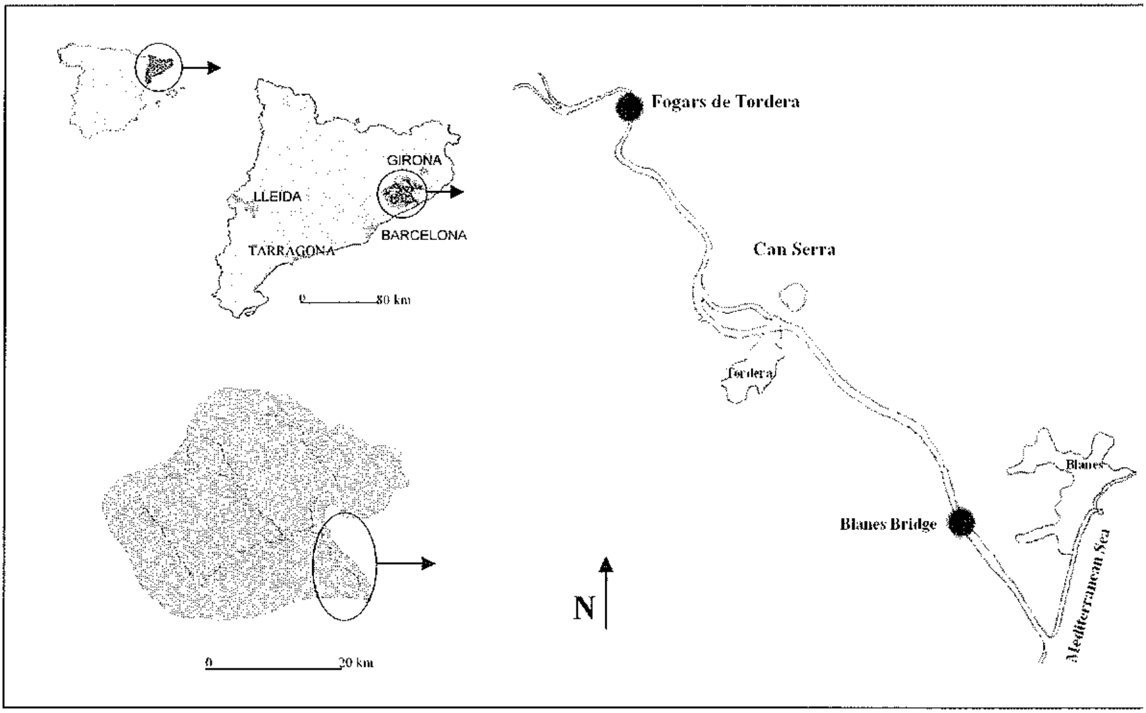

Fig. 1 Location of the Tordera drainage basin in the Catalan Coastal Ranges.

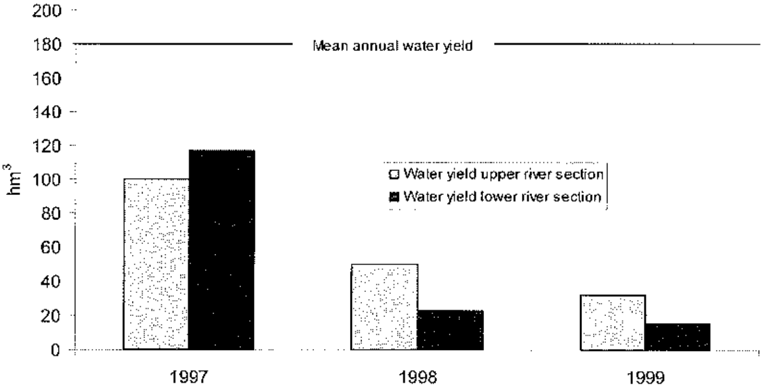

Fig. 2 Water yield in the Lower Tordera during the study period 1997–1999 (data from the Can Serra gauging station).

times more than the annual sediment yield of the Tordera River, including both suspended and bed load. Consequently, the mean channel incision was 2 m.

The main objective of this study was the construction of the Lower Tordera sediment budged focused on: (a) the measurement and analysis of sediment transport in a perennial and an ephemeral river section and, (b) the assessment of changes in river bed elevation to assess erosion and aggradation areas within the channel.

METHODOLOGY

A monitoring programme based on fieldwork was designed to fulfil data requirements for the construction of the fluvial sediment budget. Following this methodological and conceptual framework, we used an automatic water and sediment sampler to measure suspended sediment concentrations during floods at the upper section (Fogars de Tordera) and a US DH-48 depth integrating sampler to measure suspended sediment during base flows on a weekly basis. Still in the upper section, we sampled bed load at low flows by means of a hand-held Helley-Smith sampler (76-mm intake, 15-kg bag capacity).

At the lower section (Blanes Bridge) we measured bed load by means of a cable suspended 29-kg Helley-Smith sampler (76-mm intake, 15-kg bag capacity) during floods. The river bed elevation was monitored by means of periodical geodetic surveys on a series of a 20 representative monumented cross-sections. In addition, we characterized the grain size distribution of the river bed by means of pebble counts (Wolman, 1954) and volumetric samples (Church *et al.*, 1987).

RESULTS AND REMARKS

Mean concentration of suspended sediment at the upper section was 260 mg l^{-1}. Total suspended sediment input for the study period (1997–1999) was estimated to be 29 000 tonnes (Fig. 3, top), giving a mean annual sediment yield of 150 kg ha^{-1} $year^{-1}$. There, 70% of material was transported by discharges equalled or exceeded 7.5% of the time. Mean bed load rate was 90 g m^{-1} s^{-1}. Total bed load input was 48 000 tonnes (Fig. 3, bottom), yielding a mean annual contribution of 240 kg ha^{-1} $year^{-1}$. Less than 80% of the bed load was transported in less than 10% of the time. Altogether, floods at the perennial upper river sections carried 75% of sediment, but still 25% was transported during base flows mostly sand as bed load. Similar results were reported by Batalla *et al.* (1995) in the Arbúcies River.

At the lower section mean suspended sediment concentration was 69 mg l^{-1}. Total sediment output in suspension for the whole study period (1997–1999) was 20 000 tonnes (Fig. 3, top), yielding a mean annual sediment exportation of 87 kg ha^{-1} $year^{-1}$. Mean bed load transport rate was 47 g m^{-1} s^{-1}. Bed load yield was 37 000 tonnes (Fig. 3 below) giving with a mean annual contribution of 188 kg ha^{-1} $year^{-1}$. Altogether, > 90% of the sediment debouched to the sea was transported during floods, pointing out the enormous role played by floods on sediment transport in ephemeral Mediterranean streams.

Sediment transport during small floods (usually with peak discharges below 20 m^3 s^{-1}) did not reached the lower sections of the river, causing a mean net accumulation of sediment of around 8500 tonnes per year in the active channel (Fig. 4), mostly sand and fine gravels. This means a rate of aggradation of the river bed of 4.5 mm $year^{-1}$, calculated from a mean channel width of 100 m and a sediment density of 1.65 tonnes m^3 (in submerged weight). The accumulation of sediment takes place mainly between the upper sections and the village of Tordera, where intensive gravel mining during the 1960s and 1970s caused a large and extensive river bed degradation of 2 m on average. At this rate of mean annual accumulation of sediment,

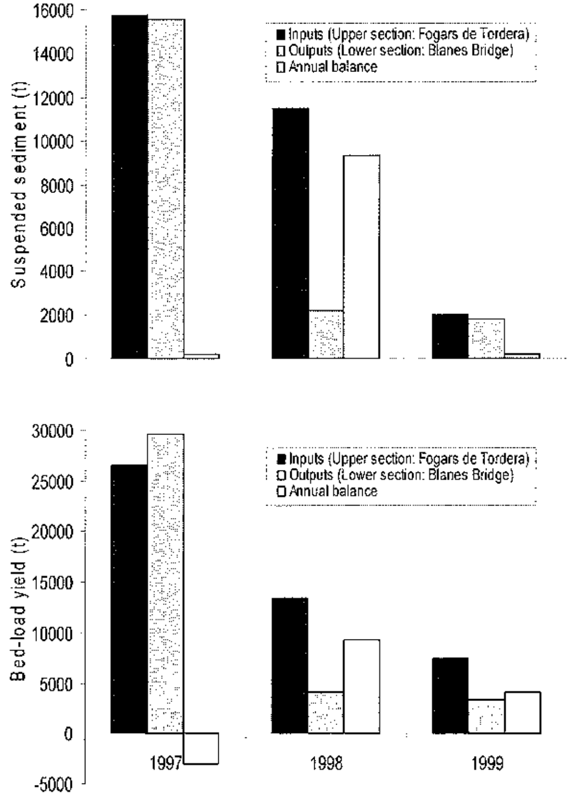

Fig. 3 Sediment yield, including both suspended sediment and bed load, in the Lower Tordera River during the study period 1997–1999.

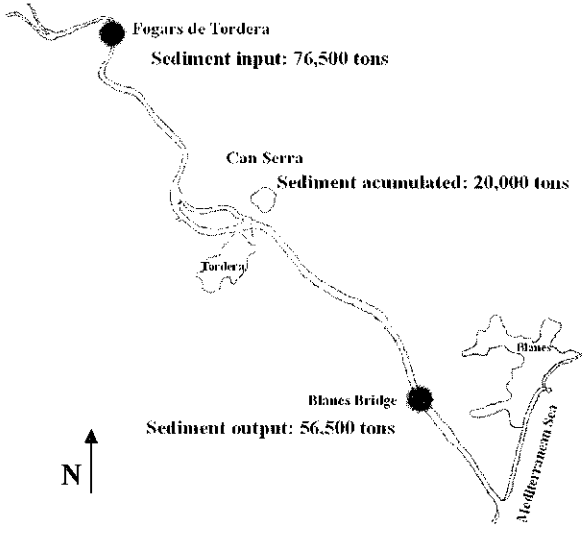

Fig. 4 The sediment budget of the Lower Tordera River (1997–1999).

recovery of the pre-extraction river bed level may still take 200 years. Sections close to the sea outlet still showed some current incision.

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