MORPHODYNAMICS PROCESSES IN THE LAGOON OF VENICE: THE SCANELLO SALT MARSH AREA

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Abstract.

Geomorpholgical variations have been naturally occurring in the Lagoon of Venice since its formation. In recent times, however, complex morphodynamic changes, caused by natural processes and by the direct or indirect impact of man activities have been recognised. Moreover, there remains a lack of knowledge concerning sediment erosion, re-suspension, transport and sedimentation, sea-lagoon balance and the role played by the hydrodynamics.

A detailed study of the Scanello salt marsh area, in the Northern part of the Venice Lagoon, was carried out, in order to better understand the erosion-transport-sedimentation processes and the hydrodynamics interaction. Understanding the role that the hydrodynamics plays in the erosion, transportation and deposition of sediments in this test area, is essential to the understanding the morphological variations, that are presently occurring in the Venice Lagoon and morphological and environmental restorations required.

A 2D hydrodynamic finite element model was used to provide the circulation field of the entire Venice basin. Results obtained by different simulations allowed the investigation of the main hydrodynamic features of the Scanello area.

Key-words: Hydrodynamics, Morphology, Erosion, Transport, Sedimentation.

1. *Introduction.*

Geomorphological variations have been naturally occurring in the Lagoon of Venice since its formation. In recent times, however, complex morphodynamic changes, caused by natural processes and by the direct or indirect impact of anthropic activities have been recognised. Consequently, an effective management of the Venice basin requires an in depth understanding of physical and geomorphological processes, which present a huge complexity. Despite numerous debates over the past few years, there remains a lack of knowledge concerning sediment erosion, re-suspension, transport and sedimentation, sea-lagoon balance and the role played by the hydrodynamics.

The Venice Lagoon, with a surface area of about 550 km^2 and an average water depth of about 0.6 m (Cossu & de Fraja Frangipane, 1985), is Italy's largest lagoon. It is connected to the Adriatic Sea through three inlets (Lido, Malamocco and Chioggia), which guarantee the water exchange with the sea. The primeval lagoon reached approximately its present position 6,000 years ago, even if it was smaller than the present one and the flowing out of its waters was possible through eight sea openings against the three it has now (Carbognin et al., 1984). The lagoon morphology, consisting of shallows, mud flats, salt marshes, islands and a thick network of channels, was subjected to the great mutability of those factors which had generated and developed the morphology throughout the ages. Among these, the activity of the main lagoon tributaries (Adige, Bacchiglione, Brenta, Sile and Piave) was determinant and threatened to make it a marshland. Together with the increase in the depth of the lagoon due to subsidence and eustatic rise, human activities have now inverted the lagoon's natural tendency to silt up and have triggered off the opposite process, transforming it slowly into a sea environment.

We report the results of a detailed study of three salt marshes, called BV (*Barena Vecchia*), BN (*Barena Nuova*) and BNW (*Barena Nord Ovest*), of the Scanello area (fig. 1), carried out in order to better understand the erosion-transport-sedimentation processes and the hydrodynamics interactions. In fact understanding the role that hydrodynamics plays in erosion, transportation and deposition of sediments in this test area is essential to understanding the morphological variations, that are presently occurring in the Venice Lagoon.

In order to integrate physical, chemical, sedimentological, mineralogical and micropalaeontological data already investigated in the past and to evaluate the long-term evolutional trends of the whole lagoonal basin 53 bottom sediment samples and 26 sediment cores were collected in the

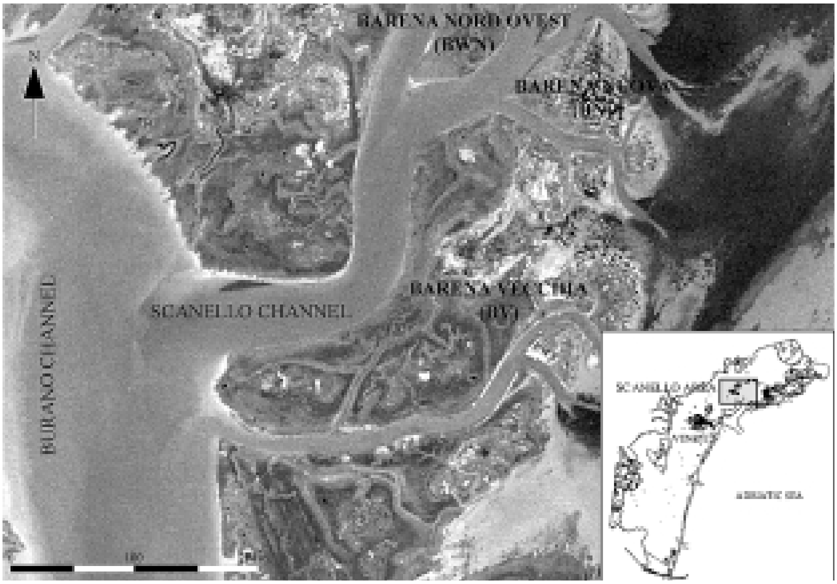

Fig. 1 - Study area.

entire Lagoon of Venice. In the framework of this general study the area of Scanello, located in the Northern basin of the Lagoon of Venice, South East of the Island of Burano (fig. 1), has been chosen as a representative site. In fact previous studies (Bonardi et al., 1997; Bonardi, 1998; Bonardi et al., 1999) highlighted the palaeoenvironmental evolution of the area, known for the presence, at different depths, of archaeological remains dating back to Roman times. The investigation of these salt marshes environments has, therefore, allowed the quantification of the mean sea level variations, related to global changes. Furthermore a detailed topographic study of two salt marshes of the area (Bonardi, 1998) was carried out in order to better understand the recent scale erosional and depositional trends.

2. *Results and discussion.*

2.1 *Hydrodynamic modeling.*

The tidal currents, in particular for the marshy area of Scanello, have been investigated by mathematical modelling. A 2D hydrodynamic finite element model, developed at CNR-ISDGM in Venice (Umgiesser &

Bergamasco, 1993; 1995), has been used to study the circulation pattern of this area.

2.1.1 *The model.*

The hydrodynamic model used is a two-dimensional finite element model. The finite element method gives the possibility to follow the morphology and the bathymetry of the area and to represent with a higher resolution the zones where hydrodynamic activity is more interesting. The numerical computation has been carried out on a spatial domain that represents the entire Venice lagoon through a finite element grid.

The grid for the Venice lagoon has been constructed manually and part of the Scanello area has been created with an automatic mesh generator. The grid contains 8072 nodes and 15672 triangular elements. A higher grid resolution has been imposed inside the area of Scanello in order to obtain more information about the circulation of water. The grid is shown in figure 2 and the zoom for the Scanello area is presented in figure 3. The bathymetric data necessary for the hydrodynamic model have been provided by CORILA.

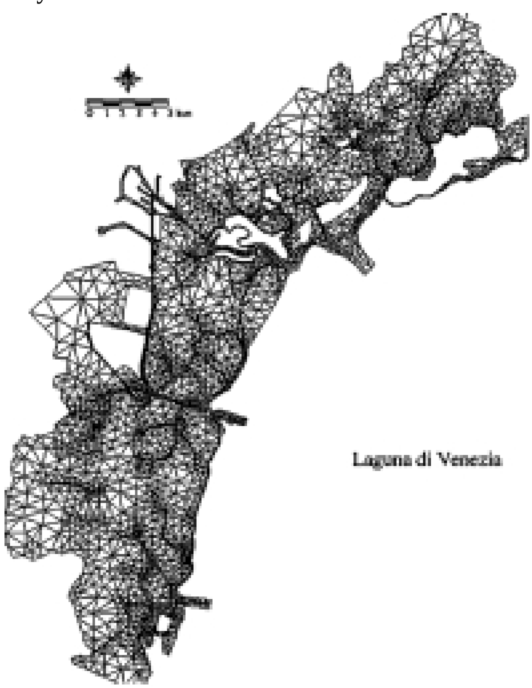

Fig. 2 - Finite element grid of the Venice lagoon.

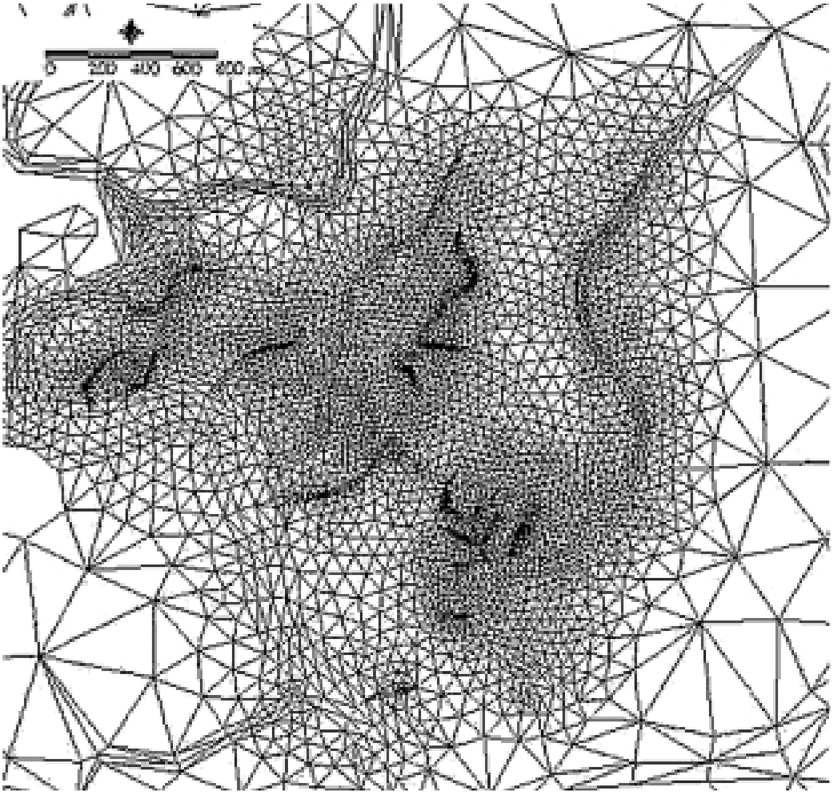

Fig. 3 - Zoom of the Scanello marshy area.

The model considers as open boundaries the three inlets of Lido, Malamocco and Chioggia, elsewhere as closed boundary the whole perimeter of the Venice lagoon.

The model uses finite elements for spatial integration and a semi-implicit algorithm for integration in time. The terms treated implicitly are the water levels, the friction term in the momentum equation and the divergence term in the continuity equation, all other terms are treated explicitly. The model resolves the vertically integrated shallow water equations in their formulations with levels and transports:

$$\frac{\partial U}{\partial t} - fV + gH\frac{\partial \zeta}{\partial x} + RV + X = 0$$

$$\frac{\partial V}{\partial t} + fU + gH\frac{\partial \zeta}{\partial y} + RU + Y = 0$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0$$

where ς is the water level, U and V the vertically-integrated velocities (total or barotropic transports), g is the gravitational acceleration, $H=h+\varsigma$ the total water depth, h the undisturbed water depth, t the time and R the friction coefficient. The terms X and Y contain all other terms like the wind stress, the nonlinear terms and those that need not to be treated implicitly in the time discretization.

The following provides a description of the simulations and results.

2.1.2 *Simulation and results.*

The model has been calibrated using the sea level data measured by fourteen tide gauges located inside the lagoon. The parameter to be varied was the bottom friction (Strickler coefficient).

Different values of bottom friction were assigned to channels and shallow water zones, because of the different morphology and bottom vegetation. The calibrated model reproduces quite faithfully the tidal oscillation in most part of the lagoon.

Simulations have been carried out with a time step of 300 seconds and have been extended to one full year (2001). At the three inlets of the lagoon the same tidal forcing has been imposed. The tidal wave prescribed at the open boundaries is complete of all principal tidal components (M_2, S_2, N_2, K_2, K_1, O_1 and P_1). Other types of forcings have been neglected. The river runoff and the wind forcing have not been taken into account for the time being. A spin up time of one day has been always used for the simulations. Spring and neap tide events have been simulated. The results obtained concerns the main hydrodynamic features of Scanello marshy area.

The tidal circulation has been investigated. The instantaneous circulation in this area is completely driven by the inflowing and outflowing of water through the three main channels of Gaggian, Burano and Della Dolce. The channel of Scanello plays a marginal role in the hydrodynamics of the system because of its smaller section. The magnitude of the current inside this channel reaches the maximum value at the beginning and decreases towards the end. During ebb flow (Fig. 4) the velocity rises up to the maximum value of 0.36 m/s. However, during the flood flow, the maximum current velocity reaches the lower intensity of 0.32 m/s.

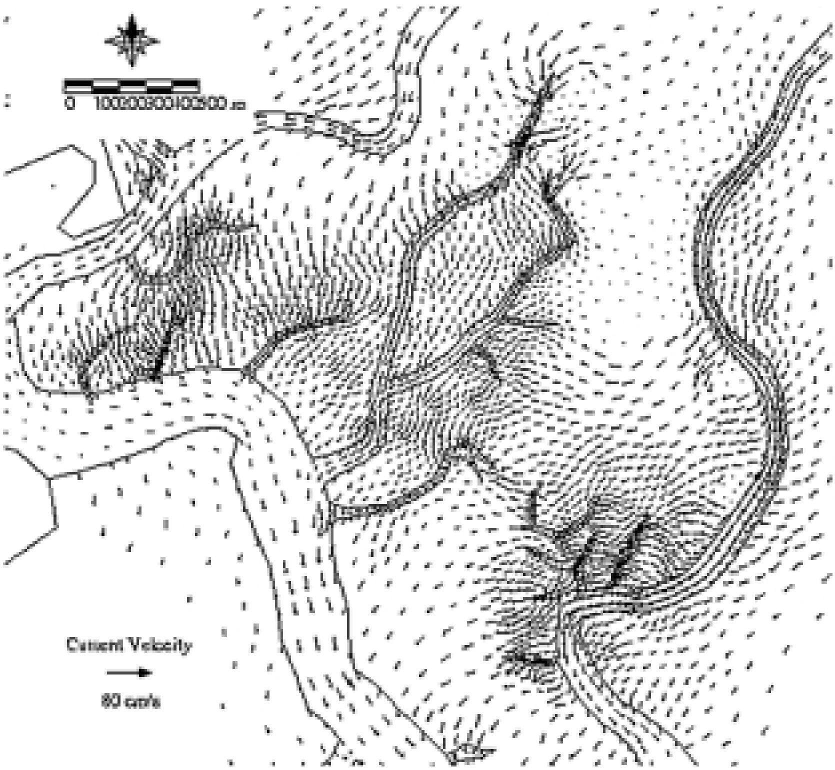

Fig. 4 - Instantaneous circulation pattern of Scanello area observed during ebb tidal cycle.

The residual currents inside this channel are weak: less than 0.01 m/s. The current pattern is entirely caused by non linear topographic effects, especially due to the bottom friction. The magnitude of the residual velocity is an order less then the instantaneous velocity one. The dominant direction is toward the beginning of the channel and it is parallel to its major axis. Similar behaviour of the current velocity has been observed inside the deepest channels where the residual circulation is dominated by ebb tide. Otherwise in the surroundings, where the average depth is less than 0.5 m, residual current magnitude is greater and it reaches values of

0.03 m/s. In these areas the residual circulation is still driven by ebb tidal forcing and the velocity is directed toward the Treporti channel.

More information about the circulation of water in this area will come from further analysis, which will consider both wind and tidal forcing.

2.2 *Geomorphological features.*

Previous studies (Bonardi, 1998) have revealed the evolutive trend of two of the salt marshes, called BV (*Barena Vecchia*) e BN (*Barena Nuova*), under study. Comparing historical topographic maps from 1931 to 1986 and air photos taken in 1961, 1968, 1987 and 1996, it has been possible to evaluate the spatial variations of the salt marshes. In a time span of about 70 years a maximum withdrawing of 58 m of the edge lining the Burano Channel of *Barena Vecchia* was observed (fig. 5, tab.1), whereas a maximum accretion of 80 m of the mud flat facing the northestern edge of *Barena Nuova* was deducted (tab. 1). Table 1 indicates how sedimentation rates are apparently higher than erosional ones; the comparison, however, is purely speculative because it is not possible to directly compare the amount of eroded and deposited sediments if their thickness and spatial distributions were not previously quantified.

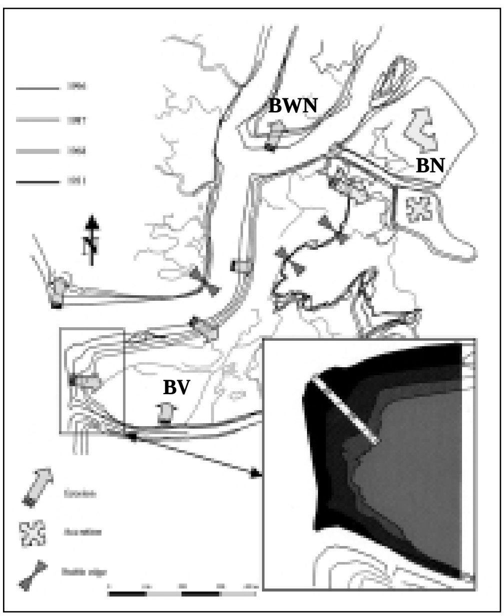

Fig. 5 - Comparison of *Barena Vecchia* (BV), *Barena Nuova* (BN) and *Barena Nord Ovest* (BWN) edges between 1931 and 1996.

Tab. 1 - Erosion rates at *Barena Vecchia* (BV) between 1931 and 1996 and accretion rates at *Barena Nuova* (BN) between 1931 and 1996.

Time span	Maximum surface reduction at Barena Vecchia (BV) (m)	Erosion rates (m/year)
1931-1968	23	0,6
1968-1987	24	1,3
1987-1996	11	1,2
1931-1999	*58*	

Time span	Maximum surface accretion at Barena Nuova (BN) (m)	Accretion rates (m/year)
1931-1968	0	0
1968-1987	56	2,9
1987-1996	24	2,7
1931-1996	*80*	

Furthermore, a series of GPS (Global Positioning System) surveys, conducted for 18 months between 1996 and 1997 and referred to the air photos taken in 1987, has led to the annual quantification of erosional processes (4m/year) occurring along the edges of *Barena Vecchia* and of the area extension of the salt marsh-mud flat limit and the consequent increasing of the salt marsh accompanied by the formation of tidal creeks, the so-called ghebi, at *Barena Nuova* (fig. 6). On the basis of textural and mineralogical analyses performed on the sediments from some cores taken in the Scanello area (Bonardi, 1998) we can suppose that the clayey silts eroded at the edge of *Barena Vecchia* settle down at the mud flat facing Barena Nuova concurring to expand its surface area.

In the framework of the morphological recovery activities of salt marshes performed by the Italian Ministry of Public Works, Water Authority of Venice by way of its concessionary Consorzio Venezia Nuova, the edges of the Barena Vecchia salt marsh have been marked out with containing piling. Therefore, during the topographic survey performed in 2000 the reconstructed edges of Barena Vecchia were mapped; the restored southwestern limits of the salt marsh actually lie approximately along the ones surveyed in 1996. Since salt marshes encourage water exchange, attenuate wave motion and limit the dispersion of sediment in the lagoon and the loss of sediment to sea, the topographic sur-

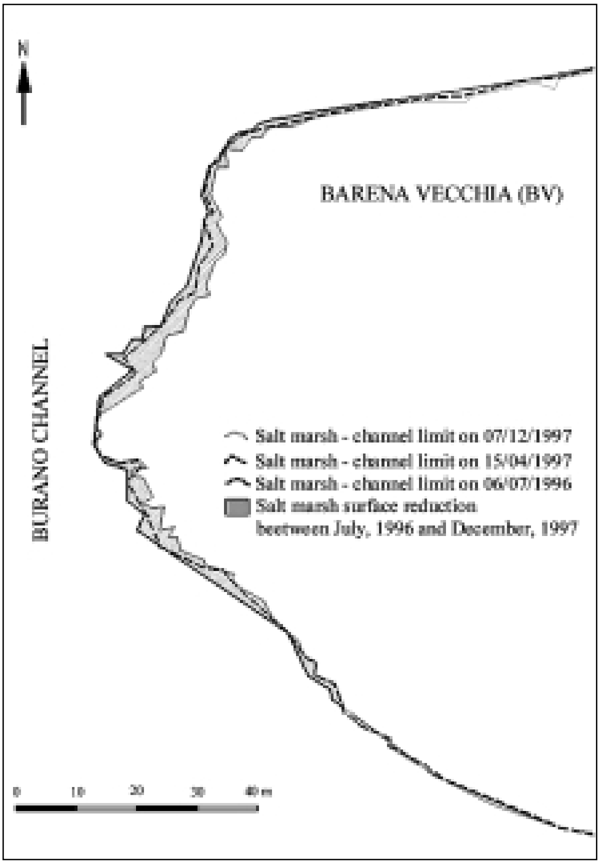

Fig. 6 - Comparison of *Barena Vecchia* (BV) edges between July, 1996 and December 1997.

vey was extended also to Barena Nord Ovest, in order to find out if these restoration activities could interfere with the natural morphological trends of the adjacent mud flats and salt marshes.

In 2002, a new series of GPS measures was so performed only at *Barena Nuova* and *Barena Nord Ovest* (fig. 7). *Barena Nuova* shows a general surface reduction even though it is very limited and meanly quantified in 0.50 m in the two years considered time span. A maximum shifting back of about 2 m was observed at the southwestern corner and in correspondence of the main tidal creeks. Nevertheless, it is important to note that between 2000 and 2002 at the salt marsh edge retreat there was a contemporaneous increase in its altitude, which varies between a mini-

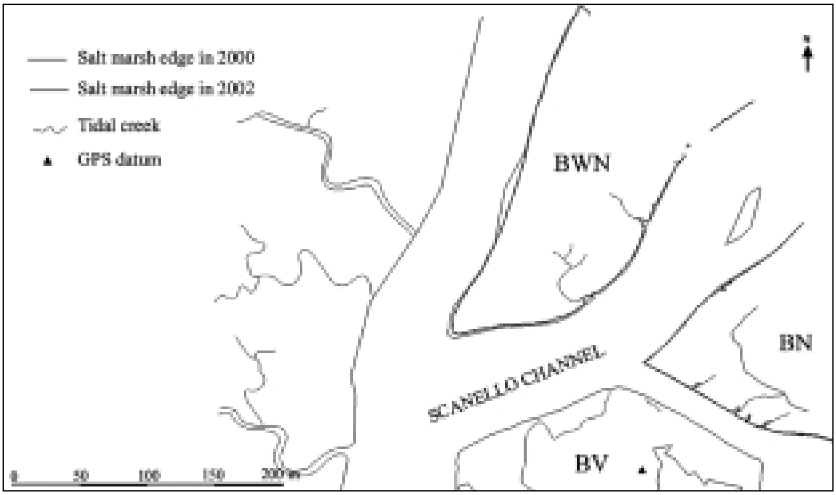

Fig. 7 - Comparison of *Barena Nuova* (BN) and Barena Nord Ovest (BWN) edges between 2000 and 2002.

mum of about 2 mm to a maximum of about 2 cm, and deepening of the tidal creeks. *Barena Nord Ovest* also suffers a general surface reduction, but it is greater than the one observed at *Barena Nuova*. In fact it retreated about 3.75 m at its southwestern corner and more than 7 m along Scanello Channel (fig. 7); however, a slight accretion of about 1 m was observed along the northwestern edge facing Scanello Channel. Even though altitude measures were not performed in 2000, it appears that a tidal creeks deepening is actually taking place on the edge facing *Barena Nuova* of this salt marsh.

Therefore, the 2002 topographic survey supported our hypothesis on sediment erosion, i.e. eroded sediments from *Barena Vecchia* deposit in the mud flat facing *Barena Nuova* and *Barena Nord Ovest*. In fact, after the recovering activities carried out at *Barena Vecchia* the adjacent salt marshes have shown a progressive, even if slight, surface reduction. In any case, the altitude increase and the tidal creeks deepening both indicate that the salt marshes under investigation are becoming more stable. The altitude elevation reflects a depositional trend governed by the tidal regime, which favour the transport and settling of the sediments transported as suspended load. Further, the tidal creeks deepening could be connected to the actual local hydrodynamics which feels the effects of an improvement in water exchange linked to the restoration of *Barena Vecchia*.

3. *Conclusions.*

The study of the salt marshes of the Scanello area, chosen as a representative site in the Lagoon of Venice, has permitted to integrate the data which has been collected in previous research projects in order to evaluate the current geomorphological changes and hydrodynamics interactions.

The topographic surveys, which have been conducted since 1996, and their comparison with historical topographic maps from 1931 to 1986, as well as air photos taken in 1961, 1968, 1987 and 1996, have permitted to evaluate the medium and short term erosional and depositional trends of the salt marshes under investigation. The use of hydrodinamic modeling has given an effort to understand the role that the hydrodynamics plays in the erosion, transportation and deposition of sediments in this test area.

These first results on the actual morphological evolution of the area also contribute to a better understanding of the other studies, in part already carried out, which evaluate the depositional palaeoenvironments.

The medium and short term erosional and depositional trends seem to be strongly connected to local hydrodinamics. In fact, it has been pointed out that the sediments, eroded at *Barena Vecchia* before its restoration, settled down at *Barena Nuova* and *Barena Nord Ovest*. Even if the wave motion produced by motor boats along Scanello Channel could be considered the most disintegrating agent on the edges of *Barena Vecchia*, it seems plausible that local hydrodynamics favour the transport of the eroded sediments northwards as well as their deposition. Actually *Barena Nuova* and *Barena Nord Ovest* suffer a slight surface reduction which can be correlated to the lack of supply of the sediments coming from *Barena Vecchia*. Nevertheless, local hydrodinamic features appear to be fundamental in explaining their increase in altitude and the tidal creeks deepening, considered as the signals of the morphological stabilisation of the salt marshes under study.

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References.

Bonardi M., Canal E., Cavazzoni S., Serandrei Barbero R., Tosi L., 1997. Sedimentological, archaeological and historical evidences of paleoclimatic changes during the Holocene in the Lagoon of Venice (Italy). World Resource Review, 9(4), 435-446.

Bonardi M., 1998. Studio dei processi evolutivi di alcune barene della Laguna di Venezia (Bacino Nord) in relazione alle variazioni del livello marino. Rapporto Finale, Consorzio Venezia Nuova, pp.65.

Bonardi M., Canal E., Cavazzoni S., Serandrei Barbero R., Tosi L., Enzi S., 1999. Impact of paleoclimatic fluctuations on depositional environments and human habitats in the Lagoon of Venice (Italy).

Carbognin L., Gatto P., Marabini F., 1984. The city and the Lagoon of Venice. A guidebook on the environment and land subsidence. In: Proceedings of the Third International Symposium on Land Subsidence, Venice (Italy), 1-36.

Cossu R., de Fraja Frangipane E., 1985. Stato delle conoscenze sull'inquinamento della Laguna di Venezia. Consorzio Venezia Nuova, Servizio Informativo, 4 volumes.

Umgiesser G. & Bergamasco A., 1993. A staggered grid finite element model of the Venice Lagoon. In: K. Morgan, E. Ofiate, J. Periaux, Zienkiewicz, O.C. (eds), Finite Elements in Fluids. Pineridge Press.

Umgiesser G. & Bergamasco A., 1995. Outline of a Primitive Equation Finite Element Model. Rapporto e Studi, vol. XII, pp. 291-320, Istituto Veneto di Scienze, Lettere ed Arti, Venice, Italy.