ADAPTATION TO BEACH EROSION AT MAREMMA REGIONAL PARK (TUSCANY, ITALY)

Luigi Enrico CIPRIANI[(1)], **Enzo PRANZINI**[(2)], **Giovanni VITALE**[(2)], **Lilian WETZEL**[(2)]

[(1)] *Settore Protezione e Valorizzazione della Fascia Costiera e dell'Ambiente Marino, Regione Toscana, Via di Novoli 26, 50127 Firenze, Italia.*
e-mail: luigi.cipriani@regione.toscana.it
[(2)] *Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Borgo Albizi 28, 50122 Firenze, Italia.*
e-mail: epranzini@unifi.it, giovanni.vitale@unifi.it

Abstract. Severe erosion has been affecting the Ombrone river delta apex since the second half of the 19th Century and is currently expanding gradually to adjacent beaches. Main causes of this process include coastal marsh reclamation, land-use changes within the watershed, dam construction, and river bed quarrying. In addition, the Ombrone river delta area is subsiding at an average rate of approximately 10 mm/yr. As a result, the river mouth underwent shoreline retreat of over 1100 m in the past 130 years, and the erosion rate currently reaches a peak of 10 m/yr. During recent decades, the Maremma Regional Park decided to allow for beach erosion to proceed, and therefore not to build shore protection structures along the coast. This aimed at keeping the natural landscape unaltered whereas preventing triggering beach erosion on neighboring coastal sectors fed by sediments eroded from the delta apex. However, due to recent acceleration in erosion rates, the shoreline now cuts the coastal dune system and salt water stems interdune swales during storms; as a consequence, valuable junipers, pine forests and freshwater ecosystems have been seriously damaged. In face of that, the Park administration applied for a sustainable shore protection project within the scope of the Regional Coastal Protection Plan, which consisted of managed realignment of 150 m shore extension. The existing, obsolete 420 m long dyke, presently located along the shoreline of the delta southern wing, will be removed and reconstructed 150 m inland as a major protection measure against extreme storm events. From the offshore side of the new seawall a set of 18 groins will be buried into the ground with the crest at –0.50 m; these structures will reach the present shoreline underground; six of them, in the southern sector, will be extended in the nearshore as submerged groins for approximately 150 m. Beach erosion will gradually exhume these structures, which will become progressively more effective in reducing current shoreline retreat rates. Shoreline is forecasted to reach the seawall within 15 to 25 years in such protected conditions. In the meantime the Ombrone River Basin Authority will have to implement efficient measures for restoring river sediment transport at a magnitude capable of allowing natural beach stabilization in the littoral cell. If these parallel actions are developed in the near future, shoreline retreat will be halted before the seawall is reached, resulting in a sandy beach stabilized by the submerged groin set.

Key words: river delta, natural park, coastal erosion, shore protection, managed realignment, submerged groins

INTRODUCTION

The Ombrone river delta (Fig. 1), one of the most uninhabited areas of the Tuscany coast, is located within Maremma Regional Park and comprises the alluvial plain, coastal dunes, beach ridges, lagoons and interdune swales. A wild Mediterranean environment is the main attraction of the site, characterized by agricultural crops, deciduous woods, artificially implanted pine trees and long sand beaches, lacking any tourist structures (Natura 2000 sites; European Commission, 2011).

The coast is microtidal (tidal range = 30 cm) and exposed to south - south western storms, with a limited angular dispersion and resultant energy coming from 190°N (Fig. 2).

The delta formed during the past 25 centuries, due to deforestation within the river watershed since Etruscan times. Relationships between human occupancy of the territory and delta evolution were studied by Innocenti and Pranzini (1993) who showed that accreting phases occurred during intense demographic expansions (Etruscan, Roman, Middle Ages and Renaissance), whereas retreating phases date from the Roman Empire Fall (with its demographic and economic consequences) and the Black Death, which halved the population in Tuscany (Pinto, 1982). In its most prominent position, the delta apex was approximately 7.4 km far from the innermost detectable beach ridge in the coastal plain, demonstrating the intensity of soil erosion in this river basin, which has approximately 3495 km^2 surface.

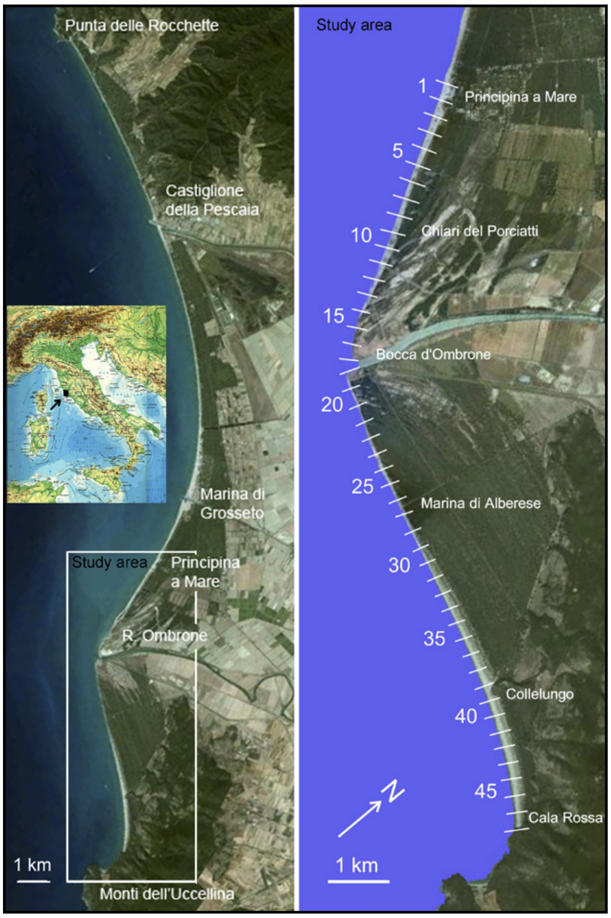

Fig. 1 Location map; on the right, division of the coast into sectors for shoreline evolution analysis.

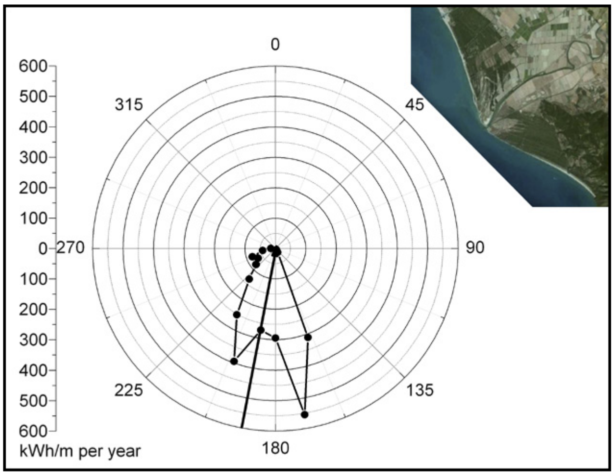

Fig. 2 Wave energy offshore Ombrone river delta based on KNMI observations (1961 – 1990); black line shows the resultant direction.

Wetland was reclaimed in the coastal plain from 16th to 19th Century (Barsanti and Rombai, 1986) through river diversion for delivering sediment to the settling ponds, resulting to be the first cause of beach erosion in this area (Milano *et al.*, 1986). Changes in land use, reforestation, river bed quarrying, and dam construction are further factors which have been inducing a drastic reduction in sediment input to the coast, from the late 19th Century to present.

Nevertheless, no shore protection measures were considered necessary for halting beach erosion in this area; at first, because of its marginal character; and later, due to the creation of the Regional natural park. Along the retreating area, some agriculture and pasture were implemented by a Regional farm even though shoreline retreat allowed for salt water intrusion in the interdune swales after delta cusp beheading - thus leading to the death of pine trees and to changes in freshwater habitats that had historically developed in these marshes (Fig. 3).

However, further to shoreline retreat of approximately 1.1 km, making the delta cusp less protruding onto the sea, erosion rates did not decrease and a coastal restoration project was requested by the Regional park administration.

Coastal evolution and sediment dynamics were studied to design a "sustainable" shore protection project, considering that, in the face of the reduced river sediment transport, the main input to the lateral beaches is provided by the erosion of the delta itself.

SHORELINE EVOLUTION

Early 19th Century maps show a very protruding delta, with sandy lobes closing elongated paddles, but the accuracy of these documents is not such to allow for a reliable shoreline evolution study. However, comparison of maps and written documents allow assessing that the last shift from accreting to eroding phases is dated from the second half of the 19th Century (Pranzini, 1994).

More accurate evaluations can be performed over Italian Army Geographic Institute maps, firstly surveyed in 1883 (1:50,000 scale) and in 1929 (1:25,000 scale). During these 45 years, the delta tip flattened and the shoreline retreated for over 320 m at the river mouth (Fig. 4).

Nevertheless, only 1500 m of the beach are eroding, whereas the remaining coastline is accreting, according to a model described by Pranzini (1989) where an equilibrium point, sharply separating retreating and accreting segments, moves from the delta apex to the furthermost beaches along time.

The first map based on aerial photo restitution dates from 1954 and shows that the process is following the same pattern, causing erosion of approximately 4700 m of coastline (2000 m to the south and 2700 m to the north of the river mouth), with shoreline retreat of approximately 300 m at the river mouth.

This severe erosion of the delta apex was studied by Innocenti and Pranzini (1993) and related to land use changes in the Ombrone river watershed, with a close symmetry to what happened at the Arno river mouth (Pranzini, 1983). A similar retreat was found for isobathic contours from 1883

Fig. 3 Coastal marshes flooded by seawater inducing death of freshwater vegetation and pines

to 1977 (Bartolini and Pranzini, 1984), a process acting also outside the depth of closure, possibly due to gravity-induced processes responsible for the slumping observed on seismic profiles (Bartolini and Pranzini, 1982).

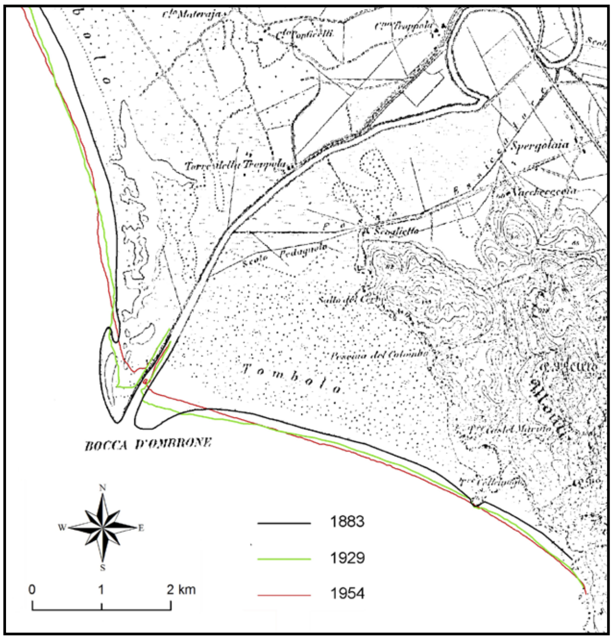

Fig. 4 1929 and 1954 shorelines drawn over the 1883 to pographic map (original scale 1:25.000)

Due to the SSW provenience of most storms (Fig. 2), such a reshaping changed wave refraction patterns near the delta apex, increasing northward longshore transport on the northern side and reducing the transport in the opposite direction along the southern lobe (Aminti and Pranzini, 1990).

Higher spatial and temporal details are required for the analysis of the processes reshaping the delta in the past decades, in order to define coastal management strategies and shore protection projects. Shoreline evolution was thus studied from 1954 to 2006 using aerial photo restitution (1954, 1973 and 1984) and direct topographic surveys (1998 and 2006). The coastline from Principina a Mare, in the north, and Cala Rossa, in the south (Fig. 1), was subdivided in 47 sectors 250 m long for which *mean shoreline displacement* (m) and *mean shoreline displacement rate* (m/yr) were computed with AUTOCAD rel. 2004 (Tab. 1).

From 1954 to 1973 the Ombrone river delta apex (sectors 10 ÷ 29) retreated an average of 99.8 m, (*i.e.* 5.2 m/yr), whereas side beaches accreted - values higher at the northern extremity (average 51.2 m; 2.7 m/yr) and lower at the southern tip (average 35.3 m; 1.85 m/yr) (Fig. 5).

In the delta apex area 540,425 m^2 of land were lost, and along its wings 115,174 m^2 (north) and 158,879 m^2 (south) were acquired. On the south side the rocky headland; there is a fixed cell boundary (*sensu* Carter, 1988) and all the sediments moving in this direction were trapped between Collelungo and Cala Rossa (Fig. 1), whereas on the northern side the physiographic unit ends at Punta delle Rocchette, 24 km far from the river mouth, and only a limited part of the sediments moving northwards actually feed Principina a Mare beach (Fig. 1).

From 1973 to 1984, sediment redistribution from the delta apex to lateral beaches continued; the eroding area expanded though, reaching sector n. 8 to the north and sector

Table 1 Mean shoreline displacement (m) and mean shoreline displacement rate (m/yr) in the 47 coastal sectors during the studied periods

	Mean shoreline displacement [m]				Mean shoreline displacement rate [m/yr]			
	1954÷1973	1973÷1984	1984÷1998	1998÷2006	1954÷1973	1973÷1984	1984÷1998	1998÷2006
1	45.10	-3.10	14.00	-1.40	2.37	-0.28	1.00	-0.18
2	46.50	0.90	19.70	9.10	2.45	0.08	1.41	1.14
3	37.20	28.50	24.80	2.60	1.96	2.59	1.77	0.33
4	13.20	75.00	15.40	-0.20	0.69	6.82	1.10	-0.03
5	30.90	58.80	13.20	11.90	1.63	5.35	0.94	1.49
6	57.60	28.60	5.90	4.00	3.03	2.60	0.42	0.50
7	94.40	17.20	-54.60	44.20	4.97	1.56	-3.90	5.53
8	91.40	-20.20	-102.10	62.70	4.81	-1.84	-7.29	7.84
9	44.50	-64.00	-96.00	60.80	2.34	-5.82	-6.86	7.60
10	-25.20	-59.30	-105.60	54.50	-1.33	-5.39	-7.54	6.81
11	-26.00	-105.10	-17.70	-16.70	-1.37	-9.55	-1.26	-2.09
12	-85.80	-93.80	16.40	-41.60	-4.52	-8.53	1.17	-5.20
13	-90.80	-89.30	45.40	-88.50	-4.78	-8.12	3.24	-11.06
14	-133.70	-77.90	22.40	-61.80	-7.04	-7.08	1.60	-7.73
15	-127.50	-112.10	-44.40	-22.60	-6.71	-10.19	-3.17	-2.83
16	-126.70	-91.10	-89.50	-50.40	-6.67	-8.28	-6.39	-6.30
17	-294.08	-126.94	-77.36	-56.35	-15.48	-11.54	-5.53	-7.04
18	**River mouth**				**River mouth**			
19	-185.70	-21.80	-139.40	0.00	-9.77	-1.98	-9.96	0.00
20	-208.50	-121.80	-89.10	-78.00	-10.97	-11.07	-6.36	-9.75
21	-156.00	-98.00	-64.70	-67.50	-8.21	-8.91	-4.62	-8.44
22	-128.20	-81.80	-49.80	-40.00	-6.75	-7.44	-3.56	-5.00
23	-112.40	-81.20	-50.00	-26.50	-5.92	-7.38	-3.57	-3.31
24	-90.20	-68.10	-48.50	-21.80	-4.75	-6.19	-3.46	-2.73
25	-64.40	-57.80	-47.00	-18.40	-3.39	-5.25	-3.36	-2.30
26	-52.90	-50.10	-43.40	-26.30	-2.78	-4.55	-3.10	-3.29
27	-36.70	-33.80	-34.90	-17.20	-1.93	-3.07	-2.49	-2.15
28	-39.30	-27.50	-34.40	-18.50	-2.07	-2.50	-2.46	-2.31
29	-23.90	-12.60	-24.30	-15.80	-1.26	-1.15	-1.74	-1.98
30	11.30	-6.60	-20.30	-12.40	0.59	-0.60	-1.45	-1.55
31	16.50	-0.60	-14.40	-5.00	0.87	-0.05	-1.03	-0.63
32	20.30	8.50	-10.60	-7.80	1.07	0.77	-0.76	-0.98
33	18.20	18.90	-0.40	-1.00	0.96	1.72	-0.03	-0.13
34	16.20	19.90	7.90	-1.40	0.85	1.81	0.56	-0.18
35	27.00	15.20	13.20	-1.60	1.42	1.38	0.94	-0.20
36	26.70	15.90	16.50	0.30	1.41	1.45	1.18	0.04
37	30.70	15.00	18.70	5.00	1.62	1.36	1.34	0.63
38	40.90	5.80	25.10	7.90	2.15	0.53	1.79	0.99
39	39.00	4.20	20.50	11.40	2.05	0.38	1.46	1.43
40	38.00	3.30	18.20	15.60	2.00	0.30	1.30	1.95
41	42.10	2.20	23.20	15.70	2.22	0.20	1.66	1.96
42	39.00	4.40	19.60	10.20	2.05	0.40	1.40	1.28
43	46.50	-0.40	24.10	5.50	2.45	-0.04	1.72	0.69
44	47.20	-1.10	26.60	2.50	2.48	-0.10	1.90	0.31
45	61.30	0.40	19.20	6.80	3.23	0.04	1.37	0.85
46	60.80	0.10	20.40	9.30	3.20	0.01	1.46	1.16
47	53.60	-0.60	17.40	0.00	2.82	-0.05	1.24	0.00

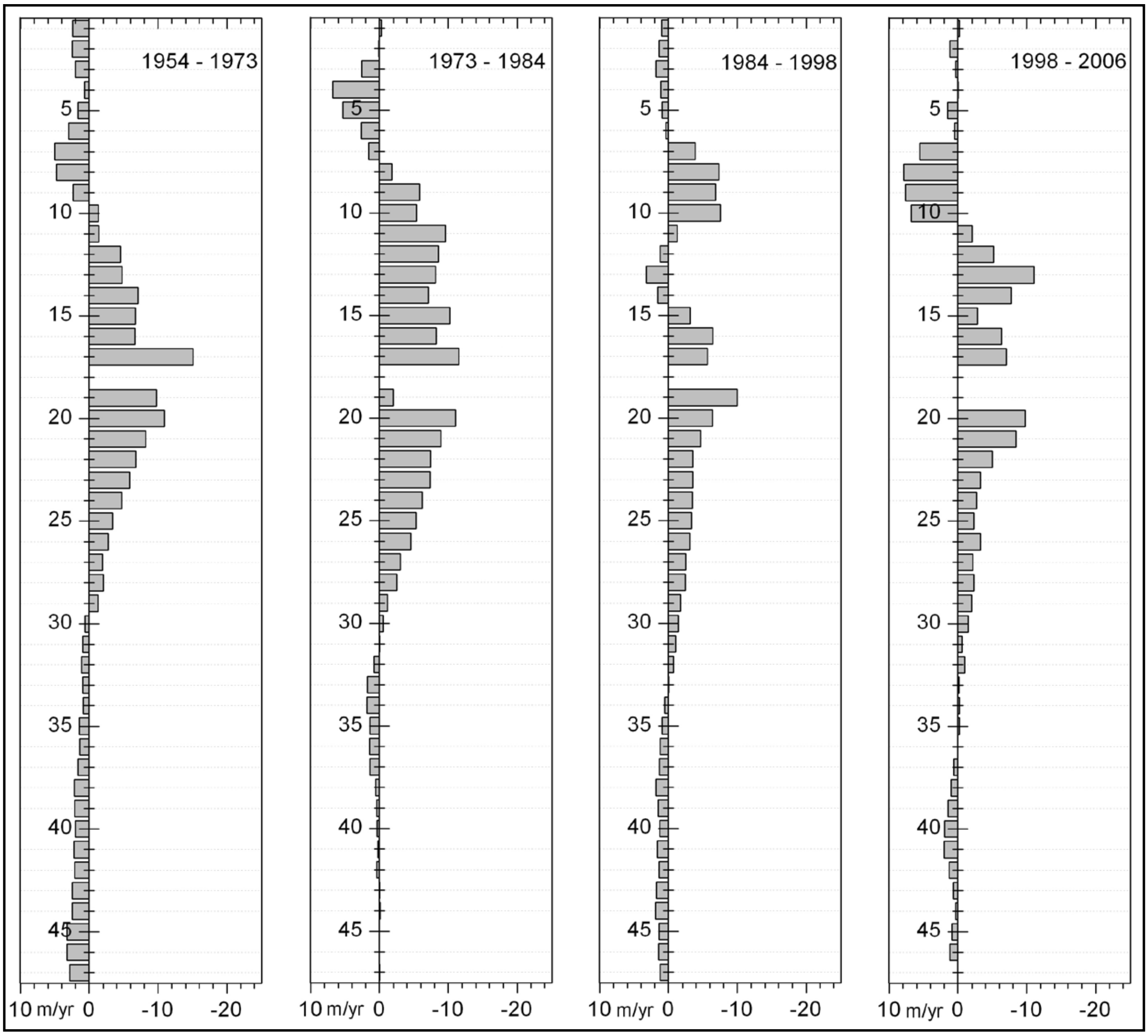

Fig. 5 Mean shoreline displacement rate (m/yr) along the 47 sectors for each period

n. 31 to the south. Mean shoreline retreat value is 70.2 m and mean beach accretion is 29.4 m (north) and 7.0 m (south).

There was beach surface loss of approximately 391,787 m^2, and accretion of circa 51,497 m^2 in the northern sectors and 27,758 m^2 in the southern ones. At Marina di Alberese, sector n. 27, 33.8 m of beach were eroded and the only existing building near the beach (a restaurant) was destroyed; the same happened to the parking lot and the final part of the coastal road (Fig. 6).

The general trend of beach erosion at the delta apex and deposition alongside beaches was confirmed in the 1984 – 1998 period, with the exception of three sectors on the northern lobe, now accreting. This side of the delta has always been characterized by the presence of mega-cusps, and their longshore movement can create alternate conditions of accretion and erosion if one considers a short time lapse. In addition, a nearshore sand bar was present in 1998 in front of the accreting sectors.

In the eroding coastal segment, there was mean shoreline retreat of 4.2 m/yr, with the highest value (10 m/yr) in sector n. 19 - just south of the river mouth, where the shoreline reached a rip-rap built to prevent inland flooding (Fig. 7), thus resulting stable in the following periods. The 14 southern sectors had an increase in beach width of 1.4 m/yr on average (1.9 m/yr max value), whereas in the northern beach there was average accretion of 1.1 m/yr (1.9 m/yr max value).

During 1998 – 2006, there was average beach erosion of 3.9 m/yr (max 11.1 m/yr) in the retreating area. Beach retreat extended down to sector n. 35 on the southern lobe, but the process turned out to be more complex on the northern one, where significant accretion moved from sectors 12 - 14 to sectors 5 - 10; however, the whole beach in the north expanded. In the 11 southernmost sectors there was average beach accretion of 1.1 m/yr.

Fig. 6 Marina di Alberese: the road cut off by erosion. A parking lot and a restaurant were present in this area during the 1970s

Fig. 7 Rip-rap on the southern side of the Ombrone river mouth (sector n. 19)

Fig. 8 Accreting beaches north (Principina a Mare) (**left**) and south (Collelungo) (**right**) of the eroding area. In the 1950s it was possible to dive into the sea from the cliff at Collelungo. Note embryo and foredune formation on both sites (photos were courtesy of Provincia di Livorno)

During the 52 years studied, the delta apex was hit by severe erosion, with extreme values of 845 m (16.2 m/yr) on the northern lobe and 497 m (9.6 m/yr) on the southern one.

Along the eroding sectors 1,234,224 m^2 of land were lost in this period, whereas in the side beaches there was accretion of 246,773 m^2 (south) and 167,785 m^2 (north).

Globally, there was surface reduction of approximately 819,667 m^2, mostly lost by northern beaches to the sediment sink situated out of the study area. However, in sectors characterized by deposition along the 52 years under study, there was expansion of over 110 m on the northern beaches and over 70 m in the southern ones (Fig. 8).

RECENT NEARSHORE EVOLUTION

Nearshore evolution between 1998 and 2006 was documented through the comparison of 48 bathymetric profiles (Fig. 9) extended from the dune foot to the 10 m isobath - approximately the depth of closure for a return time of 50 years (De Filippi *et al*., 2008).

Significant changes are related to seasonal bar migration, mostly on the northern side where nearshore bars are more numerous and extended. Onshore deposition is evident on both delta lobes, showing good correlation to a similar process offshore.

Analysing changes along single sections (Fig. 10) we can see that the central area, from Chiari del Porciatti to Collelungo, has a negative budget, whereas the northern sector, from Chiari del Porciatti to Principina a Mare, and the southern one, from Collelungo to Cala Rossa, have a positive budget. Along nearly half of the profiles (25 out of 48) mean bathymetric change happens within ± 10 cm, *i.e.* inside the accuracy of the method (Carli *et al.*, 2004); along the rest of profiles mean depth variation occurs within 10 and 41 cm, mostly with negative values.

Bigger changes can be seen from the backshore to the nearshore at water depth of approximately 5 m, both in eroding and accreting areas, mostly for bar migration. Profiles at the delta apex show consistent lowering in most of their length, whereas in accreting areas sedimentation occurs almost exclusively in the nearshore (Fig. 9). Consequently, sediments produced from uniform surface erosion result to be larger than those necessary for an expansion of the beach in the same magnitude, as proven by Anfuso *et al*. (2011) for the northern Tuscany coast.

Summing up all the differences, a negative sediment budget of approximately 1,914,000 m^3 can be retrieved over a surface of approximately 17,757,000 m^2, with mean lowering of circa 11 cm.

If the eroding sector is considered, loss of approximately 2,333,731 m^3 results; *i.e.* circa 300,000 m^3/yr, with an average lowering of 21 cm in the 8 years under study.

Sediments eroded here feed the southern beach with 220,000 m^3 (mean seafloor elevation of 7 cm) and the northern one with 199,000 m^3 (mean seafloor elevation of 5 cm) (Fig.11); most of the missing sediment will feed the 24 km long beach northwards (up to Punta delle Rocchette).

SHORE PROTECTION STRATEGY

Maremma Regional Park designed a shore protection project within a Regional Coastal Protection Plan, with funds of 6 million Euro provided in 2003 by the Region of Tuscany.

Data analyzed in this paper and the following conclusions are the basis for this project, for which the University of Florence gave the following guidelines.

The protection of the southern delta lobe is of prime importance; here erosion is more severe and the coastal marshes are exposed to seawater flooding. The northern sector, with a possible longshore sediment transport reversal, consequent to the erosion of the delta, will potentially receive more sediment.

In spite of considering nearshore change values as gross estimations for the actual sediment budget in the different areas (due to the accuracy problems mentioned), their mag-

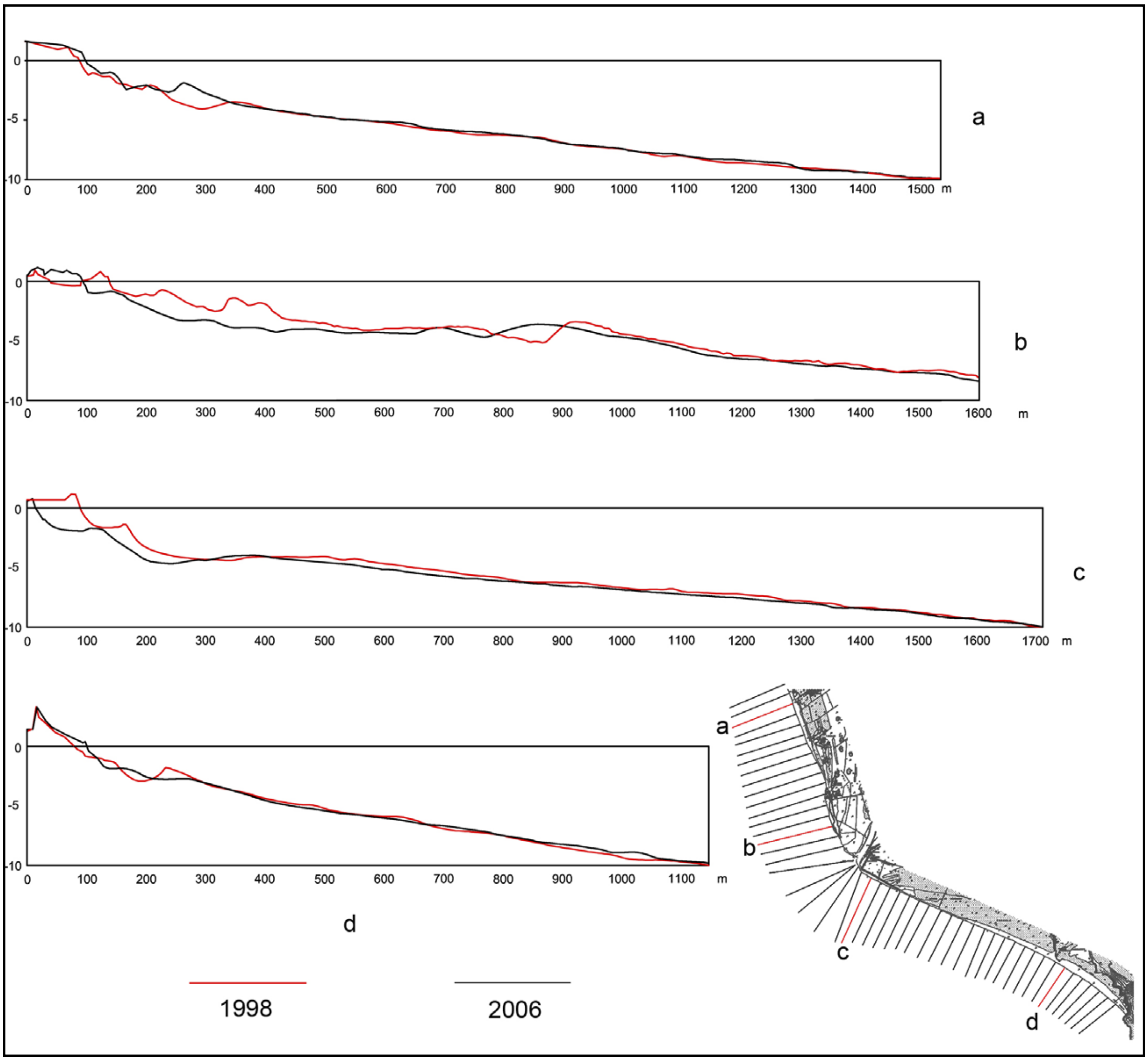

Fig. 9 Nearshore changes from 1998 to 2006 along four profiles that represent the different evolution trends (Vertical exaggeration = 20)

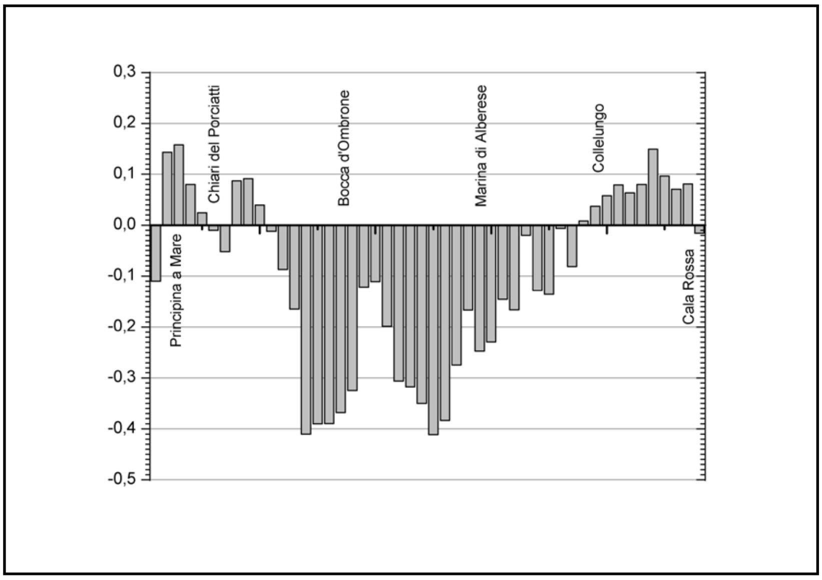

Fig. 10 Mean depth variation on the different sections surveyed from 1998 to 2006

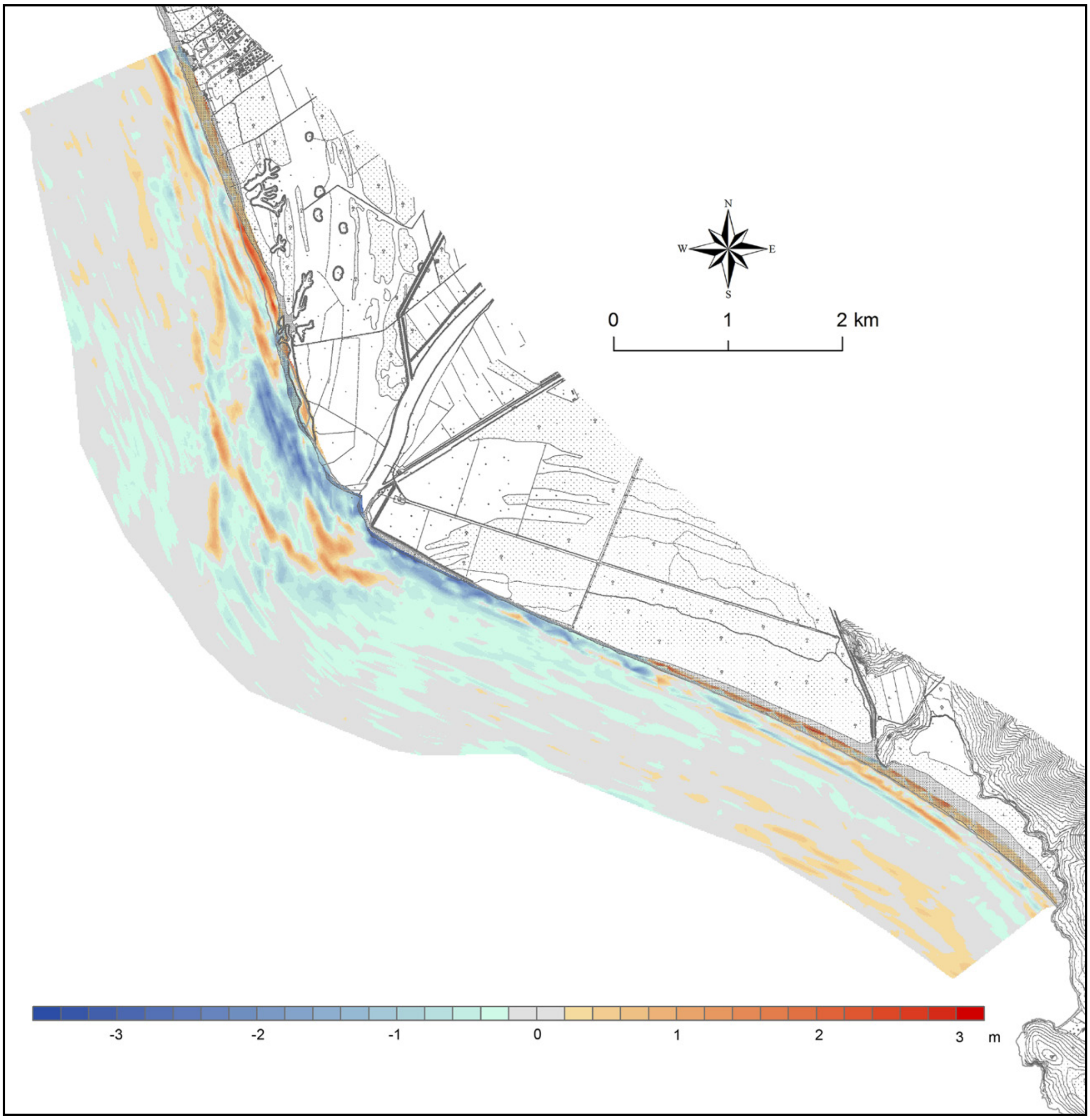

Fig. 11 Nearshore variations between 1998 and 2006 for the Ombrone river submerged delta

nitude orders are reliable and this data influence the future coastal defence strategies.

Possible solutions are: 1) frequent and expensive artificial beach nourishment 2) engineering works to reduce sediment loss; 3) no active intervention, *i.e.* live with coastal retreat.

Given the impossibility of nearshore sediment dredging, due to environmental restrictions at regional level, and the temporary unavailability of continental shelf sand reservoirs near the study area (Chiocci *et al.*, 2009), the use of inland aggregates was considered. Unfortunately, very limited volumes of sand are available on the Tuscany market, thus recent nourishment projects in the region were performed using sand quarried in the Po River alluvial plain (Emilia-Romagna Region); actual beach fill cost is estimated as approximately 40 €/m^3, unsustainable in an area where beach tourist activity produces little income.

The use of traditional hard shore protection strategies was abandoned for two reasons: 1) the landscape value of the Park area must be preserved; 2) beach erosion produces sediments that feed the more touristic beaches in the north, where local stakeholders will not agree with a measure that halts this input.

Shoreline retreat was considered acceptable since no infrastructure or buildings are present along this stretch of coast. The only limitation to this solution is the maintenance of the artificial draining system to collect water and pump it onto the river in order to allow for agriculture and forestry activities in this subsiding lowland (1 cm/yr according to Salvioni, 1957).

Following these considerations, a shore protection project was designed, allowing shoreline retreat of approximately 150 m. The existing and obsolete rip-rap, presently located along the shoreline of the southern delta wing, will be removed, whereas a new seawall will be built 150 m inland as a major protection measure against extreme storm events. This will be vegetated and will be used as an extension of the existing bicycle route of the Regional Park system.

From the offshore foot of the seawall, 18 trenches will be cut to host concrete groins with the crest at - 0.50 m; their offshore tip, outcropping on the present beach, will be constructed with wooden piles for environmental reasons. Beach erosion will gradually unbury these groins, which will start to work as submerged structures (Aminti *et al.*, 2004), thus reducing the erosion process itself.

With the present erosion rate (circa 10 m/yr at the delta apex) shoreline should reach the seawall in about 15 years; a longer time is expected for the submerged groins. Within a wider perspective of integrated river basin management, the Ombrone River Basin Authority will be asked to act in order to increase the natural river sediment load before waves start to attack the seawall. If nearshore sediment mobility will be reduced by submerged groins and river sediment input will be partially restored, it is expected that the coastal system reaches equilibrium, and the seawall remains only as the last defence under extreme events. Additional river sediment input will be able to feed side beaches.

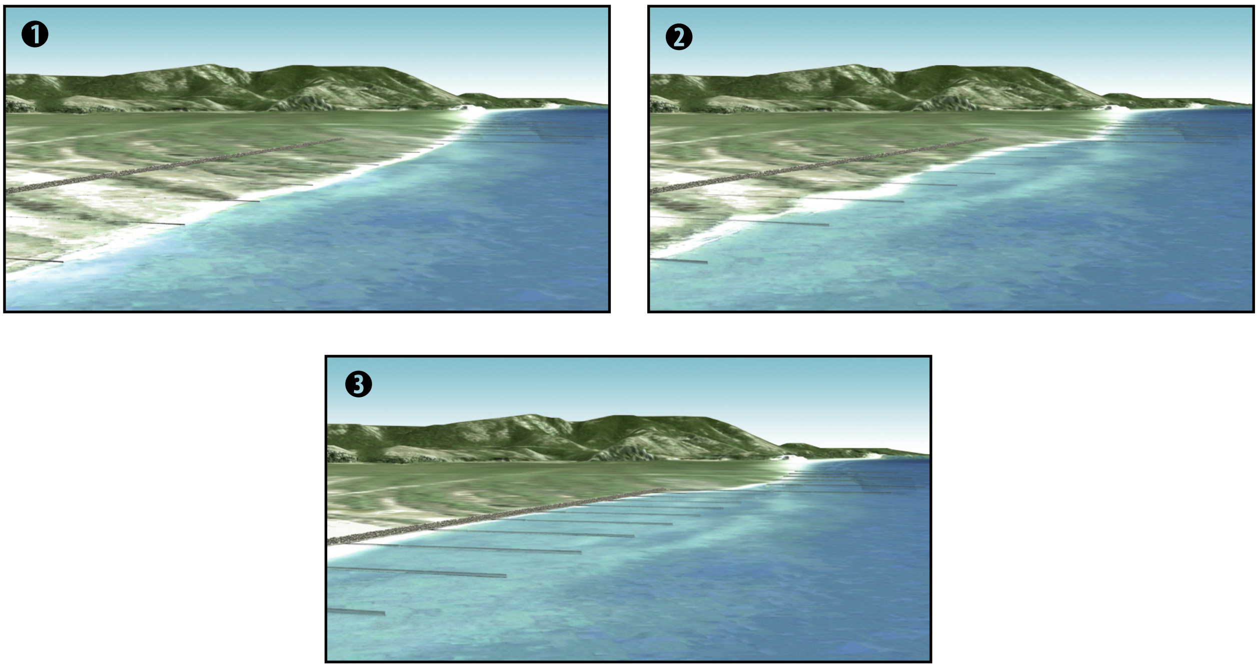

Fig. 12 Managed realignment project along the southern side of Ombrone river delta (Rendering: Nevio Danelon, DST-UNIFI). **Legend: 1)** Retreated seawall and buried groins. **2)** Partial exhumation of groins, which start acting as submerged structures **3)** Utmost position of the shoreline with the seawall able to protect inland areas from extreme storms.

CONCLUSIONS

Coastal erosion on the Ombrone river delta proceeds at the same velocity from the past 130 years, and there is mean sediment deficit at the delta apex of circa 300,000 m^3/yr. Such a deficit cannot be compensated with artificial nourishment, due to the high cost of sand in this area; it can neither be limited by traditional hard shore protection measures, due to the environmental value of the site. In addition, further to a severe reduction in river sediment input, this coastal sector now acts as sediment source for side beaches, the northern ones supporting a blooming tourism industry.

Beach retreat of approximately 150 m is acceptable; the artificial channels and pump system draining the entire delta area could collapse under shoreline retreat of over 150 m, therefore a seawall will be constructed. From the offshore side of the seawall a set of 18 groins will be buried into the ground with the crest at - 0.50 m; these structures will reach the present shoreline underground. The groins will be unburied by erosion and gradually start to work reducing beach retreat. It will take the shoreline a long time to reach the seawall – a time long enough to allow the Ombrone river Basin Authority to take measures for restoring part of the original river sediment input to the beach (which could potentially find equilibrium before reaching the seawall).

This adaptation strategy was adopted here for the first time in Italy, further to a participatory process involving local stakeholders, NGOs, local and regional Administrations and the Park community. The demand for such a strategy shall increase in the future, since sea level rise and shortage of sediment adequate for beach nourishment will make it unsustainable to maintain the present shoreline position everywhere. The present case study will now be monitored as to physical and socio-economical issues in order to provide data able to support further adaptation projects in the region.

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