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An integrated approach to coastal erosion problems in northern Tuscany (Italy): Littoral morphological evolution and cell distribution

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ABSTRACT

Occupation of the coast has significantly increased in recent decades, mostly due to a greater demand for recreation and tourism. Today, erosion threatens many human-made structures and activities, requiring an integrated approach for the understanding of coastal dynamics and identification of alternatives to associated problems. This study investigates a 64 km-long coastal physiographic unit in the northern microtidal littoral of Tuscany (Italy). Vertical aerial photographs and direct field surveys were used to retrieve changes in shoreline position over 1938–1997 and 1997–2005 time intervals. Significant beach accretion was observed during the first period updrift of Carrara (84 m) and Viareggio (280 m) harbours and at Marina di Pietrasanta (100 m), whereas severe erosion occurred downcoast of Carrara harbour (−130 m, at Marina dei Ronchi) and on the northern side of Arno river mouth (−400 m). Similar trends were observed between 1997 and 2005; beach slope between the 1997 shoreline position and the closure depth correlated well with the distribution of erosion/accretion patterns from the 1938–1997 period (slopes were lower in eroded areas than at sites under accretion). Longshore distribution of erosion/accretion patterns was controlled by coastal compartmentalisation. Three of the main littoral cells were mostly formed by natural limits (i.e., Punta Bianca promontory, Marina di Pietrasanta, the Arno river mouth and the port of Livorno). Several sub-cells were created within these cells due to the introduction of human-made structures (such as Carrara and Viareggio harbours), which formed artificial fixed limits that allowed the transport of sediments (exclusively fines) in one direction only. Results will help improve the understanding of coastal processes and manage littoral sediment transport in a sustainable manner. This will reduce the need for structural interventions, such as breakwaters and groynes, which in the past decades prevented coastal retreat at local scale but shifted erosion downdrift, leading to degradation of the investigated area and requiring continuous maintenance.

1. Introduction

The 64 km-long coastal physiographic unit located in the northern littoral of Tuscany, Italy (Fig. 1) recorded significant erosion problems in recent decades due to reduction in sediment input from rivers (Pranzini, 2001) and to the feeding effect of harbours, ports and shore protection structures (Cipriani et al., 2001).

Recent studies based on the evolution of the shoreline (defined as the zero isobath position) from 2000 to 2010 show that circa 38.6% of this coast experienced severe erosion in the period, reaching 20 m yr^{-1} at some sites. Regional administration authorities are currently spending approximately 65 million Euros in the execution of nine shore protection projects—as a measure to counteract erosion and reduce its negative impact on tourism, which is the main economic activity in this part of the coast (Sargentini et al., 2004).

Such interventions, all part of a regional erosion management plan of 107 million Euros, may trigger important changes in coastal dynamics. These have already been modified from the natural condition by the construction of 16 km of hard engineering structures which started in the beginning of the 20th century (such as seawalls, rip-rap revetments, detached breakwaters, groynes, and submerged structures). Most of these structures will now be reduced in size or in height, and some new structures will be built, whereas artificial nourishment will be carried as the main defence strategy (Aminti et al., 2003).

A regional framework was evaluated in order to reach an appropriate design for coastal defence structures, following guidelines adopted by several authors (e.g., Bray et al., 1991; Pilkey and Dixon, 1996; Berlanga and Ruiz, 2002; Cooper and Pethick, 2005). This assessment included estimation of sediment input and output, determination of erosion/accretion areas, and the identification of sediment transport pathways and distribution of littoral cells.

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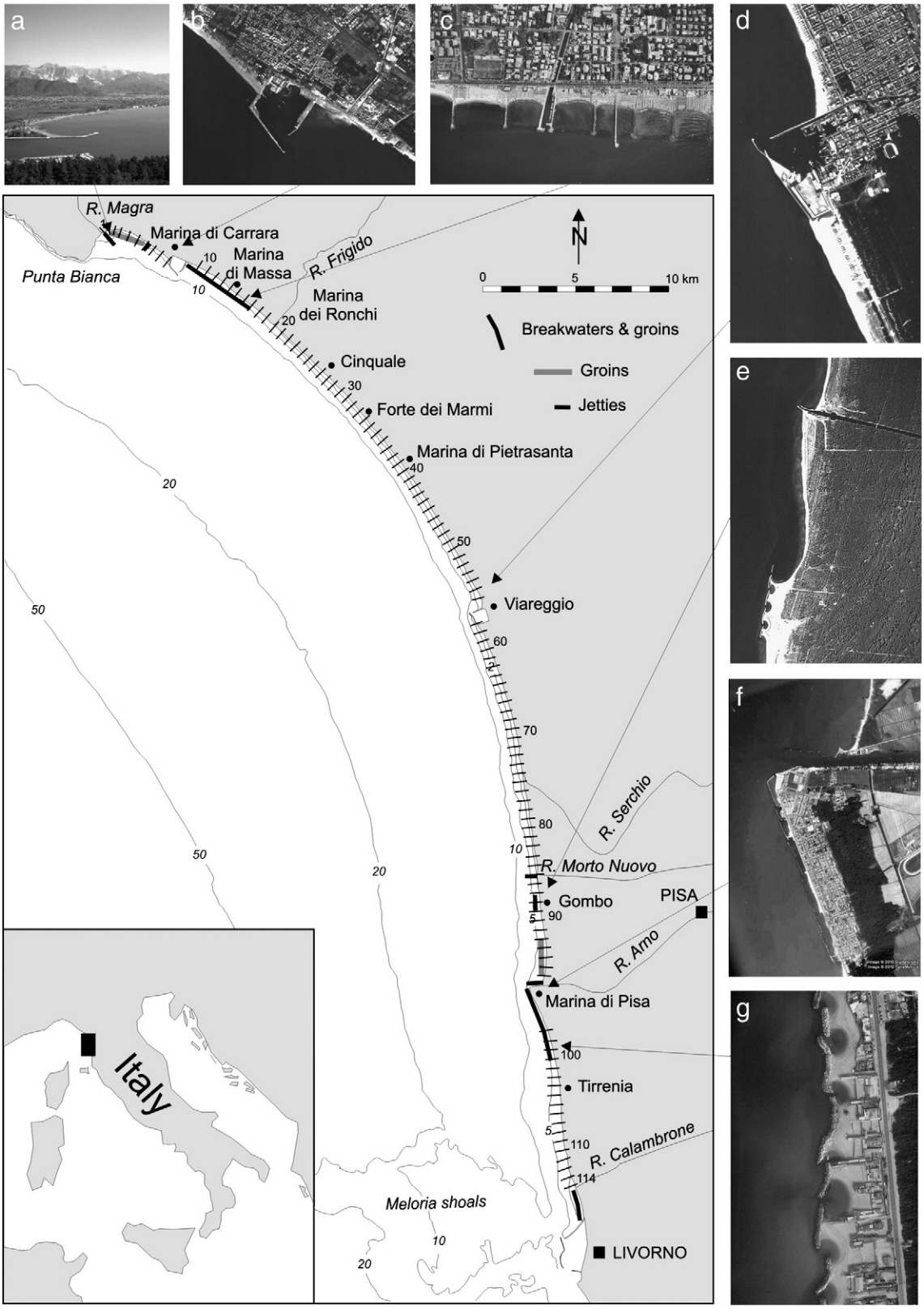

Fig. 1. Location map with major coastal villages, protection structures and sectors used in the study of coastal evolution (see tickmarks along the coast). Bathymetric contours are also presented. Photographs show the Magra river mouth (a), Marina di Carrara harbour (b), Marina di Massa (c), Viareggio harbour (d), the Gombo and Morto Nuovo river mouths (e), the Arno river mouth (f) and the southern area of Marina di Pisa (g).

A budgetary approach was considered in this coastal area to further a quantitative assessment of sediment inputs/outputs and transport pathways within each littoral cell; transfer processes, which operate over a range of spatial and temporal scales, were also investigated between adjacent cells (Regione Toscana, 2006). This follows the concept where understanding the distribution and characteristics of