SEDIMENT SUPPLY AND MORPHOLOGICAL EVOLUTION OF A SMALL RIVER MOUTH (FIUMI UNITI, RAVENNA, ITALY): SHOULD RIVER MANAGEMENT BE STORM-DRIVEN?

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Abstract

The current paper links direct measurements of river bedload during floods, estimates of annual sediment input and monitoring of beaches at a small river mouth, the Fiumi Uniti just south of Ravenna. Direct bedload measurements led to the identification of an empirical method for quantifying sediment supply to the river mouth. Long-term morphological monitoring of the mouth beaches (2005-2008) confirms that the evolution of the beach strictly depends on river sediment supply. At times a drop in sediment stocks on the beach makes it vulnerable to the impact of storms. It is suggested that an intelligent management of a sluice gate just before the mouth could optimise sediment availability at the mouth.

INTRODUCTION

The relationship between sediment delivery by rivers and coastal changes is becoming a matter of concern even for small fluvial systems (Inman and Jenkins, 1999) or for coastlines that were traditionally unaffected by erosion. In a recent paper, Sherman et al. (2002) calculated that the impoundment of sand behind dams in California each year is equivalent to the loss of a beach slice 100 m wide, 10 m deep, and 1.7 km long. The process is one of the main causes of the coastal erosion observed also along Italian coastlines since the 1970s. Northern Italy, as many other Mediterranean-facing countries, has undergone conspicuous river-mouth engineering during the last 30 years (Surian and Rinaldi, 2003). Additionally, a plethora of coastal structures has been built to counteract coastal erosion and it is hard to predict any geomorphic response in the years to come. To study natural processes due to river sediment discharge, small rivers can be considered as appropriate sites since they may represent a model also for larger scale systems and the experimental work is more affordable, in the terms of human and financial resources.

A common feature of the rivers in the study area (the Emilia-Romagna coast) (Fig. 1), is the northward migration of the mouths that has taken place since the 1980s onwards (Regione Emilia-Romagna, 2000), coupled by a decrease in river sediment supply. Regarding the rivers in the Emilia-Romagna region, there is a lack of information on bedload transport even for the larger systems. A recent field study by Billi et al. (2007a) on the Reno River, calculated that the present bedload is only 50% of that computed for the period 1929-1978. The reasons for that are unclear though a reduction in river bedload, due to several factors including streambed dredging, the construction of a large number sediment retaining structures in the catchment, the implementation of soil conservation measures on hillslopes, and the subsidence in the area between Ravenna and the Po Delta are considered as the most important.

The main aim of this paper is to analyse the relationship between river bedload discharge and mouth evolution through field measurements of the river sediment flux at a cross-section near the river mouth and the morphological changes of the beaches facing it. Special attention was dedicated to the operations of a flood gate near the mouth in relation to coastal changes observed.

1. Characteristics of the Fiumi Uniti River

The Fiumi Uniti River is located south of Ravenna in the Emilia-Romagna region (Fig. 1). It originates in the northern Apennines, crosses the lower Po Plain and outflows into the Adriatic Sea near Ravenna. The river headwater is predominantly underlained by sedimentary rocks such as the Marnoso-Arenacea Formation (Miocene), a siliclastic flysch unit with variable carbonate content. Localized and thin Messinian gypsum outcrops and Pliocene-Pleistocene marls, marine clays and sands are found at the transition to the lowland, alluvial deposits of the Po Plain. . The climate in this region is classified as temperate sub-continental (Mennela, 1972). The mean annual temperature is 13.3°C and the precipitation rate has two relative maxima in April-May and October-November. The average annual precipitation is 983 mm.

The river name, Fiumi Uniti (*"United Rivers"*), derives from the river engineering works undertaken around 1740 when the lower reaches of two individual rivers, the Montone and Ronco, were artificially merged into one river channel in order to gain access to the sea and improve the management of water resources. The channel reshaping and straightening continued during the following centuries together with continuous levee construction, leading to the present setting. The floodplain on both sides of the Fiumi Uniti is cultivated by small farms, whereas fishing houses are present along the river embankments. Due to soil compaction, the floodplain is currently below the river bed, resulting in a high level of flood risk if overtopping of the banks would occur. The farmland is dissected by drainage canals controlled by a system of pumping stations that keeps the level of the unconfined aquifer low.

The Fiumi Uniti mouth is located north of the beach of Lido di Dante, an area heavily protected by erosion control structures built between the 1980s and 1990s to counteract the beach retreat that has been taking place from the 1970s onwards. The beach to the north of the river mouth is partly controlled by river discharge and wave action during storms. Here, a beach dewatering system has been operative till last winter, but profile monitoring by Ciavola et al. (2009) indicates that the behaviour of the mouth beaches is substantially controlled by natural processes and more specifically by the sediment that the river delivers during floods.

Billi et al. (2007b) undertook a bathymetric survey along the whole Fiumi Uniti River and its mouth during 2006. The data analysis resulted in the identification of bed forms with various wavelengths and heights and a submerged delta. As proposed by the authors, the occurrence of a submerged delta and migrating sand bedforms in the non-tidal part of the river confirms the existence of bedload supply from the river, as it was inferred by bedload measurements carried out on the Fiumi Uniti a few kilometres inland. Moreover, the sediment of the river bed and the submerged delta showed very similar grain size distributions (Tab 1).

2. Data available

2.1 Measurements of bedload transport

The in situ measurements of river bedload took place in the period April 2005-February 2006 at a pedestrian bridge in a cross-section not influenced by tidal processes. In figure 2it is possible to see the measuring site and the sluice gate (Rasponi Station) located 4.6 km downstream of the bedload measuring site and 3.5 km upstream of the river mouth.

The in situ measurements of bedload began in January 2005 by using a standard Helley-Smith bedload sampler. Flow velocity was measured as well by a cable suspended current meter type AA. Bed material samples were collected along the river from a few hundred meters upstream of the Ronco and Montone rivers confluence to the sea and from the submerged delta using a BMH-60 sampler (see Billi et al., 2007b, for methods and further details).

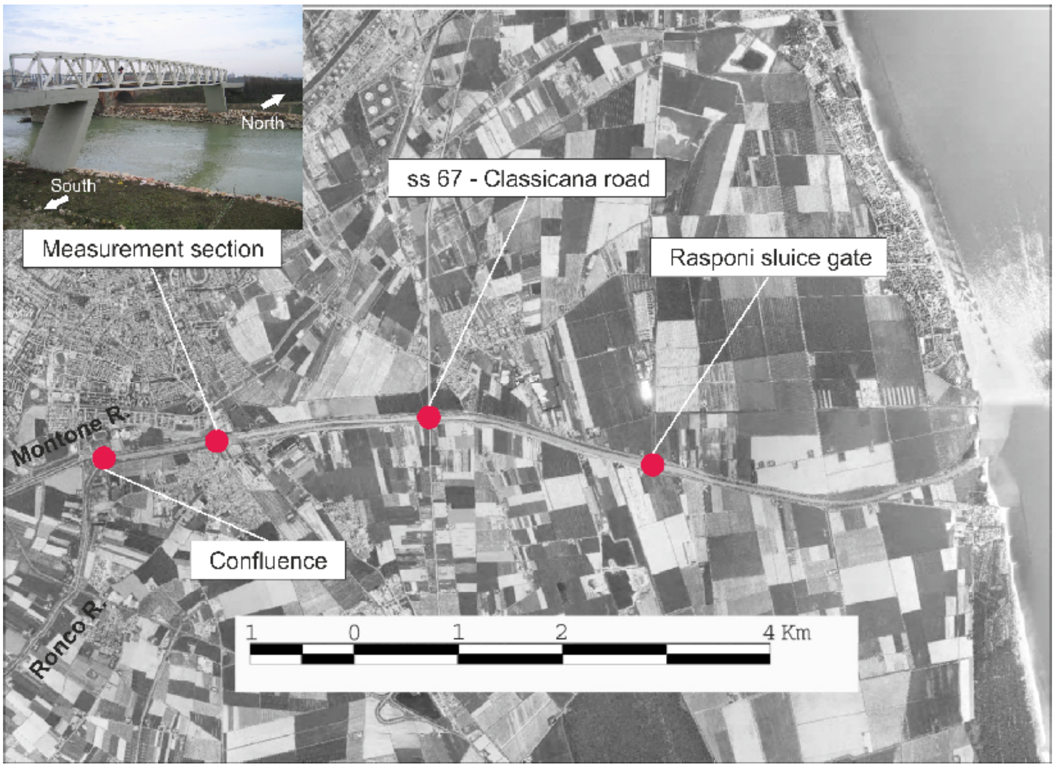

Fig. 2 - The bridge used for bedload measurements and aerial photo of the lower part of the Fiumi Uniti with location of the measuring site and of the sluice gate (Chiusa Rasponi).

The Rasponi sluice gate is mainly used for irrigation and to prevent the salt water wedge from geting inland during low flow periods. The gate rises from the bottom of the river bed upwards, i.e. when the gate is fully open it lies flat on the river bed and full sediment bypassing is achieved. Unfortunately, the operator manoeuvres are not recorded and the only way to understand if the gate is opened or closed is through the water level monitored by the gauging station located at the site. The water levels are recorded automatically, and although a small tidal signal is evident when the gate is opened, it disappears if the gate is raised. When the gate is held in open and semi-opened position the river water level is corrected subtracting the tidal signal recorded by the Porto Corsini tide gauge. By the field measurements carried out in the period 2005-2006, a bedload rating curve was obtained for the bridge section (Billi et al. 2007b) and the bedload yield of the Fiumi Uniti has been calculated (Fig. 3).

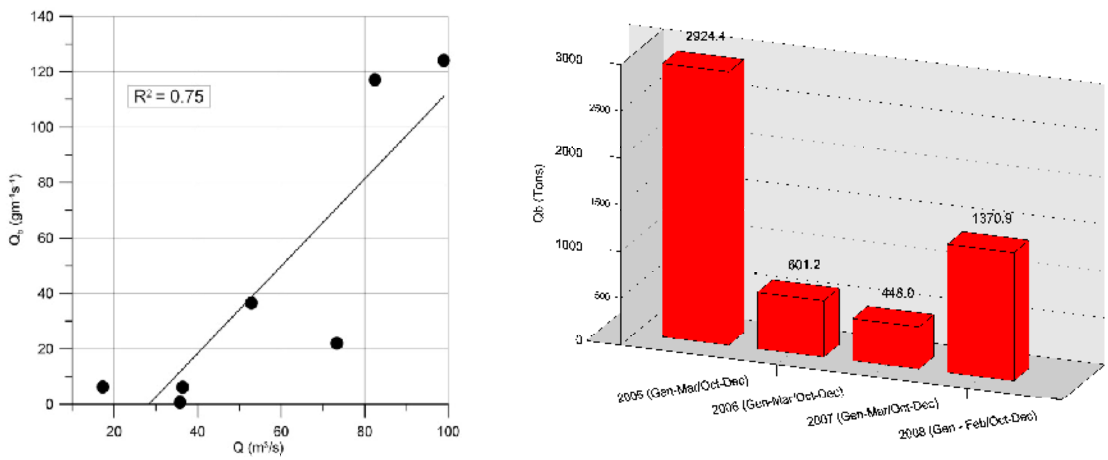

Fig. 3 - Bedload rating curve obtained for the measuring site section. Bedload yield for the period 2005-2008 expressed in Tons.

2.2 Measurements of the sub-aerial beach volume change

Field surveys of the northern beach have been undertaken since March 2005 using DGPS-RTK technology with monthly frequency and after major storms. As the monitoring was performed to assess the efficiency of a beach dewatering system (see Ciavola et al. 2009), the volume of the sub-aerial beach was computed above MSL and referred to the first survey of March 2005 when the system was installed. A beach dewatering system is an experimental mean of shoreline protection, based on installing a drain on the beachface and connecting it to a pumping system to lower groundwater in the swash zone. The shoreline was defined as the intersection between the beachface and the elevation +0.3 m which corresponds to the average high tide level. The shoreline position at selected time intervals is reported in Fig. 4a. According to Ciavola et al. (2009), these data show some evidence of stabilization on the drain. On the other, the total budget of beach sediment seems completely unrelated to the beach drainage (Fig. 4b). While in the 2006-2007 interval it remained stable but for some occasional losses, a large increase is observed in 2008. This coincided with a year generally characterised by low wave energy, a relatively high sediment supply from the river (Fig. 2) and the sluice gate open for many days.

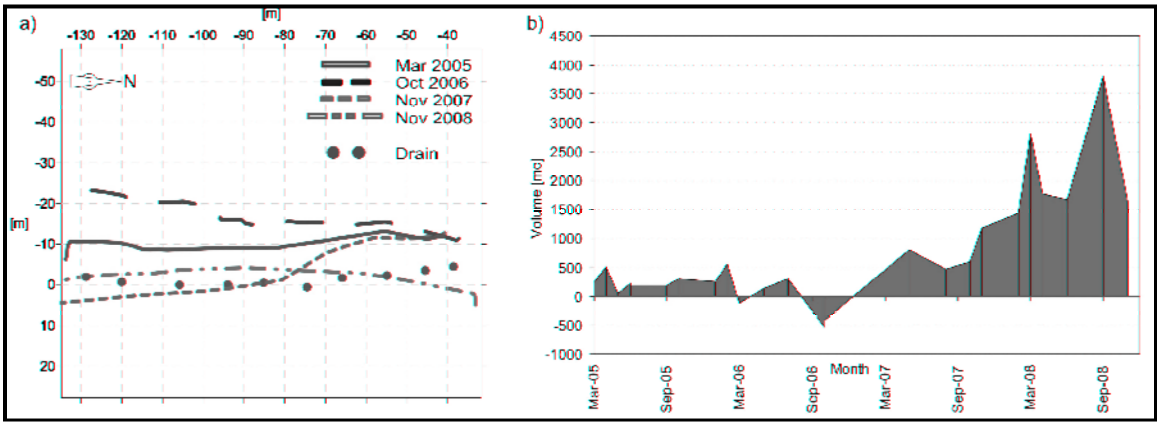

Fig. 4 - Measurement of shoreline movement over the drained area and beach volume changes on the left bank of the mouth for the period 2005-2008 (for further details about the methods see Ciavola et al., 2009). In Fig. 4a the distances are referred to a local benchmark, negative values are offshore while positive ones are onshore. The volumes in Fig. 4b are computed as difference from the first survey.

Tab. 2 - Summary of bedload yield in relation to maximum and average flow discharge and days of available for sediment transport (i.e. gates opened).

Year	Average Discharge Q_{av} (m^3/s)	Maximum Discharge Q_{max}(m^3/s)	Bedload yield Q_b (t/yr)	Days of sediment transport
2005	37.43	432.65	2924.38	33.20
2006	24.60	188.44	601.18	16.10
2007	23.91	96.98	402.60	6.40
2008	29.81	390.96	1370.90	40.80

A comparison between Table 2 and Fig. 4 shows that the continuous sediment supply recorded in 2005 contributed substantially to stabilise the beach volumes, while higher variability observed in 2006 and 2007 is to be accounted for by the interplay between floods and storms in controlling sediment supply and/or redistribution it between the emerged and submerged beach. In 2008 the sluice gates were opened for the longest period in the series. This coincided with a year having a very limited wave action and virtually no storms. The increase in beach volume presented in Fig. 4b confirms the input from river bedload in providing sediment feeding to the beach.

CONCLUSIONS

This brief paper summarizes three years of continuous monitoring of beach sediment volumes and a reconstruction of the river sediment delivery as sand available for beach feeding and it has shown the relevance of parallel field studies of river sediment input and beach responses.

In our study case it is evident that the frequent opening of the sluice gate tends to stabilise the sediment budget of the beach making it to withstand more efficiently the impact of sea storms or allowing recovery after storms. Presently, the gates are opened only as a flood is approaching and are closed when there is water demand. It should be noticed that we did not compute the amount of sediment retained by the gates since it is washed downstream and delivered in "pulses" to the mouth when the gate is lowered.

The beaches fed by the Fiumi Uniti River are an important tourist resort and the local environment and economy would greatly benefit from a stable beach shoreline. We believe that a more adequate management strategy of the gate taking pace with the beach volume variations would be advisable. Since this situation is common in northern Italy, the considerations and findings of this paper can be applied also other areas where new impoundment systems are being built to properly manage the river sediment influx and avoid the onset of sediment shortage at river mouths.

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