READING SIGNATURES OF THE PAST TO PREDICT THE FUTURE:
1000 YEARS OF STRATIGRAPHIC RECORD OF THE VENICE LAGOON

Ph.D. candidate: MARCELLA RONER, III course
Tutor: Prof. ANDREA D’ALPAOS
Co-Tutor: Prof. MASSIMILIANO GHINASSI
Cycle: XXVIII

Abstract
This PhD project aims at analysing signatures of the past natural and anthropogenic forcings imprinted in the landscape and sedimentary record of the Venice Lagoon. To this end we studied the governing bio-geomorphological processes acting on salt marshes analysing modern salt-marsh sediments to provide solid bases for the investigation of the Latest Holocene deposits of the Punta Cane succession (southern Venice Lagoon). Here we analysed 25 cores integrating sedimentological, magnetostratigraphic, chronological and elemental data in order to describe the depositional history of the 3.5 m thick deposits which lye below the modern topographic surface. The results suggest that salt-marsh platforms developed since the 14th century. During its lifespan, the salt-marsh system varied its extent and progressively changed its accretion rate in response to anthropogenic-induced perturbations, which caused remarkable variations in subsidence or sediment supply rates.

Introduction
Coastal salt marshes represent a crucially important ecosystem because they provide a shoreline buffer against waves and storms, filter nutrients and pollutant, furnish nursery areas for coastal biota (e.g., Perillo et al., 2009) and serve as an important organic carbon sink due to their great ability to sequester atmospheric carbon (e.g., Chmura et al., 2003). These landforms and ecosystems are exposed to possibly irreversible transformations due to climate changes and human interferences (e.g., Marani et al., 2007; Kirwan et al., 2010; Murray et al., 2011) and, indeed, their extent has dramatically decreased worldwide in the last century, as demonstrated by the reduction of about 70% of the salt-marsh area in the Venice lagoon between 1811 and 2002 (Marani et al., 2007; Carniello et al., 2009). The rising of the relative sea level and the paucity of available sediments are the dominant factors controlling the drowning of salt marshes (e.g., Mudd, 2011), which give pace to tidal flats or to a subtidal platforms. Marshes are populated by halophytic vegetation species (i.e. adapted to live in salty environments) which interact with the inorganic sedimentation in order to keep pace with relative sea level rise (RSLR) and keep a constant salt-marsh elevation in the tidal frame (e.g., Mudd et al., 2009).

Improving current understanding of salt-marsh biogeomorphic processes is therefore a critical step to address salt-marsh response to changes in the environmental forcing. Although in the last few decades a number of studies have analysed salt-marsh biogeomorphic evolution (e.g., D’Alpaos, 2011; Fagherazzi et al., 2012; Marani et al., 2013), a predictive understanding of the two-way feedbacks between physical and biological processes still appears to be elusive. Moreover, analyses of biogeomorphic feedbacks based on data collected in the field at the marsh scale are rare.

Towards the goal of analysing signatures of past environmental forcing imprinted in the landscape and sedimentary record of the Venice lagoon, this PhD program has been performed during two main stages on two different areas of the Venice lagoon. The first stage focused on modern salt-marsh deposits of the northern Venice lagoon (Rigà and S. Felice salt marshes), which is the most natural part of the lagoon, and aimed at better understanding the current physical and biological processes acting on salt-marsh surfaces. The second stage focused on the latest Holocene deposits of the southern Venice lagoon (Punta Cane salt marsh and Valle Millecampi tidal flat), and aimed at understand the main changes in sedimentary patterns occurred over the past 1000 years.

Study areas
The Venice Lagoon represents an outstanding example of man-landscape co-existence. It is the largest lagoon in the Mediterranean area (≈550 km²) with a mean water depth of 1.5 m and a semi-diurnal micro-tidal regime. The exchange with the Adriatic sea occurs via three inlets (from the north): Lido, Malamocco and Chioggia.
The Rigà and S. Felice salt marshes have been the focus of a large number of studies, since they preserve their main natural features being scarcely affected by anthropic pressure over the past century. The study of these modern deposits provided a suitable sedimentological and geomorphological dataset to be used as a solid basis to approach the Late Holocene succession of the southern Venice lagoon. The Punta Cane salt marsh and Valle Millecampi tidal flat, given the considerable anthropic pressure which affected the southern Venice lagoon over the past century, represent an excellent and unique field laboratory to study the effects of natural and anthropogenic-induced modifications on tidal environments. In this area, repeated re-direction of the Brenta River played a key role in terms of freshwater and sedimentary input leading to significant landscape modifications.

**Methods**

**Rigà and S. Felice salt marshes.** A total number of 33 sediment samples distributed along three different linear transects was collected. Each transect consisted of 11 nodes and was delimited on one side by the large San Felice channel and on the other side by two small tidal creeks which wind through the middle of the marshes. We analyzed elevation, sediment dry bulk density, inorganic and organic sediment density, grain-size distribution of the inorganic fraction, vegetation cover for each sample, and we provided estimates of the organic carbon accumulation for these two marshes (Roner et al., 2015).

**The Punta Cane salt marsh and Valle Millecampi tidal flat.** In this area, we collected 25 cores, from 1.0 to 1.5 m deep involving salt-marsh, tidal-flats and subtidal-platform cores. The cores are distributed along a linear transect about 5.2 km long and oriented NE-SW. By high-resolution sedimentological analyses we defined the spatial arrangement of the different deposits along the transect. Magnetic susceptibility was measured for all the cores at ISMAR-CNR of Bologna (Dr. L. Vigliotti). Wood fragments (16 samples) were radiocarbon dated at the INFN-Section of Florence (Dr.ssa M.E. Fedi). Three well-preserved cores, located on the seaward part of the transect, were examined at higher resolution in order to: i) identify changes in organic/inorganic content (Loss On Ignition and a chemical treatment with hydrogen peroxide – Dept. of Geosciences of Padova); ii) define grain size distribution (Dr.ssa E. Franceschinis, Dept. of Pharmaceutical and Pharmacological Sciences of Padova); iii) establish key element distribution through XRF analyses (Dr. A. Gilli, ETH of Zürich); iv) perform geochronological $^{210}$Pb and $^{137}$Cs analyses (Dr. L. Bellucci, ISMAR-CNR of Bologna).

**Results and Discussions**

**Rigà and S. Felice salt marshes**

The topographic analyses show that the San Felice and Rigà salt marshes display a weakly concave-up profile with elevations and coarser grains along the marsh boundaries. The deposition of inorganic sediment is maximum along the marsh edges, where it dominates over the organic deposition, and tends to decrease toward the inner marsh. On the contrary, the organic deposition is low along the channel levee and tends to increase with increasing distance from the marsh borders. The accumulation rates of the organic and inorganic components, related to the position on the salt marsh and to the distance from the channel, are basically driven by the inorganic fraction in proximity of the channel, whereas the organic one becomes more important toward the inner marsh. The accumulation of organic matter in the soil does not increase with the above-ground biomass, which is generally higher along the channel banks and lower in the inner part of the marsh. The organic accumulation in the soil, governed by the plant biomass productivity coupled with the decomposition rate of the organic matter, is highest in the better aerated edge. At least we find that the potential carbon accumulation rate of San Felice and Rigà salt marshes (132 g C m$^{-2}$ yr$^{-1}$) is comparable with the results obtained by other authors (e.g., Chmura et al., 2003; Duarte et al., 2005) for marshes worldwide.

**The Punta Cane salt marsh and Valle Millecampi tidal flat.**

The 25 sediment cores in the Punta Cane area were analysed through the principles of modern facies analysis, which allowed us to identify different type of deposits and to speculate about their depositional environment. The substrate of the study succession is made of peat which consists of plant debris with abundant fragments of reeds. These deposits, at least 2.0 m thick, were accumulated under conditions of reduced clastic input in a brackish to freshwater setting. Above the basal peat both salt marsh and tidal
flat deposits are documented. Salt-marsh deposits are about 2 m thick and consist of brownish laminated silt and mud with spread sub-millimetre layers of sand. They formed since 1360_{-23}^{+32} calAD. Tidal flat deposits covering the basal peat are up to 1.30 m thick and consist of a massive to poorly laminated, organic-rich blackish mud. This mud is floored by a shell-rich lag 3-15 cm thick containing plenty of the brackish bivalve Cerastoderma edule. This layer formed in shallow water conditions as a consequence of wave winnowing during progressive expansion of tidal flat areas which occurred in parallel with the decrease of salt-marsh areas. The results obtained by magnetic susceptibility are not consistent in adjacent cores, suggesting local and variable redistribution of the detritic magnetic fraction. The analyses on the organic content and sediment grain size do not show significant changes along the cores. The XRF results highlight the presence of two intervals in which Si, K, Al, Fe show positive peaks, while Ca has an opposite trend. The accumulation rate model, built up from the $^{14}$C, $^{210}$Pb and $^{137}$Cs data, shows a non-constant aggradation rate with two main values corresponding with peaks of Si, K, Al, Fe. These changes in element distribution and aggradation rate are interpreted as the signature of the re-directions of the Brenta River into the southern lagoon. Nevertheless these peaks appear to be younger if compared with the effective presence of the Brenta River into the lagoon, suggesting that a lag exists between the delivering of the fluvial sediment and its redistribution over the salt marsh, and the increase in the correspondent accretion rate. The present study confirms, through field evidence, what was previously proposed on the basis of mathematical models (Kirwan and Murray, 2008; D’Alpaos et al., 2011), which suggested the occurrence of a lag between changes in the forcings (e.g. re-direction of the Brenta River and related increase in the suspended sediment concentration) and related changes in the vertical accretion rate of the marsh surface.

Conclusions

Rigà and S. Felice salt marshes

• These marshes show a concave-up profile, with higher elevations and coarser grains along their edges.
• The inorganic deposition is maximum on the channel levee and tends to decrease toward the inner marsh. On the contrary, the organic deposition is minimum along the marsh edge and tends to increase moving away from the channel.
• Marsh accretion is basically driven by the inorganic component in proximity of the channel, whereas the organic contribution, determined by the organic deposition coupled with the decomposition rate, becomes more important toward the inner marsh.
• The potential organic carbon accumulation on these marshes ($132$ g C m$^{-2}$ yr$^{-1}$) highlight the considerable carbon stock and accretion rate associated with coastal salt marshes.

The Punta Cane salt marsh and Valle Millecampi tidal flat

• The succession testifies a change from a palustrine to a saltmarsh depositional environment in the 14$^{th}$ century.
• The accretion rate of the salt-marsh surface does not remain constant in time.
• Salt-marsh aggradation, stemmed out from both mud settling and organic accumulation, occurred in parallel with the increase of tidal-flat areas and the decrease of salt-marsh extent.
• Our findings support the results obtained from mathematical models in terms of dynamic response of marshes to changes in the external forcings.

References


**SUMMARY OF ACTIVITY IN THESE THREE YEARS**

**Courses:**

**2013**

ANGEL, R.J.: “Scientific communication”, Dipartimento di Geoscienze, Università degli Studi di Padova.

CALANDRUCCIO, E: “Corso d’inglese parlato”, Dipartimento di Geoscienze, Università degli Studi di Padova.


**2014**


MARANI, M.: “Hydrologic and Environmental Data Analysis”, Nicholas School of Environment, Division of Earth and Ocean Science, Duke University, NC, US.

**2015**

MARANI, M.: “Remote sensing in Hydrology”, Nicholas School of Environment, Division of Earth and Ocean Science, Duke University, NC, US.

**Publications:**


RONER, M., D’ALPAOS, A., GHINASSI, M., BELLUCCI, L.G., BRIVIO, L., FEDI, M.E., AND VIGLIOTTI, L. Morphodynamic evolution of a tidal system during the last millennium in the southern Venice lagoon. *In Preparation.*


**Communications:**

**2013**

2014


2015


Visiting period:

Teaching activities:
- Teaching assistant: 25 hours, “Geologia” (Prof.ssa C. Stefani), Laurea di primo livello in Scienze Naturali (2012/2013).
- Teaching assistant: 24 hours, “Geologia del sedimentario” (Dr.ssa A. Breda), Laurea di primo livello in Scienze Geologiche (2013/2014).

Other:
- Collaborator of guide-book “Geology of Tuscany (Italy)”, NFES Fieldtrip 25th - 29th September 2014, Tuscany, Italy.
- Collaborator of guide-book “Geology of the Pliocene-Pleistocene Crotone basin (Italy)”, NFES Fieldtrip 17th – 21st September 2015, Calabria, Italy.