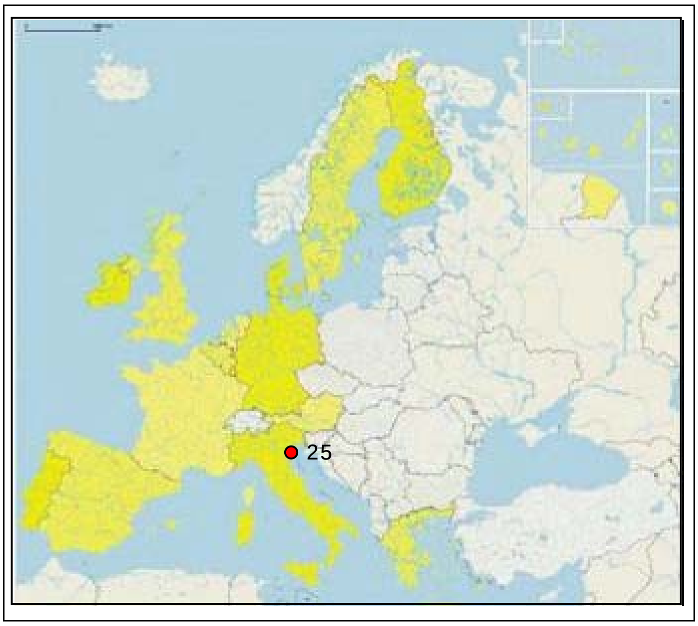
GORO MOUTH
PO DELTA
(ITALY)



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1. GENERAL DESCRIPTION OF THE AREA

The examined area is located in the right side of the Goro Po mouth, inside the southern part of Delta Po system in the High Adriatic Sea, at the south of Venice. Po river, after 600 kilometres of its main course, divides their waters in five branches (respectively from north to south, Maestra, Pila, Tolle, Donzella and Goro rivers). Every branches produced its depositional coastal plain body and deltaic front.

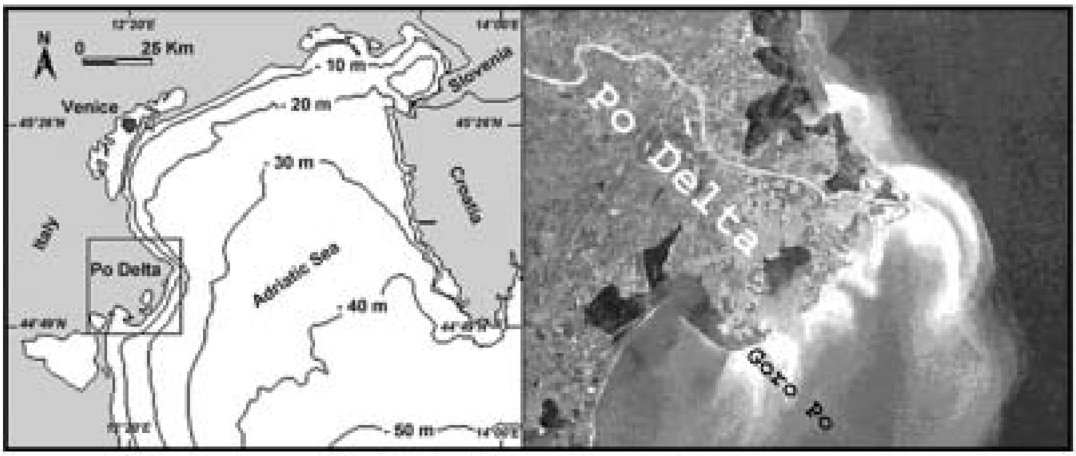

Fig. 1: Po Delta apparatus location. In the southern part of Delta lobe near the Goro Po mouth, there is the described area.

1.1 Physical process level

1.1.1 Classification

- General: River deltas in microtidal zones.
- CORINE: Delta.
- Coastal Guide: Coastal plain.

The deltaic littoral area is mainly characterized by bars sometimes related to wide spits evolution, that edge large inner land lagoons with high anthropic pressure. A submerged delta area, ranging about 6 to 10 km width toward the sea, closes the deltaic apparatus. In all the “Scanno di Goro” spit (Simeoni *et al*., 2000) a beach of about 60 meters wide and a submerged bar at 350 metres distance about are present. The considered mouth area is a focal point for the “Sacca di Goro” lagoon, because the littoral spit system starts from this point, and separates the lagoon from the Adriatic sea.

Fig.2: In the picture are highlighted the main near shore sediment transport directions (arrows) and, as percentages, the frequency and directions from which the waves reach.

1.1.2 Geology

The spit formation start at the last 1800 and the early 1900: for the fist time it was documented in a nautical map of 1897-1907. Today his extension is about 5,5 km. A study (Simeoni *et al*., 2000) highlighted three different way of growth: until '40 years a parallel growth, between '40 and '80 a fan growth, in the following years a branched growth. Today the spit is characterised by tidal mouth: the smallest one by anthropical activities. The sediments of the emerged beaches are medium-fine sands, having about D_{50} = 2-2.5 phi. In the submerged beaches (about 6 meters below the sea surface) the sediments are clay silts.

1.1.3 Morphology of the coast

At nowadays in Goro Po area a sandy beach edged by coastal dunes ridges and submerged bars on the bottom are present. The spit defines the homonymous behind lagoon, 200 hectares wide and about one meter deep. The morphology of the emerged lands in the Delta area shows wide portions under the present sea level.

The Goro Po mouth shows a clearly asymmetric morphology dues to the erosive trend acting in left side of the mouth and a large bar in the upstream side. All these conditions indicate that the environment evolution is strongly controlled by waves (Del Grande and Tessari, 2000; Simeoni *et al*., 1998).

Fig. 3: Airborne photo referred to1994 year (Ferrara Province courtesy) where is clearly possible to see the mouth asymmetry and the fluvial sediment supply curvature.

1.1.4 Physical processes

The delta area is part of the Po river Plain and is inclusive of temperate – cold climatic zone. The annual average rainfall ranges is about 600 mm. The wind direction ranges from 260-280° with modes also from 130° to 160°. The Po Delta prominence generally stops many waves that occur to southern littoral where normally the waves are very low and come from 60 and 120 degrees. The low energy events, with a significant wave high less then 0.5 meters, show a frequency of about 68.1% with middle energy. With waves high from about 0.5 to 1.5 meters the frequency is about 2.7 %. Waves having high energy (significant high more than 1.5 meters) are very rare. The tidal range is about 1.20 meters.

Nearshore currents

The longshore transport is connected to Sirocco and Levanter winds; the other winds have less importance for the protection offered by Po Delta apparatus prominence. The sedimentary supply for the Goro spit are mainly due to Goro Po river contribute, less from Gnocca and Tolle Po rivers and, partially comes from reworked sediments coming from northern beaches with a transportation average about of 180 millions m^3 every year.

From 1975 to 1980, 1.3 million m^3 of sandy sediments was brought to the sea from Goro Po. Only partly these sediments supply the Goro spit growth because most part of these are dispersed on the bottom and trapped, by mouths, in the backward lagoon. In the last tens years 8 million m^3 of sediments have nourished the sea bottom in front of Goro spit, but great part of these counterbalance the local natural and human induced subsidence. The whole Po river water flow, from 1918 to 1991, range from 902 e 2620 m^3/s. From 1984 till to 1997 a lowering of water flow happens (1486 m^3/s) even if, during the 1992-1994 years, many important floods occur.

At the some time also an alluvial sediments occurrence lowering occur in these years, stabilized on values of about 5.1 Mt/yr during 1984-91.

Subsidence

Former researches (Bondesan e Simeoni, 1983) show that from 1900 to 1957 , the Goro area lowers in a differentiate way about 8mm/yr. To the natural subsidence, after 1938, the human induced subsidence adds up. The lowering rate, after this time, in fact highly raises, mainly in the period 1951-1962. After this year the rate little decreases: it is possible verify that, after the period 1950-1970, the average lowering was of about 50 cm. The lowering rate also today is important: in the neighbouring Goro area, from 1987 to 1993, ranges from 1.63 to 2.31 cm/yr.

1.1.5 Erosion

Till to 50ties the Goro Po mouth always moves seaward (Simeoni and Bondesan, 1997) with rate progressively lesser: from 1599 to 1869 (during 270 years) the advancing was of about 80 m/yr (Dal Cin, 1983); between the end of 19th and the beginning of 20th centuries (1893-1911) the advancing was about 10 m/yr, reaching more recently, between 1911 and 1932-34 years, rate of 17 m/yr and, in the subsequent twenty years, rate of 5 m/yr. The Goro Po mouth shows an highly asymmetric morphology: an erosional trend of the mouth right side and an advancing trend or steadiness of left side, that also presents, in the in front sea bottom, a well developed submerged bar system (Del Grande and Tessari, 2000).

These morphologies are due to the relationship between subsidence and sediment river supply,. that from the middle of 50ties becomes unvarying. The littoral tract, near to the mouth right side, presents more intensive erosional phenomena than other beaches on the spit; here the beach is very narrow and also lacking in some points. This fact induced the need to protect this littoral tract, where there is the Goro lighthouse, realising, from 70ties, works to mitigate the coastal erosion risk (Idroser, 1994). The erosional phenomena, in the last years, still increased, beginning again for the lighthouse area and the spit a stability crisis, increasing the sea storm risk on the inner lagoon and in the little towns of Goro and Gorino, not anymore sheltered by the littoral spit.

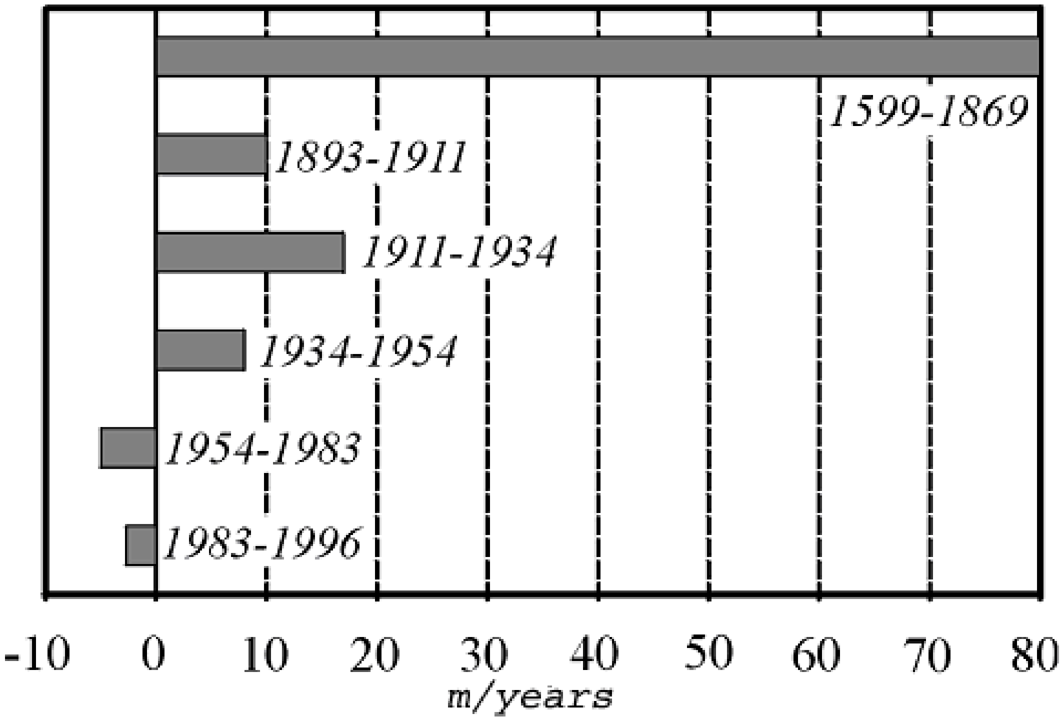

Fig. 4: Diagram of coastline movements in the Goro Po mouth area; the values are referred to about one kilometre of littoral in the right side of the mouth.

1.2 Socio economic aspects

Two small towns are inside the described area, Goro and Gorino: the first one with 3500 inhabitants and, the second one, with 700 inhabitants.

The most important activities of this area are referred to fishery that, from '80 years, became the main profit for the inhabitants, after the introduction of breeding of clams (*Tapes philipinarum)* inside the lagoon, and of mussels in the in front sea. These new income possibility induced the rejection of the agriculture activities in the reclaimed inner lands. The present fisheries activities employ about 1000 fishermen and 200 employed in induced activities: about 164 fishing boats and 599 motorboats are used. The incomes related to the whole fisheries activities is approximate around 50 million of € /year.

In the last years a daily ecological tourism of the Goro Po environments takes place; the area in fact is completely inside the Po Delta Regional Natural Park: in the last year about 40,000 people visited these areas.

Investments for lagoon and coast maintenance, from 1977 to 2001, range around 12 million of euros.

2. PROBLEM DESCRIPTION

2.1 Description of eroding sites

At the end of 1999 a very important erosive phase started to affect the right side of the Goro Po mouth, likewise yet happened in the 70[ties]. The Goro Po fluvial lug impedes the nearshore drift of sediments coming from Pila, Torre and Donzella Po-delta branches, and, working as a breackwater, modifies the sediments transport and favours the left side mouth advancing, inducing, at the same time, the retreating of the right mouth side (Del Grande & Tessari, 2000).

In few months (during winter of year 2000) the beach nearest the Gorino Lighthouse was eroded and the sea, also without storms, started to lap the wall that bounder this area. The waves during sea-storms or/and high tides, flood a large area at the back of the beach.

Fig. 5: The lighthouse area before that the main destructive erosional trend begins (60 [ties]); note the little wall that bounder the lighthouse sea.

Fig. 6: Little wall near to lighthouse referred to his former position (29 November 2000), as shown in figure 5.

2.2 Impacts

Erosion could produce the lighthouse lost but, mainly also the break down of the littoral spit in his connection with the inlands. This evolution will produce the demolition of this tongue of land that, at the present, divides the lagoon from the sea and guarantee the lagoon survival. If the spit will break, the lagoon economic activities will be prejudiced and improved the flooding and sea-storms risk for the Goro and Gorino towns. The erosion progress ,in fact, will demolish the lagoon internal defenses (banks) inducing the flooding of large part of these lands that are below the present sea level.

3. SOLUTIONS / MEASURES

3.1 Policy options

Many policies concur to sustain the maintenance of this area: the regional policy (Environment Councillorship- Soil and coasts Defense) aims to safe the areas, when populated or industrial activities could be damaged by natural hazards. Po Delta Natural Regional Park policy is to keep relevant natural areas and, when possible, to restore the natural value of damaged areas, mainly trough eco-compatible actions. The Goro Municipality and the Ferrara Province policies aim to safe the economic activities and the natural value of this land.

3.2 Strategy

The tools and methods used have been adopted after studies on the hydro and morphodynamic evolution of this areas, trough researches and numerical models used to test possible different option to mitigate the natural risk. The studies, done by the Earth Science Department of Ferrara University, have been financed by Environment Councillorship of Emilia-Romagna Region. Having the aim to respect the particular and quick natural morphodynamic evolution (Simeoni, 2000) the possible solution ought to have a very soft environmental impact, in order to keep the natural hydrodynamic and the environment peculiarities.

The aim of the chosen integrated strategy is: to allow the navigability of the Goro Po mouth; to break the circular hydrodynamic cell evolution (that with this clockwise trend induced the sandy beach erosion and the sediments transfer to sea bottom in front of the beach); to re-nourish the sandy beach in front of lighthouse; to defend from flooding the inner lands.

3.3 Measures

All the past and recent measures have been done in the right side of the Goro Po mouth. The first big measure date to 70$^{\text{thies}}$ with groins made with Longard tubes, filled with sand. This measure induced a beach growing for some years, but, from the middle of 80$^{\text{ties}}$, the erosion trend restart till to the completely lost of the beach in front the lighthouse.

Fig.7: The Londard tubes placed during ‘70ties

In the 2002 springtime the new integrated soft measure starts. To improve the navigability at the Goro Po mouth, the sands are taken from the submerged bar in front of the lighthouse beach, and, these sediments (about 80.000 m^3), are used for the beach re-nourishment, for about 600 meters of length.

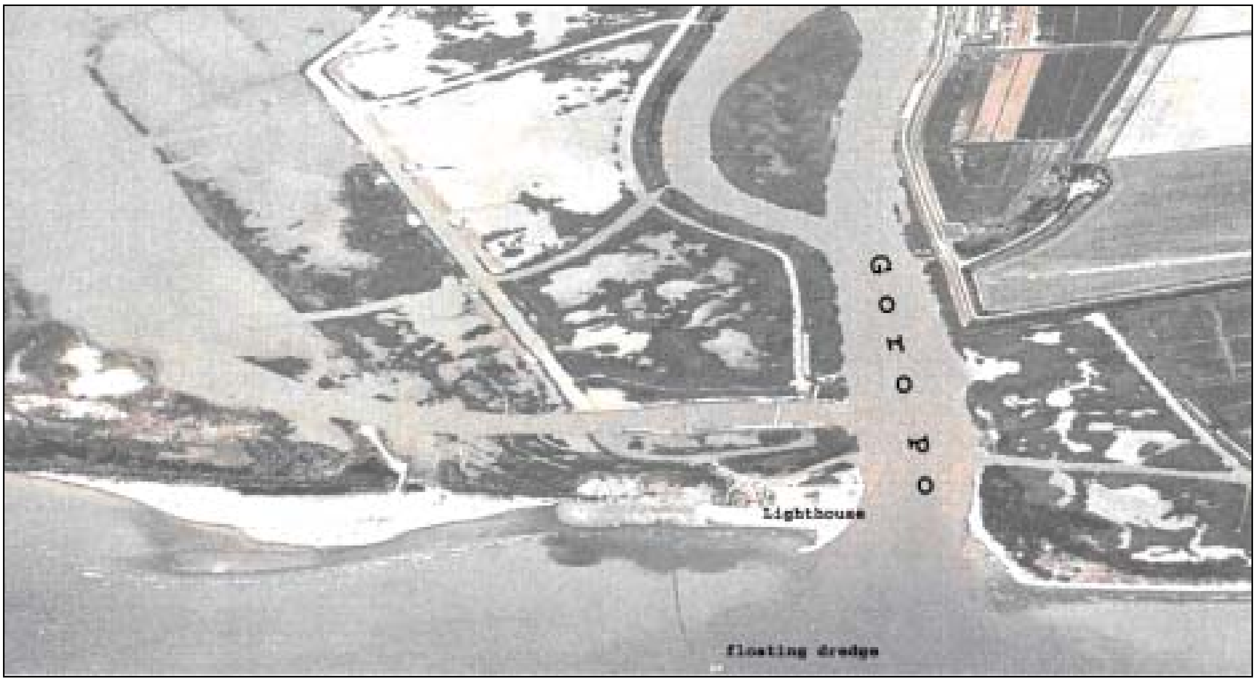

Fig.8: The last measures to mitigated the costal risk in the lighthouse area are in progress; a dredging machine is working drawing bottom sediments to pour them on the beach.

At the external boundary of the new beach a little groin has been built to stop the moving away of beach sands toward the sea, induced by the circular hydrodynamic cell.
Only these measure do not allow to protect the inner lands from flooding and to keep the Goro spit survival. To achieve also these results, a coastal dunes rebuilding plan has been made, based on morphological surveys on nearest natural coastal dunes. Data have been collected regarding winds, waves and historical coastline evolution. These data have been used as input for mathematical models to project the new beach and dune morphologies.

These coastal dunes rebuilding can work better than natural coastal dunes, because their core is armed with gabions filled with stones covered by a permeable geotextile. To favour the artificial dunes bodies capability to adapt them to any future possible new beach profile changes, the gravel mattresses have been placed over a wood poles structure done by vertical poles fixed in the bottom of the beach and connected among them trough horizontal poles. This system will consent adjustment movements of the gravel mattresses that could assume the better position in relation to any new beach profile.

Fig. 9: The reinforced costal dunes construction: a) the wood poles structure on what have been placed the gravel mattresses; b) the gravel mattresses under the sands shaped as dunes; c) the coastal dune building; d) the final armoured dunes shaping.

The armed core, that now is completely covered by sand, if some erosive event will happen, till to demolish the wholeness dunes body, can come out and work as seawall perfectly accordingly with the new beach profile. This capability to change and adjust their position, will allow to reduce the main negative effects tied to the reflection, typically induced by this kind of seawall.

Fig. 10: The Goro Po mouth (right side) appearance after the beach and dunes rebuilding accomplishment.

3.3.1 Costs

The whole cost of these measures, done from 4 March to 31 July 2002, is about 656,600 euros. The costs (euros) of each different action done are:

Beach nourishment	274,600
Dunes rebuilding	158,000
Geotextiles purchasing and in site setting	15,000
Poles purchasing and in site setting	3,600
Stones in site setting	113,400
Metal gabions purchasing and in site setting	92,000

4. EFFECTS AND LESSONS LEARNT

4.1 Effects related to erosion

The measures have been well tested during the recent storms (winter 2002-2003). The rebuilt beach, after a first adjustment phase, got stability and, locally, overcome of about 10 meters, the former nourishment shoreline position. This is probably tied to the small groin activity that breaks the hydrodynamic erosive cell activity.

The coastal “armed” dunes offered an efficacious defense against sea water flooding during sea storms, because never waves overcome them. This is a very important fact considering the tendency of this littoral area to be submerged in the future scenarios, especially during sea storm events.

At regional level this new approach to mitigate the coastal flooding risk assumes a very great relevance mainly related to wider sea storm defense programs. A large part of littoral of the Emilia-Romagna Region that is nowadays below the present sea level, is subsequent to very strong subsidence phenomena and the coastal dunes have been intensively destroyed both, by sea erosion, and human activities.

At present, this area is stabilized with measures completely accordingly with the natural evolutionary dynamics and with the environmental characteristics.

4.2 Effects related to socio economic aspects

The measure do not have any negative impacts on the environments, on the contrary, a former coastal dunes- beach system has been recovered. The spit stability was kept and that guarantee the safe of the Goro and Gorino towns. Moreover, the monitoring activities are in progress and highlighted that the coastal dunes system is in equilibrium: some new in embryo dunes are growing and, on the artificial dunes, a natural flora is increasing.

4.3 Relation with ICZM

In the managerial plans, to mitigate natural risks, a great relevance is given to a “cybernetic” interpretation of Nature concept (Van Zoest, 1992). Today, accordingly with this tendency, in the coastal management solutions more respectful of the beach system dynamic and able to favour the natural re-settlement, are preferred.

The measures used in the area nearest the Gorino lighthouse agree to transform the coastal dunes into coastal defense works, keeping and also improving the environment quality, applying innovative building techniques.

The experience carried out beyond to give important suggestions for similar cases, encourages programs to keep and rebuild the coastal dunes because highlights their possible role as “defense works” for the coastal lands.

4.4 Conclusions

This integrated approach, to mitigate the coastal erosion and inner lands flooding, has shown its efficaciousness. It allows to propose a rebuilt ecosystem that is capable to evolve without environmental bad impacts.

It proves that is possible to combine coastal defense works with an ecological sustainable approach having all the guarantees for inhabitants and economic activities: this is possible to achieve without necessarily use extensively hard works. Furthermore it highlighted the possibility to use coastal dunes or rebuild them join the need to keep the fragile ecosystem like coastal dunes, without antagonism with coastal management plans in areas with high natural value.

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