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Rapid response of tidal channel networks to sea-level variations (Venice Lagoon, Italy)

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ABSTRACT

The aim of the present paper is to examine the effects of long- and short-term sea-level fluctuations (i.e. relative sea-level rise and tides) on the geomorphologic evolution of modern tidal channels through the joint interpretation of channel modifications, the 1938–2010 yearly time series of relative sea-level rise, and the variations of strength and frequency of high tides which occurred in the same period.

We analyzed a salt marsh area not particularly modified by human interventions, located in the northern Venice Lagoon, Italy.

The availability of a long historical record of high-resolution aerial photographs provided us the opportunity to reconstruct in detail the evolution of the drainage patterns from 1938 to the present.

Results from our analyses gave us information about the degree of control of long- and short-term sea-level fluctuations on planimetric development of tidal channels and provided demonstration of the rapid response of the drainage network to these oscillations.

We found that both relative sea-level rise and high tide frequency greatly influenced salt marsh margin shift and meander evolution of tidal channels in the long term, but short-term sinuosity changes of creeks were often also closely related to tide variations. Channels nearer the marsh margin were more exposed to the action of the increasing tides.

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1. Introduction

Salt marshes are delicate and vulnerable ecosystems of the lagoon environment. They develop in response to multiple interacting factors that control geomorphology, wetland surface elevation, habitat stability, and ecosystem function (Mitsch and Gosselink, 2000; Cahoon, 2006). Their existence mainly depends on the natural equilibrium among sea-level changes, variations in tidal energy and frequency, storms, and depositional processes (Coats et al., 1995; Leonard et al., 1995; Wang et al., 1999; Allen, 2000; Fagherazzi and Furbish, 2001; Davidson-Arnott et al., 2002; Hood, 2006).

Tidal courses are an essential part of coastal wetlands as they play a major role in water and nutrient exchange (Perillo et al., 2009) and their geometry affects sediment transport (French and Stoddart, 1992) and hydrodynamics (Rinaldo et al., 1999).

Origin and evolution of tidal courses are still matters of discussion due to the complexities of the dynamic processes responsible for their initiation and development. One of the major questions is what actually controls course meandering on tidal flats (Perillo et al., 2009).

The purpose of this study is to demonstrate the rapid geomorphologic response of tidal creeks to sea-level variations through the analysis of two representative examples of salt marshes chosen from the northern Venice Lagoon, Italy (Fig. 1). The availability of a long historical record of images provided the opportunity to reconstruct the evolution of drainage patterns within the marshland from 1938 to the present and to make comparisons of channel morphology.

In the past, several authors applied methods based on interpretation of aerial photos and satellite images (e.g. Garofalo, 1980; Shi et al., 1995; Wang et al., 1999; Fagherazzi et al., 2004; Hood, 2004, 2006; Watters and Stanley, 2007; Hughes et al., 2009), but their record was reduced to a shorter period of time or pictures were not available in such a number to allow the detailed analysis of geomorphologic modifications in response to very short-term sea-level variations. Moreover, with reference to the Venice Lagoon, studies on salt marshes carried out before Rizzetto and Tosi (2011) were mainly performed only by means of accretion measurements, without analyzing the geomorphic implications through the determination of the real morphological changes, implications that are fundamental for management and preservation of marsh areas.

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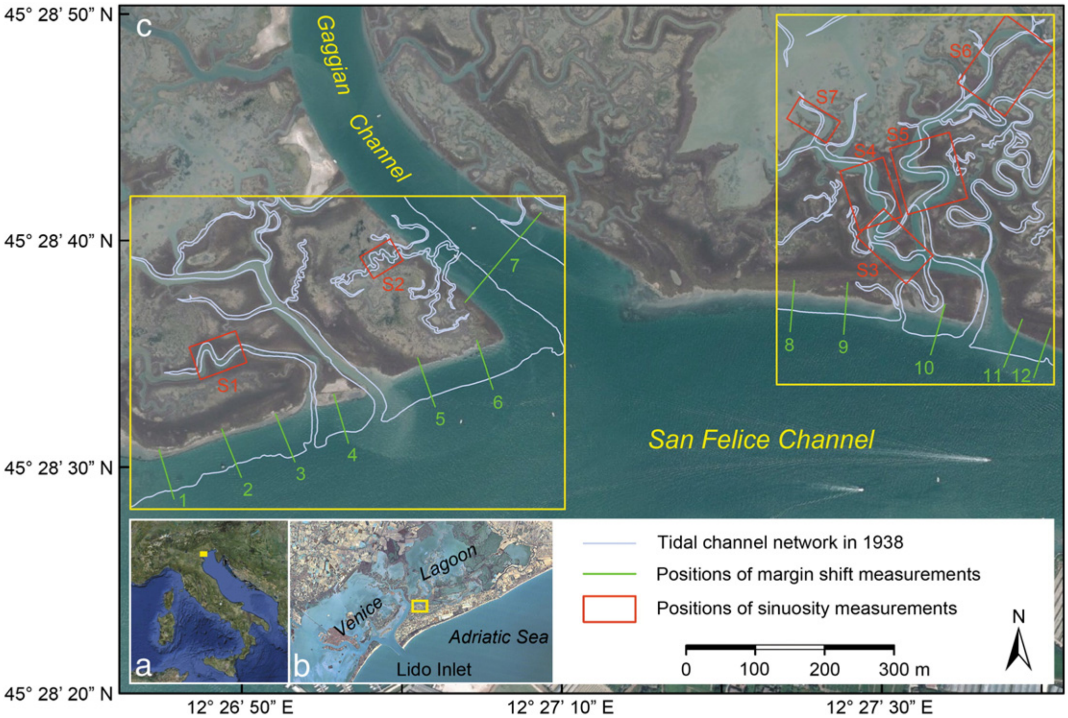

Fig. 1. Location of the study areas and their evolution since 1938. Location of the investigated salt marshes in Italy (a) and in the northern Venice Lagoon (b), indicated by yellow rectangles. (c) Modifications of tidal creeks and salt marsh margin from 1938 (pale-violet lines) to 2010 (aerial photograph). Positions of margin shift and sinuosity measurements are also shown.

2. General characteristics of the Venice Lagoon

2.1. Study area

The Venice Lagoon, located in the northwestern Adriatic Sea, is the widest lagoon basin in Italy, covering an area of about 550 km^2.

It is characterized by a complex system of shallows, tidal flats, salt marshes, islands, and tidal channels. Its present geomorphologic setting is the result of both natural and anthropogenic processes, as, over the past centuries, a number of human interventions (e.g. river mouth diversions, groundwater withdrawal, reduction in the number of inlets and deepening of those still preserved, tidal channel dredging, fish farming, land reclamation) have largely affected its evolution.

Water exchange between lagoon and sea occurs through three inlets (named, from north to south, Lido, Malamocco, and Chioggia, respectively) stabilized with long jetties that, since their construction, have greatly reduced the import of marine sediments into the lagoon (Day et al., 1998). Moreover, a few tributaries are responsible for scarce freshwater and sediment inputs.

Tides and winds (i.e., Bora from NE and Sirocco from SE) are mainly responsible for water circulation in the entire basin. The tidal regime is semidiurnal; tidal range averages between 1 m at springs and 0.5 m at neaps (Cucco et al., 2009).

Over the last decades, deficit of sediment supply, loss of material discharged to the open sea through the inlets, relative sea-level rise (RSLR), and erosion processes have significantly reduced the salt marsh extent. However, some natural salt marshes in the northern lagoon are locally growing and display development of the tidal creek network (Ciavola et al., 2002; Rizzetto and Tosi, 2011). The aptitude of these wetlands to preserve and evolve induced us to select them as case studies.

In particular, to achieve the aim of this research, we focused our attention on the fringe of salt marshes that borders the San Felice Channel, close to the Lido inlet. These marshes are composed of clayey sandy silt, having a higher sand content west of the Gaggian Channel. Grain size decreases in a SW–NE direction; consequently, in the north-eastern part of the studied area sand content is very low.

The salt marshes are mainly colonized by halophytic species, i.e. *Spartina maritima*, *Limonium narbonense*, *Sarcocornia fruticosa*, and *Juncus* spp. (Belluco et al., 2006). *S. maritima* grows on the lowest soils, *L. narbonense* over slightly higher areas, *S. fruticosa* on even higher soils, whereas *Juncus* spp. displays a relative indifference to soil elevation (Silvestri et al., 2005).

The marsh platform is drained by a dense branching network of sinuous dead-ended creeks, generally characterized by asymmetric meanders. Salt marsh elevation ranges from 0.0 m to about 0.7 m above sea level (ASL); the highest values are measured on the southern margins and on the creek banks (Rizzetto and Tosi, 2011). The northern parts have the characteristics of a marsh flat and exhibit an unstable drainage pattern with a large number of ponds, locally having very complex shape, setting, and distribution. In low tide conditions, ponds appear isolated and exhibit circular or elliptical shapes, whereas during high tide they enlarge, join together or to nearby creeks, and become irregular.

2.2. Sea-level rise in the Venice Lagoon over the past century

In the past century, in the Venice basin sea-level rise was strongly affected by the high subsidence rates caused by groundwater exploitation. The process, begun in the 1930s, reached its maximum in the period 1950–1970, and then decreased when the extraction was regulated (Carbognin et al., 2010). As a consequence, analyzing RSLR curve for the last seventy-three years, we identified two main intervals (Fig. 2a): (1) 1938–1970, when higher subsidence rates were responsible for acceleration in RSLR, and (2) 1970–2010, when RSLR slowed (Rizzetto and Tosi, 2011). The identification of minor RSLR fluctuations, probably related to climatic phenomena such as the North Atlantic Oscillation (NAO), the East Atlantic/Western Russia

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