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FIELD MONITORING OF A RETREATING SALT MARSH IN THE LAGOON OF VENICE (ITALY)

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ABSTRACT

A field monitoring campaign is carried out in the Lagoon of Venice (Italy) in order to investigate the role of wave climate in the evolution of a retreating salt marsh. Erosion data were systematically collected by means of erosion pins located horizontally along the marsh scarp for a time period of over one year. Pressure transducers were used to measure the wave climate close to the bank edge during three storm surges. A relationship between measured significant wave height and estimated wave height from wind, fetch and depth data has been calibrated to avoid recurrent field measurements. Wind and water level data are collected hourly from measurement stations located in the Lagoon of Venice. Field observations revealed that marsh retreat is characterized by continuous erosion alternate to mass failures, mostly of cantilever-type. Retreat rates are in the order of 50-90 cm/year. A linear relationship between wave energy flux and erosion rate is identifiable in case mass failures are not accounted for in the erosive process. Furthermore, mass failures can almost double the annual erosion rate, even if at shorter time scale, the slumped block can temporarily protect the bank from wave attacks.

Keywords: salt marsh, waves, erosion, field measurements

1. INTRODUCTION

Salt marshes are characteristic geomorphic structures present in ecotone environments such as lagoons and estuaries. Their importance is related to the ecosystem services they provide to coastal populations (Barbier et al., 2011). Nowadays, marsh areas show a reducing trend in various parts of the world due to several factors like increased anthropic pressure, sea level rise and erosion processes (Gedan et al., 2009).

The retreat of the salt marsh edge is one of the chief mechanisms leading to this reduction and it is strictly related to the local wave climate (Schwimmer, 2001; Marani et al, 2011), which is in turn controlled by the morphology of the adjacent tidal basin (Mariotti and Fagherazzi, 2013) and to the alternation of continuous erosion and occasional mass failures (Van Eerdt, 1985; Francalanci et al., 2013; Bendoni et al., 2014). Available relationships between erosion rates and wave energy flux for salt marsh systems are based on field data referred to large spatial and temporal scales: of the order of the basin size and years (Schwimmer, 2001; Marani et al., 2011). However, the role of the single processes (e.g. mass failures and mass and surface erosion) in promoting marsh edge retreat is not explicitly identified.

The present work describes the development of a field measurement campaign and the subsequent data analysis, to monitor and investigate the evolution of a retreating salt marsh in the Lagoon of Venice (Italy). First, the setup of the instrumentation and the summary of the activities are presented. Then, the methodology employed to analyze data is described. In the following section results from wave climate measurements and collected erosion data are reported in order to identify a relationship between wave energy flux and erosion rates. Finally, conclusion and outlook are drawn.

2. FIELD MEASUREMENTS SETUP

The monitored marsh is located in the north part of the Lagoon of Venice (Figure 1a). Six different sectors were identified based on the marsh morphology and the possible exposition to wind and boat waves. 78 erosion pins were located horizontally along the scarp of the marsh boundary. At higher banks two pins per vertical were deployed. The positions of the pins, the top of the bank and toe have been referred to the zero level of Punta Salute (P.S., city of Venice) by means of a GPS device. Erosion data were collected periodically. Each measurement corresponded to an interval (ΔT_S) between two consecutive surveys. Globally, 13 surveys were carried out, from November 2013 to December 2014, leading to 12 available erosion data.

Wave climate has been measured during 3 storm surges occurred in February 2014. Pressure transducers provided pressure data to be transformed into wave height measurements $H_{m0,in}$ (wave height inshore) [m]. They were deployed around 10 m from the bank edge, fixed to poles at 15 cm from the bottom. Sampling frequency was set to 6 Hz, with burst length of 17 minutes every 1.5 hours. Before the analysis, spikes were removed (0.2% of the total amount of data) and data were validated to check the correct behavior of the instrumentation.

Wind speed and direction and water level were obtained hourly by the fixed measurement stations in the lagoon of Venice. Bathymetry was obtained by local cartography produced by the Municipality of Venice. Such data were used to estimate wave climate offshore, $H_{m0,off}$ [m] during the interval between surveys. Wave height at the monitored marsh has been obtained applying a correction to the offshore wave climate, $H_{m0,off}$ based on $H_{m0,in}$ (see next sections).

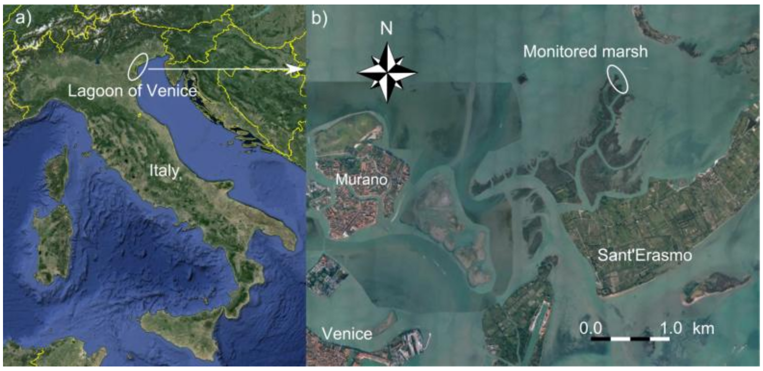

Figure 1. a) Location of the Lagoon of Venice in Italy. b) Location of the monitored salt marsh in the north part of the Lagoon, north-east of Venice.

3. DATA ANALYSIS

Time series (bursts) of pressure data have been subjected to spectral analysis using a modified Welch method (Welch, 1976), obtaining a pressure head density spectrum S_{pp} [$m^2 \cdot s$] representative of a burst. Wave energy density spectrum $S_{\eta\eta}$ [$m^2 \cdot s$] has been obtained applying a transfer function $K_p(f)$ to the pressure head spectrum (Jones and Monismith, 2007). Significant wave height has been determined by $H_{m0,in} = 4\sqrt{m_0}$ where m_0 is the zero-th moment of $S_{\eta\eta}$.

Wave climate offshore $H_{m0,off}$ has been estimated following Breugem and Holthuijsen (2007) using data (wind intensity and directions and water depth) provided by measurement stations. Water levels $\eta(t)$ are obtained from the station of Burano, located around 2 km north-east to the monitored marsh. In order to check if the water level at the two locations was the same, a hydrodynamic model of the lagoon (Defina, 2000) was run for an entire tidal cycle. Results showed no phase displacement and a maximum difference in water level between the two points around 2 cm at the tidal crest and trough for a tidal amplitude of 1 m. A relationship $H_{m0,in} = f(H_{m0,off})$ was then determined based on the correlation among the two datasets.

Erosion rates have been determined considering the framework depicted in Figure 2. To obtain the eroded material per meter of bank [m^2], eroded length measured at each survey L_{er} [m] is multiplied by its competence height L_p (0.4 m). Then, the erosion rate Er_i [m^2/yr] for a specific pin, during the interval ΔTs, is obtained by:

$$Er_i = \frac{24 \cdot 365}{\Delta t_i} Ler_i \cdot L_p \qquad [1]$$

where Δt_i is the cumulative time during which $z_i - L_p/2 \leq \eta \leq z_i + L_p/2$ and wave direction (assumed instantaneously aligned with wind direction) influences the sector in which the i-th pin is located.

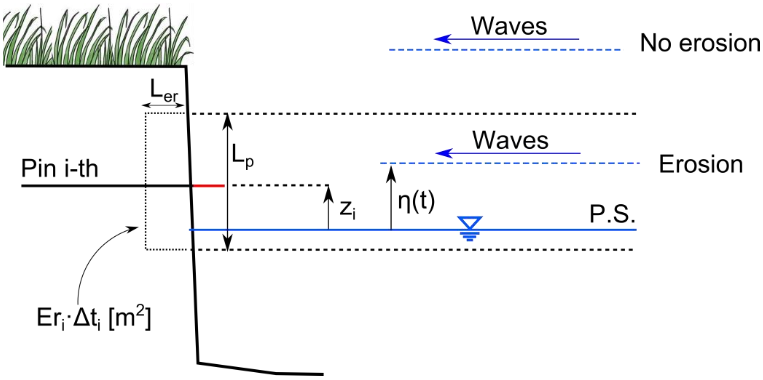

Figure 2. Sketch of the framework employed to determined the erosion rates related to each erosion pin during a specific interval ΔTs.

Hourly wave energy flux related to a specific sector j is determined by:

$$W_j = E \cdot n \cdot c_p \cdot \cos(\theta - \theta_j) \qquad [2]$$

where $E = 1/16\rho g(H_{m0,in})^2$ [J/m^2], $n = ½[1+2k \cdot h_m/\cosh(k \cdot h_m)]$ [-] and $c_p = \omega/k$ [m/s]. k [m^{-1}] and ω [s^{-1}] are respectively the wave number and wave period and h_m [m] is the mean water depth. θ is the wind direction and θ_j the direction orthogonal to the marsh edge of sector j-th. Afterwards, the wave energy flux W_i at the i-th pin (located in the j-th sector), is obtained by a weighted average of Wj on the interval Δt_i. Finally, erosion rates of the pins of sector j-th and associated wave energy fluxes are averaged to obtain a sector averaged erosion rate $\overline{Er}_j$ and sector averaged wave energy flux $\overline{W}_j$.

4. RESULTS

The following relation has been obtained by a linear regression (R^2 = 0.87) between the measured wave height, $H_{m0,in}$ and the estimated wave height $H_{m0,off}$:

$$H_{m0,in} = 0.84 \cdot H_{m0,off} \qquad [3]$$

Such a relation is used to correct the estimated wave height used to characterize the wave climate between two consecutive surveys.

In Figure 3 the scatter plot between $\overline{Er}_j$ and $\overline{W}_j$ for 2 of the 6 sectors monitored is reported. Erosion rates have been determined without considering mass failure events, otherwise data resulted too scattered and a clear trend was hardly identifiable. The different regression lines obtained can be attributed to the possible perturbation due to boat waves. Indeed sectors 5, which is potentially subjected to boat waves, shows higher erosion rates with respect to sectors 1.

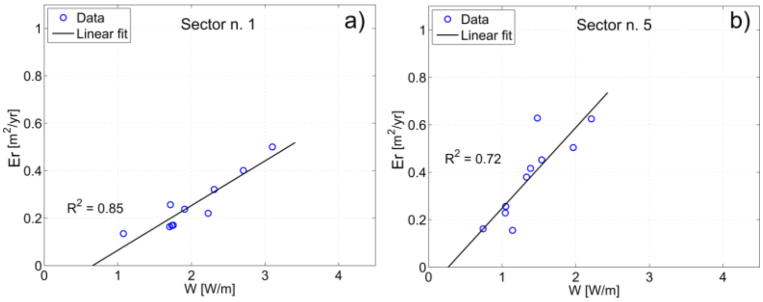

Figure 3. Scatter plots between erosion rates and wave energy flux for different sectors in case mass failures are not considered. a) Sector 1, b) sector 5.

5. CONCLUSIONS

A field monitoring activity has been carried out on a salt marsh of the Lagoon of Venice. it provided several information about the retreat process of the edge of the marsh platform due to wave attack. A linear relationship between erosion rate $\overline{Er}$ and wave energy flux $\overline{W}$ is identified at the time scale of months in case mass failures are not considered. This is because a mass failure events is not necessarily related to an intense wave forcing period. For example, one month characterized by a strong wave climate can induce the formation of a cantilever profile, preparing the mass failure. Such a failure can occur the next month, even if it is characterized by a lower wave forcing. This aspect tends to reduce the possibility to identify a clear functional relationships between the two quantities $\overline{Er}$ and $\overline{W}$ in case several mass failures occurred between two surveys. Furthermore, slumped blocks provide a local protection to bank toe against wave attack and they can persist for months before they are completely eroded by hydrodynamic forcing.

The obtained relationships between erosion rate and wave energy flux are linear, though with some differences among sectors. They can be attributed to the potential exposition to boat waves, which lead to a perturbation of the functional relationship. Furthermore, the analysis carried out did not consider the differences in local bathymetries among sectors, focusing on the offshore bathymetry of the area. This aspect, more than possible variations in soil composition, might have promoted the different linear trends.

Importantly, the effect of mass failure events can almost double the retreat rate of the bank, which is around 80 cm/year for the most exposed sector (6). Other sectors are characterized by a smaller number of failures and this can be ascribed to the different exposition to wave forcing or to the local morphology.

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