

—In : Transformations and evolution of the Mediterranean coastline—

## The role and responsibility of man in the evolution of the Italian Adriatic coast

by

Umberto SIMEONI and Marco BONDESAN

*Dipartimento di Scienze Geologiche e Paleontologiche,  
Università di Ferrara, Italy.*

### ABSTRACT

A large part of the 1250-km long Italian Adriatic coast is affected by significant erosive phenomena. Human activity, such as cultivation, construction of roads and railways, interventions carried out in the catchment basins, extraction of sediment from the river channels and construction of barrages for various uses, has violently changed the natural conditions of the sediment transport of the rivers. Clear proof of this is provided by the cusped river-mouths which were growing at the beginning of the century but now show in the large majority of cases worrying signs of erosive processes. In the last fifty years these anthropic factors have caused an accelerated erosion of the coast with the establishment of phenomena which are either irreversible or at least difficult to correct. In the Adriatic this problem is particularly worrying and accentuated as a result of the large urbanisation development which today extends along more than 50 % of the coast. To counter this trend extensive defensive structures have been built, mainly in the form of breakwaters and groins. These have drastically altered and rigidified the hydrosedimentary dynamics of the coast.

### RÉSUMÉ

Une grande partie des 1250 kilomètres de la côte adriatique italienne est affectée par une érosion drastique. L'activité humaine, comme l'agriculture, la construction de routes et de voies ferrées, les interventions dans les bas-

sins hydrographiques, l'extraction de sédiments dans les rivières et la construction de barrages à diverses fins, ont radicalement changé les conditions naturelles de transport des sédiments par les fleuves. La preuve en est fournie par l'évolution des embouchures qui au début du siècle avançaient dans la mer et montrent aujourd'hui, dans la plupart des cas, des signes inquiétants d'érosion. Au cours des cinquante dernières années, ces facteurs anthropiques ont provoqué une érosion accélérée de la côte et la mise en place de phénomènes irréversibles ou, pour le moins, difficiles à corriger. Sur la côte adriatique, le phénomène est particulièrement marqué et inquiétant, résultat d'un important développement de l'urbanisation qui aujourd'hui couvre plus de la moitié du littoral. Pour contrer cette tendance, de vastes structures défensives ont été construites, principalement des brise-lames et des épis. Elles ont dramatiquement altéré et rigidifié la dynamique hydrosédimentaire de la côte.

## INTRODUCTION

A close connection exists between the use of the land and the evolution of the coast, making it necessary to acquire a series of parameters representative of the terrestrial domain in order to understand coastal dynamics. A study carried out by PASKOFF (1985) showed that on a global scale about 70 % of the beach is retreating and only 10 % is advancing. This highlights a general evolutionary tendency that is related to worldwide phenomena, often unavoidable, which are sometimes accentuated by local situations and are frequently caused by man. The factors that determine this situation have dimensions which are either global, as in the case of climatic variations, regional (catchment basin) or local.

On the beaches of the Adriatic Sea man has had an influence first of all by varying the sediment supply. He has in fact modified the regimes and the water discharge of the rivers, intervening in their montane basins as well as on the hydrographic network on the plains, mainly by building embankments along the rivers. In addition reclamation by alluvion and extraction of sediments from the river channels have caused a direct reduction of the sediment transport; these interventions have a notable impact, especially when carried out close to the river mouth. Other indirect reductions in the nourishment of the beach have been caused by activities which are apparently unrelated to the evolution of the coast, such as the extraction of water and hydrocarbons from the subsoil which provokes subsidence. In addition, with the anthropic destruction of the dunes the sources of nourishment of the beaches have been further impoverished. Finally, with the construction of ports, jetties, breakwaters and defensive structures, perturbations have been introduced into the hydrosedimentary dynamics of the coast.

In recent years high blooms of planktonic algae (diatoms, and mostly dinoflagellates) have frequently affected the waters of the Adriatic, especially during the summer, leading to anoxia and putrefaction and causing major damage to fishing and tourism. Further, eutrophication events are more and more frequent along the Adriatic coast. These are closely related to an excessive nutrient load, especially of phosphorous, which the Po and other rivers transport to the sea. This further demonstrates the vulnerability of the Adriatic to a continually growing anthropic impact.

### THE ADRIATIC ALLUVIAL PLAINS

Along the coast of the Adriatic Sea, which is about 1250 km long, one finds alluvial plains such as the Po plain and the Tavoliere in Puglia, as well as narrower alluvial plains which have often been formed by the conjunction of adjacent deltas (regions of Marche, Abruzzi and Molise).

The Po plain has a surface area of 46,000 km<sup>2</sup> and is divided into three large sectors: the hydrographic basin of the river Po, which is the largest one, the northeastern area which comprises the river basins in the regions of Veneto and Friuli (from the Adige to the Isonzo), and the southeastern area which corresponds with the river basins in Emilia-Romagna (from the Reno to the Conca) (Figure 1a). The coast which borders the plain extends for about 270 km (21.6 % of the Adriatic coast) and is flanked by the largest wetland zones in Italy; from north to south there are the Marano and Grado lagoons (143 km<sup>2</sup>), the Venice lagoon (about 530 km<sup>2</sup>) and various smaller lagoons on the edge of the current delta. Others paralic environments are in the form of brackish wetlands (Valli Venete, Valli di Comacchio, etc.) and freshwater marshes. These coastal areas deserve particular attention because of their continuity and economic importance, even though they represent only 8.3 % of the total length (3,263 km) of the Italian beaches.

The Tavoliere plain in Puglia has a surface area of about 3,000 km<sup>2</sup> and borders the Adriatic with 52 km of coast (Figure 1c). It is located between the Appennines, the Gargano promontary and the lower course of the river Ofanto, the largest river in the region.

The modification of the coastal plains started in the Mediaeval period and became more marked in modern times. In fact the current landscape of the Po delta and a large part of the coast to the north of it can be considered, for better or for worse, to have been planned by man, especially in order to safeguard the Venice lagoon from landfill. For this reason between 1599 and 1604 the Venetians deviated the main course of the river Po towards the south, by means of the "Taglio di Porto Viro", which gave origin to the current delta, and the branches oriented towards the north were subsequently closed (either totally or partially) (BONDESAN and SIMEONI, 1983). The rivers Bacchiglione, Brenta, Piave and Sile were also directed away from the Venice lagoon. In various epochs man has also intervened on other rivers in order to modify the mouths: the rivers Lamone, Montone and Ronco in Romagna, and the rivers Musone and Potenza in the Marche (Figure 1b) (ORTOLANI and ALFIERI, 1947). While not modifying the quantity of the sediment transported by the rivers, these interventions locally changed its distribution on the coast and therefore conditioned the evolution of the beaches.

Apart from a few exceptions, in the nineteenth century the coastal plains remained almost completely uninhabited, as they were covered by woods and marshes, exposed to the danger of flooding and infested by malaria.

The majority of the land reclamation works on the Adriatic plains took place at the end of the last century, to resume in the 1920s and 30s and again in the 1960s. In the 1970s, 98 % of the freshwater marshes and more than 70 % of the brackish wetlands present at the beginning of the twentieth century had been reclaimed. The coastal strip was notably weakened by these interventions, and in particular by the mechanical reclamation (using

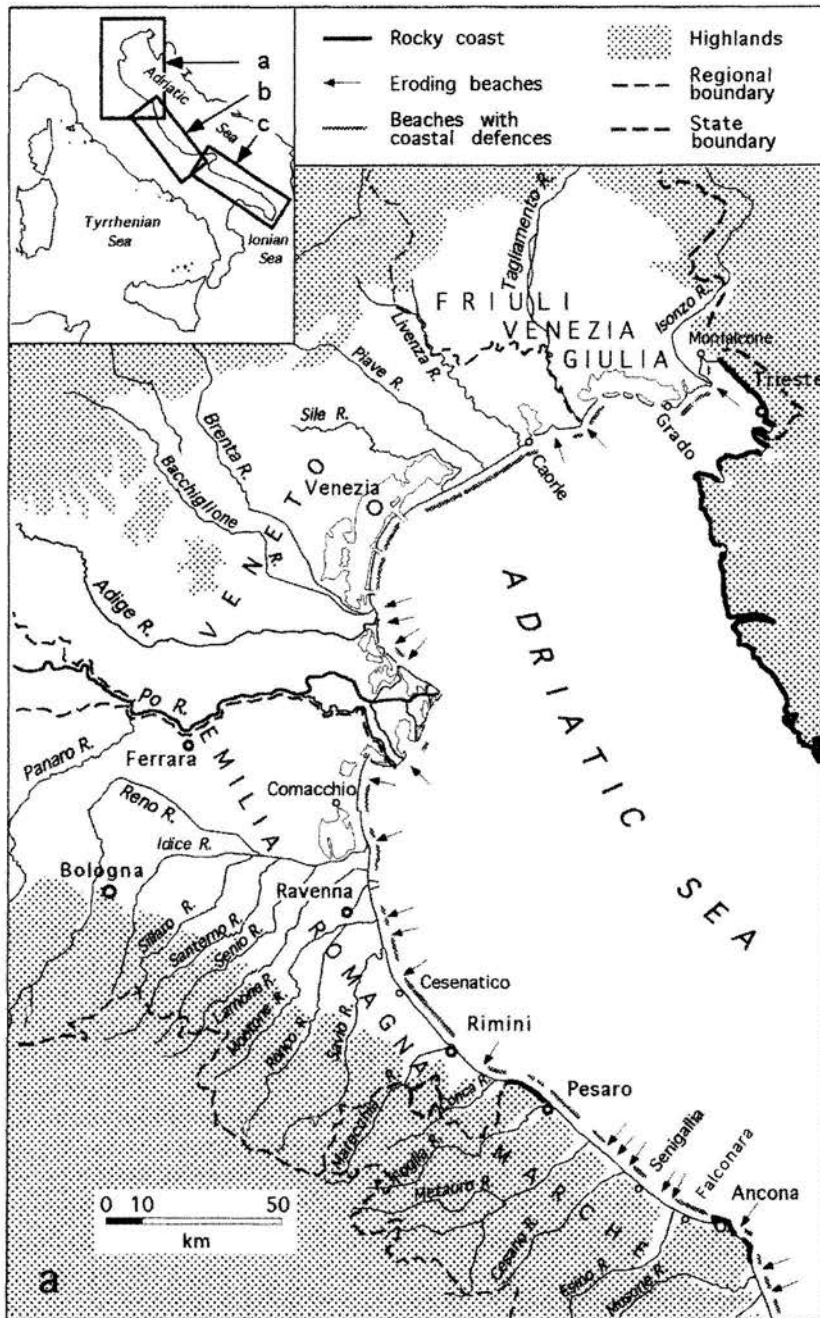


Figure 1a – Protected and eroding stretches of coast (a) in the regions of Friuli-Venezia Giulia, Veneto, Emilia-Romagna and northern Marche.

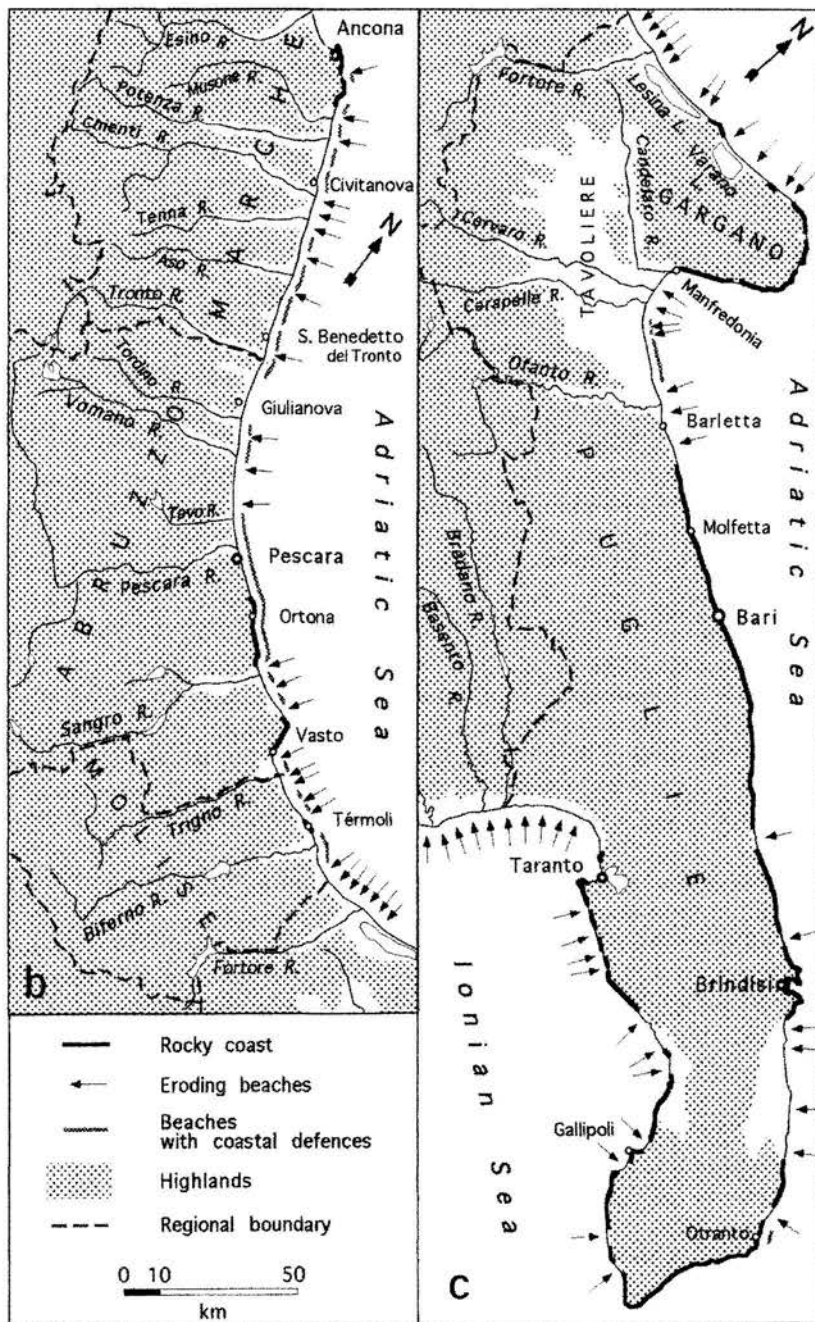


Figure 1b, c – Protected and eroding stretches of coast (b) in southern Marche, Abruzzo, Molise and (c) in Puglia

pumping stations), as they caused phenomena of accelerated subsidence. Apart from its positive aspects, the construction of the railway which connects the north with the south of the Adriatic (1860-70) led to the impoverishment and partial destruction of the coastal environment. Railway often runs along the dune ridges a few tens of metres away from the sea (especially in the Marche and Abruzzo) thus rigidifying the whole of the coastal system. In the last thirty years roads, motorways and highways have been built alongside it.

In the last fifty years one of the factors which has most incisively transformed the Italian coastal strip has been tourism. Beach tourism started during the middle of the last century at Rimini, the Venice lido and at Grado; a marked acceleration took place between the two world wars, especially in the Rimini area. In the last thirty years mass tourism has led to the construction of new settlements even on the dune ridges and river mouth areas. Since the last World War many industries have settled along the Adriatic coast, and in particular those of the oil industry as in Trieste, Venice, Ravenna, Falconara, Manfredonia, Bari and Brindisi, and the shipyards such as in Monfalcone and Ancona. The ports have been enlarged and have increased in number.

As a result, around 1.5 % of the 7456 km of coasts in Italy was urbanised in 1900, 15 % by the middle of the century, and 40 % today. At the beginning of the century urbanisation touched little more than 100 km of the Adriatic coast; today it extends for nearly 600 km (CENCINI, 1995). Some estimates (TORRESANI, 1989) calculate that in 1971 the coastal population was equal to 11 % of the population of the Adriatic region as a whole. In 1981 it had risen to 18 %, which indicates a marked movement of the population towards the coast. Finally the demands of the new, intensive use of the coastal area have led to new scenarios, such as the planting of pine forests to protect the cultivated areas behind, especially in Friuli, Veneto and Emilia-Romagna (CENCINI, 1995).

#### VARIATIONS IN THE COASTLINE

Even in the last centuries the evolution of the Adriatic beaches was complex, like that of the Italian beaches in general. In recent decades, however, there has been a clear acceleration in the phenomenon of coastline retreat.

According to the data furnished by the Ministry of Public Works, in 1982 of a total of 3263 km of beaches in Italy 1387 km were eroding. A study carried out by LA MONICA and LANDINI (1983) on 2470 km of coast showed that only 5 % were advancing compared with 45 % which were clearly retreating; the remaining 50 % were characterised by a situation of relative stability, largely resulting from the defensive interventions which had been carried out (CNR, 1985-96). According to DAL CIN (1990a) 80-90 % of the beaches in Italy which are nourished by fluvial sediment supplies are retreating, or at least they were until their recent protection. Further detail on the extension of the erosive process along the Adriatic coast is furnished by numerous works which have been carried out on a local or regional scale.

Of the coasts in Friuli-Venezia Giulia (Figure 1a), between their eastern extremity and the mouth of the Tagliamento (about 60 km), 32 % is affected

by erosive phenomena, 15 % is stable while the rest is defended or is advancing (BRAMBATI, 1987b).

Of the strip between the mouths of the rivers Sile and Brenta (Venice lidos) which is 50 km long, about 40 % is affected by erosive phenomena and the advancing areas are mainly those located updrift of the inlet jetties (BRAMBATI, 1987a).

The Po delta reached its maximum extension between the 1930s and 1940s, and then started to retreat (Figures 1 and 2); for the period 1954-1978 there has been an average retreat of 254 m on the beaches between the branches of the delta (more than 10 m a year); today almost the only part which is advancing is the main mouth of the Po di Pila (BONDESAN and SIMEONI, 1983).

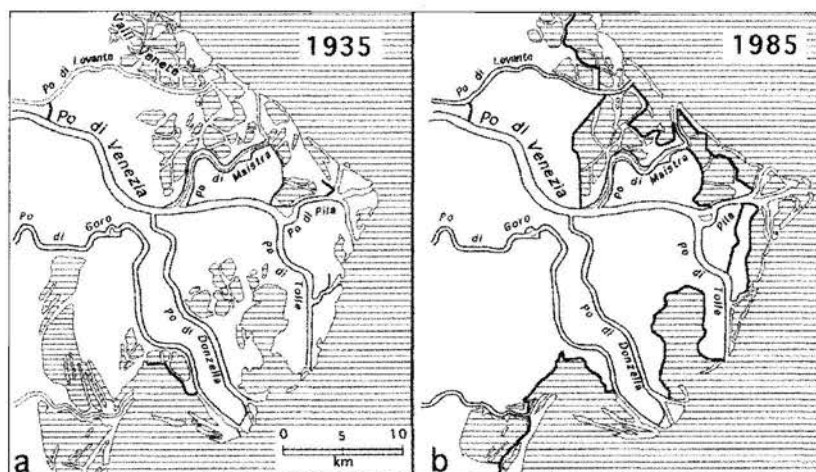


Fig. 2 – The comparison between the two figures highlights the reduction in the extension of the wetlands and the changes in the coastline which have taken place over 50 years. Extensive embankments (marked in black) have been built along the coast in order to defend the hinterland, which is subsiding, from the invasion of the sea.

On the 67 km of beaches in the territories of Ferrara and Ravenna (Figure 1a) the maximum extension was reached in the same period. In 1968 more than 45% of the beaches were eroding and only 7.5 % was protected (BONDESAN *et al.*, 1978); today the defences extend along 38 % of the coast (seawalls, detached and submerged breakwaters, Longard tubes).

Research carried out in the 1980s (DAL CIN *et al.*, 1984) on the beaches of the Marche (Figures 1a and 1b) showed that of 144.5 km of beach 42 % was protected while 33 % was eroding. GRAUSO (1989) showed how the erosion of the coast in Abruzzo (Figure 1b) was very marked in the 1950s and 1960s. First the phenomenon was concentrated on only some segments of the coast at the mouths of the rivers and then it extended along almost the whole coast. Studies carried out by ADAMOLI (1979) in Abruzzo on a strip of coast 60 km long showed that 40 km were eroding. Recent studies carried out on the coast of Abruzzo (SIMEONI, 1989; DAL CIN, 1990b) showed that only 42 % of the beaches are unprotected and of these about 35 % are eroding. Similar situations have been reported for the coast in the region of Molise (Figure 1b) where the erosion mainly started in the twentieth cen-

ture and its modifications became more intense after the 1960s (GIORGI *et al.*, 1987).

The situation in Puglia is not very reassuring either. A study carried out along the beaches between Manfredonia and Barletta (61 km) by SIMEONI (1992) showed that while in the period between 1869 and 1957 there was a general advancement of the coastline, widespread erosive phenomena started in the 1960s, especially in the area of the mouth of the river Ofanto. The same study also showed that of the unprotected coast (69.6%) more than half is characterised by erosive phenomena while the areas which are advancing (10.9%) are closely related to the blocking action carried out by the port constructions (beaches located updrift of the ports).

These data can be used to furnish an estimate of the loss of territory and the environmental damage which erosion has caused along the Adriatic coast. The phenomenon also appears to be quite worrying from a financial point of view. In fact according to an estimate made by SCOTTI (1978) on the Adriatic coast a retreat of 1-2 m of the shoreline resulted in damage of 100-150 million lira, without considering the cost of the loss of material. The economic damage has been pointed out by MASSIMI (1981) who estimated that the cost of the loss of a sandy strip of beach 11 km long and 10 m wide was 250 million lira a day during the course of the tourist season. The capital value of 1 m<sup>2</sup> of beach has been estimated by BRAMBATI (1983) to be 3 million lira. Often however these analyses of the linear tendencies, which are apparently simple, are in fact quite complex. A problem is that of verifying whether the dynamics of the coastline constitute a valid indication of the behaviour of the coast. In fact the evolutionary tendencies should be seen as indicators of variations on a wider scale, and associated with the evolution of the climatic, meteomarine, biological, sedimentological and anthropic parameters.

### THE RIVERS

The evolution of the beaches which border the alluvial plains mainly depends on the variations in the sediment transport of the rivers which flow onto them: these variations are first of all a function of their water discharge. The Adriatic Sea has a surface area of 138,000 km<sup>2</sup>, about 1/20 of that of the Mediterranean, with a volume of water of 35,000 km<sup>3</sup>, 1/125 of that of the Mediterranean. The mean discharge of fresh water flowing into the Adriatic (PICCINETTI and BOMBACE, 1989) from the river Isonzo to the river Fortore is about 3097 m<sup>3</sup>/s, of which 51 % comes from the river Po, 34 % from the rivers which lie to the north of the Po and 15 % from those which flow to the south of it (see Table I).

TABLE I  
Total water discharges (m<sup>3</sup>/s) of Italian Adriatic rivers

Po river	1580 (51%)
Rivers northwards of the Po	1061 (34%)
Rivers southwards of the Po	455 (15%)
<b>Total</b>	<b>3097</b>

The discharges of the Po and adjacent rivers are reported according to PICCINETTI and BOMBACE (1989).

The river Po (surface area of the basin 54,290 km<sup>2</sup>) has a discharge at the mouth (average of the period 1918-1991) of 1496 m<sup>3</sup>/s (IDROSER, 1994) which is distributed into five branches at the delta (about 56% flows through the Pila branch). The quantity of the sediment transport of the river Po has been the subject of various calculations (see Table II): VISENTINI (1940) estimated an average transport of 17.8 Mm<sup>3</sup>/y (millions m<sup>3</sup>/year) for the period 1886-1935 while ALBANI (1948) estimated 17.6 Mm<sup>3</sup>/y for the period 1917-44. The estimate of the quantity of the bed load, which is almost entirely constituted by material which enters the beach sediment budget, varies, according to the authors, from 15% to 22% to that transported in suspension (DAL CIN, 1983).

Research carried out by IDROSER (1983) demonstrated an average reduction in the turbidity of 1% a year between the 1940s and the 1970s, with a practically unchanging regime of water discharge; in addition it estimated that the sediment transport to the sea decreased from 8.4 Mm<sup>3</sup>/y in 1945, of which about 1.26 Mm<sup>3</sup>/y was useful for the nourishment of the beach, to 6.4 Mm<sup>3</sup>/y in 1972, of which 0.8 Mm<sup>3</sup>/y as bed-load.

IDROSER (1994) hypothesised that for the period between 1918 and 1991 the total average transport was 6.2 Mm<sup>3</sup>/y, that at the mouth 63% flowed through the Pila branch, and that 87% of it was constituted by material with grain-size > 0.13 mm. This author also noted an increase in the silty-clay sediment with respect to the coarser fraction, especially in the last three decades.

TABLE II  
*Estimates of solid loads of the Po river  
(in millions m<sup>3</sup>/year)*

Period	Year	Solid load	Authors
1886-1935	—	17.8	VISENTINI (1940)
1917-1944	—	17.6	ALBANI (1948)
—	1945	8.4	IDROSER (1983)
—	1972	6.4	IDROSER (1983)
1918-1991	—	6.2	IDROSER (1994)

There is no specific published record and above all an absence of experimental data for the discharge of the rivers in Veneto and Friuli.

As regards the rivers in Friuli, according to indirect estimates (BRAMBATI, 1987b) the maximum quantity of sand transported to the sea is 0.33 Mm<sup>3</sup>/y for the river Tagliamento and 0.43 Mm<sup>3</sup>/y for the river Isonzo.

As regards the rivers in Veneto, by means of extrapolating from available data, BRAMBATI (1987a) proposes a sediment transport of 0.020 Mm<sup>3</sup>/y for the river Piave, 0.002 Mm<sup>3</sup>/y for the river Brenta and 0.023 Mm<sup>3</sup>/y for the river Adige (4% as bed-load). For the river Piave the author estimates a minimum reduction of the discharge of 25% with respect to the 1940s. For the river Brenta, of which the water discharge has slightly increased, there has been a significant reduction of more than 68% of the suspended load recorded between the average data for the period between 1929 and 1940 and the last comparable measurements taken in 1969

(TESSARI, 1981). For the river Adige there has been a reduction of the bed-load from 0.029 Mm<sup>3</sup>/y for the period between 1922 and 1950 to 0.022 Mm<sup>3</sup>/y for the period between 1958 and 1975 (AVANZI, 1976).

To the south of the river Po the rivers in Emilia-Romagna have shown the same general tendency towards a reduction of the suspended load, although to different extents (IDROSER, 1983). Between 1945 and 1972 one can calculate that these rivers saw a reduction in suspended load between half and a quarter: for example, of 0.6% a year in the river Reno; 4.5% in the river Senio and 3.8% in the river Sàvio. In the 1950s one can estimate that the river Reno transported 3.6 Mm<sup>3</sup>/y to the sea, of which only 0.5 Mm<sup>3</sup> was useful for the nourishment of the coast; in the 1970s these values had decreased to 1.8 Mm<sup>3</sup>/y, of which 0.2 Mm<sup>3</sup> was useful.

The river Reno and the river Conca deserve a particular mention as the construction of weirs a few kilometres from the coast in 1961 and 1974 further reduced their transport capacity. One can estimate that in 1972 the rivers in Emilia-Romagna had a total sediment transport of material useful for the nourishment of the beaches of about 0.68 Mm<sup>3</sup>/y, following an annual reduction between 1945 and 1972 of close to 2%; however no significant variations in the climatic-meteorological factors were recorded during this period.

Table III summarizes the water discharge data of the main Italian rivers. In the Marche the rivers with the greatest water discharge are the Foglia, the Metauro, the Esino, the Tronto (see below), the Potenza (8.0 m<sup>3</sup>/s) and the Chienti (2.3 m<sup>3</sup>/s). The average meteoric inflow calculated for three periods (1924-50, 1951-60 and 1961-71) has remained essentially unchanged.

TABLE III  
*Measured water discharges (m<sup>3</sup>/s) from stations located in the lower courses of the main Italian rivers outflowing in the Adriatic.*

Regions	Rivers	Discharges from measuring stations
VENEZIA GIULIA-FRIULI	Isonzo	99.4
	Tagliamento	82.1
VENETO	Piave	98
	Brenta	75
	Adige	207
VENETO and EMILIA-ROMAGNA	Po	1580
EMILIA-ROMAGNA	Reno	26
MARCHE	Foglia	6.95
	Metauro	21.2
	Esino	17
	Tronto	17.6
ABRUZZO	Pescara	52.9
	Sangro	7.7
	Trigno	2.02
PUGLIE	Ofanto	13.9

Taking into account the extractions due to the anthropic interventions in the channel and drainage basin, the bed-load (AQUATER, 1982b) in 1982 has been estimated as between 0.24-0.42 Mm<sup>3</sup>/y, which is much less than what calculated for the period before 1961 (0.39-0.70 Mm<sup>3</sup>/y). These values are very low compared with the potential bed-load, derived by estimates as potential erodibility of the drainage basins, calculated as between 0.78 and 1.42 Mm<sup>3</sup>/y.

Apart from the river Tronto (which runs along the border with Marche), the rivers which condition the coastal dynamics of Abruzzo include the Tordino (2.17 m<sup>3</sup>/s), the Tavo (2.04 m<sup>3</sup>/s), the Pescara (52.9 m<sup>3</sup>/s), the Sangro (7.7 m<sup>3</sup>/s) and the Trigno (2.02 m<sup>3</sup>/s). AQUATER (1982a) showed that the meteoric inflow between 1941 and 1970 slightly diminished after 1961. The average potential annual erosion in these basins (total surface area of 10,630 km<sup>2</sup>) was estimated as between 0.37 and 0.67 mm. The eroded material which is transported on the beds of the rivers is estimated at 22 %, and therefore the rivers could transport a total of between 0.86 and 1.62 Mm<sup>3</sup>/y. However, despite this potential, in this case not all the material reaches the sea as a result of physical and anthropic factors; in fact in the stretch of coast between the rivers Tronto and the Trigno a sediment transport of between 0.50 and 0.98 Mm<sup>3</sup>/y has been estimated.

Apart from the river Ofanto (13.9 m<sup>3</sup>/s), some smaller rivers flow onto the coast in Puglia such as the Carapelle (3.02 m<sup>3</sup>/s), the Candelaro (2.56 m<sup>3</sup>/s), and the Cervaro (2.85 m<sup>3</sup>/s). There is a clear trend towards a reduction of these parameters from the 1950s onwards (SIMEONI, 1992). For example for the river Ofanto the reduction in the suspended load between the measurements taken in 1936 (0.54 Mm<sup>3</sup>/y) and those taken in 1978 (0.21 Mm<sup>3</sup>/y) appears significant; however, the amount of water which reaches the basin in the form of precipitation (about 719 mm/y) has remained almost unchanged.

The fact that at the beginning of the century a large part of the cusped river-mouths of the Adriatic Sea were growing, and that almost all of them now show worrying erosive phenomena leading in some cases to complete destruction, can be attributed to this general reduction in the sediment transport (POSTMA, 1989).

Dams have largely contributed to the reduction in the sediment transport. During this century numerous artificial lakes have been created along the rivers, especially in the mountains, for the generation of hydro-electrical energy or for irrigation purposes, retaining large quantities of water. For example, the data furnished by the Ministry of Agriculture and Forestry for 1976 show that the storage capacity of the five artificial lakes on the river Tagliamento is about 0.07 Mm<sup>3</sup>, that of the 12 lakes on the Piave is 0.32 Mm<sup>3</sup>, that of the Tronto is 0.11 Mm<sup>3</sup> and that of the Fortore is 0.33 Mm<sup>3</sup>.

Other decreases in the sediment transport, which are difficult to quantify, can be related to the construction of check dams and other stabilisation works on the rivers. One must also consider the fact that part of the water taken from the rivers (for agricultural uses, zootechnics, drinking water, industrial uses, canals, etc.) is not returned to the river network, and that in any case the removal of water affects the regime of the rivers. A direct consequence is the reduction in the maximum values of discharge. Since the majority of the material is transported during floods, this diminishes the

capacity of the total sediment transport of the river. For example, in 1960 a tunnel was opened, allowing the flood water of the river Adige to be directed into lake Garda. The reduction of flood level has had a notable influence on the sediment transport of the rivers (ZUNICA, 1971).

Other anthropic activities have had a direct influence on the sediment transport of the rivers. These include the change in land use which took place this century in the montane basins. In Emilia-Romagna (IDROSER, 1983) these changes led to a reduction of the most erodible surfaces (semi-inactive) and a slight increase in the cultivated surfaces which offer the greatest protection to the soil (pasture and woodland).

Of particular importance were the interventions of reclamation against alluvion which involved the removing of material otherwise useful for the nourishment of the beaches. An example of this is furnished by the retention ponds of the Idice and the Lamone (VARANI, 1975) into which, from the beginning of the nineteenth century until 1960, both rivers transported sediments. For the river Idice some estimates calculate a basin infill of between 1.0 and 0.5 Mm<sup>3</sup>/y, with settled material lying up to 8 m above the original level, while for the river Lamone the landfill has been of the order of 60-65 Mm<sup>3</sup>. In the Tavoliere in Puglia, between 1813 and the first half of the twentieth century, Lago Salso (circa 700 ha) was reclaimed using the suspended load of the river Candelaro and the river Cervaro, while the reclamation of lake Salpi (6500 ha) was partly carried out using the suspended load of the river Carapelle and the river Ofanto (1500 ha).

### EXTRACTIONS IN THE RIVER CHANNEL

In Italy the reduction in the quantity of material transported by the rivers has been caused mainly by the extractions in the river beds in relation to a practically unchanged transport capacity of the current. The extractions are particularly harmful as they mainly affect the sands and gravels which, although they represent a small fraction of the sediment transport of the rivers, constitute the material making up the beaches. The damage to the coast is most serious and immediate when the extractions take place near the mouth of the river or even on the beach itself.

In Italy the extraction activities started in the 1950s and peaked in the 1960s, in relation to the construction of road and motorway networks and building expansion. Subsequently the quantities of material that could be extracted were gradually reduced in order to stop and then remedy the degradation of the rivers, especially since 1993.

The data available for the Veneto region indicate that in the area north-east of the river Po (excluding the river Adige) between 0.83 and 2.39 Mm<sup>3</sup>/y were extracted between 1965 and 1971 (GAFFARINI, 1981). In particular the official data show that at the beginning of the 1980s some 3.22 Mm<sup>3</sup>/y were extracted from the Piave basin and 0.76 Mm<sup>3</sup>/y from the Adige basin. BRAMBATI (1987a) estimated that during the same period the two rivers saw a reduction in their sediments of about 2.26 Mm<sup>3</sup>/y.

The excavation of material from the channel of the river Po and its tributaries is quite difficult to quantify. For the period between 1958 and 1981 the official numbers amount to about 138 Mm<sup>3</sup> (DAL CIN, 1983). However in 1979 alone the amount that was removed from the Po can be

estimated as double that which arrived on average at the sea in the decade between 1964 and 1973 (IDROSER, 1983). This situation was favoured by the absence of controls on the concessions, and realistic estimates of the quantity actually removed must be 2.5 to 4 times as much as that permitted. DAL CIN (1983) proposes a multiplying coefficient of 5, which would indicate that between 1958 and 1981 about 690 Mm<sup>3</sup> of material were extracted (Table IV).

TABLE IV  
*Quantities of authorized and estimated aggregate extraction on the river beds  
(in millions of cubic meters)*

	Period	Authorized extraction	Estimated extraction	Authors
PO RIVER	1958-1981	138	690	DAL CIN (1983)
EMILIA-ROMAGNA REGION	1950-1959	2.5	-	IDROSER (1994)
	1960-1969	9.2	23	"
	1970-1979	8.3	20	"
	1955-1992	21	48.3	"
MARCHE REGION	1966-1975	2.9	12.7	AQUATER (1982b)
ABRUZZO REGION	1966-1975	10	25.8	AQUATER (1982a)
	1976-1981	3	-	"

For the rivers in Emilia-Romagna the extraction of about 2.5 Mm<sup>3</sup> was permitted in the decade between 1950 and 1959, 9.2 Mm<sup>3</sup> in 1960-69 and 8.3 Mm<sup>3</sup> in 1970-79. However at least 20 Mm<sup>3</sup> were actually extracted between 1970 and 1979, and more than 43 Mm<sup>3</sup> between 1960 and 1979. Between 1955 and 1992 concessions for the extraction of 21 Mm<sup>3</sup> were granted for these rivers apart from the Po (IDROSER, 1994). While from the 1980s onwards there was a marked decrease in the amount extracted, the quantity actually extracted still exceeds that permitted by a coefficient of 2.3.

In the Marche the extractions from 1970 onwards were progressively limited, and definitively forbidden in 1975. Between 1966 and 1975 more than 2000 concessions were granted for river extractions, amounting to a total of 2.9 Mm<sup>3</sup>. Estimates carried out by AQUATER (1982b) regarding the type, functionality and consumption of the extraction plants proposed corrective coefficients between 1.43 (river Musone) and 2.64 (rivers Tesino and Tronto). By applying these coefficients to all the rivers in the region of Marche the total amount of material extracted between 1966 and 1975 would amount to 12.7 Mm<sup>3</sup>. The river Metauro stands in first place with 2.7 Mm<sup>3</sup>, that is, 21.35% of the total.

In Abruzzo between 1966 and 1981 the total extractions amounted to 12.98 Mm<sup>3</sup> (AQUATER, 1982a), with a maximum of 1.42 Mm<sup>3</sup> in 1972. The largest amount was granted for the river Sangro (3.13 Mm<sup>3</sup>). From an indirect control based on the potentiality and on the consumption of the extraction plants, estimates have been calculated on the real quantity of material extracted. For example, it was calculated that 25.82 Mm<sup>3</sup> were extracted between 1966 and 1975 from the rivers, which is more than 2.5 times as much as the quantity permitted.

As regards Puglia, the available data are scarcer. In 1991 there were five permanent extraction plants operating in the river Ofanto, all of which were obviously working without concessions since their issue was suspended in the 1980s. In the river Carapelle extraction concessions were issued between 1982 and 1988 for a total of  $0.39 \text{ Mm}^3$ , while in the Cervaro the amount was  $0.49 \text{ Mm}^3$  between 1980 and 1990; finally in the Candelaro the amount was  $0.5 \text{ Mm}^3$  between 1982 and 1990. It is reasonable to assume that the quantities actually extracted were much larger.

### THE SUBSIDENCE OF THE COASTAL AREA

Subsidence, which is part of the natural development of the alluvial plains, can undergo sometimes a notable acceleration as a result of anthropic factors, as is the case in the easternmost part of the Po plain, particularly in the last decades (BONDESAN and SIMEONI, 1983; CARBOGNIN, 1986), as a result of the following:

- a – the artificial regulation of the water table, and in particular of the drainage network of the marsh areas;
- b – the extraction of methane dissolved in water, at least 600 metres below ground level, which was carried out between 1938 and 1963 mainly in the Po delta and surrounding areas: compared with a natural subsidence of less than  $2 \text{ mm/y}$ , the subsidence recorded between 1958 and 1962 was more than  $200 \text{ mm/y}$ ;
- c – the extraction of dry gas from greater depths in recent decades (AGIP, 1992);
- d – the intensive extraction of underground water for various uses, as carried out in the Venice hinterland for example, with maximum levels in the period between 1956 and 1970.

In Ravenna subsidence of  $60\text{-}70 \text{ mm/y}$  was recorded for the period between 1970 and 1977 as a result of causes a, c and d (BERTONI *et al.*, 1973, 1987, 1995; SELLI and CIABATTI, 1977; CARBOGNIN *et al.*, 1978).

Subsidence, either natural or artificial, represents the main cause of the current altimetry of the coastal strip of the Po plain which comprises an area of  $2365 \text{ km}^2$  below sea-level; in the central area of the Po delta there are areas which lie at  $-5 \text{ m}$  (BONDESAN *et al.*, 1995).

The problem of the influence of anthropic subsidence on the evolution of the coast in the Po plain has been studied mainly in the Po delta (BONDESAN and SIMEONI, 1983) and in the Emilia-Romagna area (PATRIZI, 1978; CARBOGNIN *et al.*, 1982; IDROSER, 1994). As regards the retreat of the gently sloping beaches, it can represent therefore one of the most important factors and the subsidence of only a few millimetres can result in the beach retreating a few metres.

For example, in some coastal stretches of the Po plain where the subsidence has been calculated as between  $1.5$  and  $3 \text{ mm/year}$ , the 1970s saw a loss of  $0.6 \text{ Mm}^3/\text{y}$  of material. Two precision levelling surveys carried out in 1984 and 1987 (IDROSER, 1994) showed that the whole of the  $130 \text{ km}$  stretch of coast in Emilia-Romagna was affected by subsidence with average values ranging from  $5$  to  $50 \text{ mm/year}$ . Between 1987 and 1993 the subsidence rates were comprised between  $2$  and  $36 \text{ mm/year}$ , with different rates in different areas: in the northernmost part of the coast there has been

an increase in the phenomenon while in the southernmost part of the coast there has been a marked reduction of up to 89-90%. This has been favoured by the fact that in the latter zone surface water was used for supplying the aqueducts from 1989-90 onwards, thus considerably reducing the amount of water taken from the water table.

The other plains on the Adriatic are little influenced by subsidence. For example, CRESCENTI (1975) reported a subsidence rate of about 0.3 mm/year since the Early Pliocene for the coast in Abruzzo, a value which is certainly not comparable with the average rate of the retreat of the coastline today (almost 5 m/year). Certainly the subsidence provoked by the increased urbanisation is more influential, although in quite limited areas.

#### DIRECT ACTION ON THE BEACHES

The destruction of the coastal dunes on the Adriatic proceeded in order to obtain material, to develop large-scale urbanisation or even to facilitate access of the bathers to the sea.

At the end of the nineteenth century nearly the whole of the coast in Romagna was bordered by a series of dune ridges which were a few kilometres long and between 100 and more than 700 m wide (BONDESAN, 1971; CENCINI, 1980). Their destruction or their stabilisation, which mainly resulted from urbanisation and the creation of bathing stations, has strongly rigidified the coastal system.

An example is that of the construction of the coastal road to the south of Pescara in 1960 (MASSIMI, 1981) which led to the destruction of the most complex and best preserved system of coastal dunes in Abruzzo. A large part of the sand removed was used for the building works. Today on the Adriatic coast (CNR, 1985-96) there are only a few areas left where the dune ridges have been preserved or where their natural dynamics has not been altered, such as the area at the mouth of the river Tagliamento for example, or the area of lakes Lèsina and Varano in Puglia.

However, on the Adriatic coast the natural hydrosedimentary dynamics has been almost completely modified by the presence of nearly continuous defensive structures which vary in their forms and dimensions. Breakwaters prevail in the central tracts of the Adriatic while in the northern area there is a predominance of stone groins, often semitransparent and sometimes anchored to seawalls.

If these structures, which were born from the belief that humans can govern the sea, are planned without an adequate knowledge of the dynamics of the physiographic unit, the distribution and transport of the sediments may change in a way that produces harmful effects on the whole system. Often, when these structures are put in areas with a high degree of turbidity, they have both long and short term consequences, not only on the evolution of the coastline but also on the rates of deposition, thus causing variations in the biological productivity and worsening the water quality.

One may say that the use of defensive structures in the Adriatic originated with the problem of protecting Venice from the sea, which started with the foundation of the city and the century-long transformation of the lagoon into an anthropic environment. Historical documents report the

construction of coastal defences along the Venice lidos starting with the second half of the 17<sup>th</sup> century. These defences, called "murazzi", were seawalls of limestone blocks which were partly dry stone and partly made using concrete (GRILLO, 1989). At the end of the 18<sup>th</sup> century and at the beginning of the 19<sup>th</sup>, the Venetians turned their attention to the problem of the efficiency of the tidal inlet with the construction of jetties which further conditioned the evolution of the coastline. Some data highlight the current development of the defensive structures:

- In Friuli, 30 km of the 60 km of coast are protected by defensive structures.
- In Veneto of the 43.3 km of coast between Caorle and Lido inlet, 33.75 km (about 78 %) are protected by various kinds of defence (which are often associated).
- Of the 130 km of coast in Emilia-Romagna about 104 km have been protected, especially in the last sixty years, by the construction of the following structures: 48.9 km of parallel seawalls, 8.7 km of seawalls, 13.8 km of protected nourishment, 16 km of stone groins, 4.2 km of Longard tubes and 27 km of embankments, walls and artificial dunes.
- In Marche (DAL CIN *et al.*, 1984) 42 % of the 144.5 km of low coast is protected, 16 % by seawalls and 26 % by breakwaters. For every km of beach in the region there are 420 m protected by structures; today this value is close to 50 %.
- In Abruzzo in the tract of about 80 km between the mouth of the Tronto and Ortona, 54 % of the beaches are protected (SIMEONI, 1989; DAL CIN, 1990b), mainly by breakwaters (about 29 km).
- In Puglia, of the 61 km between Manfredonia and Barletta 30.4 % is protected (SIMEONI, 1992).

Since the 1980s, given the problems created by the abnormal development of the traditional structures, recovery programmes have been set up which plan lighter interventions as well as the destruction of the badly planned or inefficient structures. Artificial nourishment is now carried out, a methodology already proposed by the Venetians in the 17<sup>th</sup> century who extracted the sand from the sea before building the embankments in order to protect their eroding beaches (GRILLO, 1989).

For example, between 1983 and 1993 in Emilia-Romagna nourishment interventions were carried out along a total of 13.8 km of coast with an initial supply of 1.9 Mm<sup>3</sup> (IDROSER, 1994). In 1984 a study was undertaken to locate suitable material in the sea, and sediments were found on the sea bed at between 34 and 40 m depth with a total potentiality of hundreds of Mm<sup>3</sup>. On the coast in Veneto at Pellestrina barrier island, between 1959 and 1990, values of 0.4 Mm<sup>3</sup>/y were reached in order to remedy the erosion (SILVA and DI GIROLAMO, 1993) and a project was set up to nourish the coast. Given the quantity of sand (about 4 Mm<sup>3</sup>) and the difficulty of transporting it to the land, sand from the fossil beaches was used which lies on the sea bed at about -20 m (BRAMBATI, 1987a).

Nowadays, more than 50 % of the planned nourishment interventions has been carried out by Consorzio Venezia Nuova along the Veneto coasts, from Pellestrina on the south to Jesolo on the north, which consist of beach replenishment together with sand recharge during the next 10 years of ca. 11.6 Mm<sup>3</sup> along 32.2 km of beaches.

While historical events regarding the ports have deeply affected the evolution of the coast, the recent urbanisation and new port structures built at the mouths of the rivers and lagoons have brought further damage. For example, the coast in Romagna has been subdivided into tracts which are almost separated by the jetties of the inlets at Porto Garibaldi, Porto Corsini, Cesenatico and Rimini. The transport of sand along the coast therefore takes place over short distances, as it is interlaced by the updrift jetties. When the sediments manage to overcome the obstacle formed by the jetties, either they cause the infill of the inlet or else they disperse on the bottom at such great depths that only a small part is pushed back towards the coast by the wave action (DAL CIN *et al.*, 1979).

#### DISCUSSION AND FUTURE PROSPECTS

It is clear that there are worrying and widespread erosive phenomena on the Adriatic beaches. Worldwide scale phenomena have certainly influenced this evolutionary tendency, but only to a small amount. In fact the mareographic data for the Upper Adriatic show that the average sea-level rose about 20 cm over the last 100 years (ADAMOLI, 1979). Considering the fact that the average slope of the beach is  $4^{\circ}$ - $2^{\circ}$  (GRAUSO, 1989), this value corresponds to a retreat of about 3-6 m in 100 years, or 3-6 cm/year. For the beaches with lower slope gradients, such as those in the northern Adriatic, the retreat can be calculated as being of the order of 20 cm/year.

Furthermore, nothing in the rainfall data suggests climatic changes in the last fifty years which would have led to a reduction in the discharge of the rivers. It is clear however that after the 1940s there has been a change from a phase of growth or stability to one of rapid and heterogeneous retreat of the coastline.

Humans alone, with their various activities, have been capable of altering in such a short time equilibria which were almost centuries long, modifying the courses of the rivers and their sediment supplies, and changing the hydrosedimentary dynamics of the beaches. For the last fifty years at least, the Adriatic coast represents a typical example of "accelerated" erosion, or in other words erosion caused and accentuated by anthropic influence. A characteristic of this erosion is often the establishment of phenomena which are either irreversible or at least difficult to correct: corrective interventions on the coast may in fact provoke negative repercussions on the adjacent areas. The problem of the Adriatic is quite disturbing and accentuated because of the large extent of coastal urbanisation.

Is it possible to quantify the influence of the various anthropic activities on the linear tendencies of the Italian beaches? For example, what would the coast of the Upper Adriatic be like today if the Venetians had not deviated the branches of the Po and the other rivers which flowed into their lagoon? It is difficult to find answers to these questions. Almost as a game, with all the limitations that can be associated with it, we have tried to depict what the Po delta would be like today if there had been no reduction in the discharge and no deviations in its terminal part in the last four centuries (Figure 3). Certainly this representation is only a matter of conjecture, but it may furnish some idea of what it could have been like.

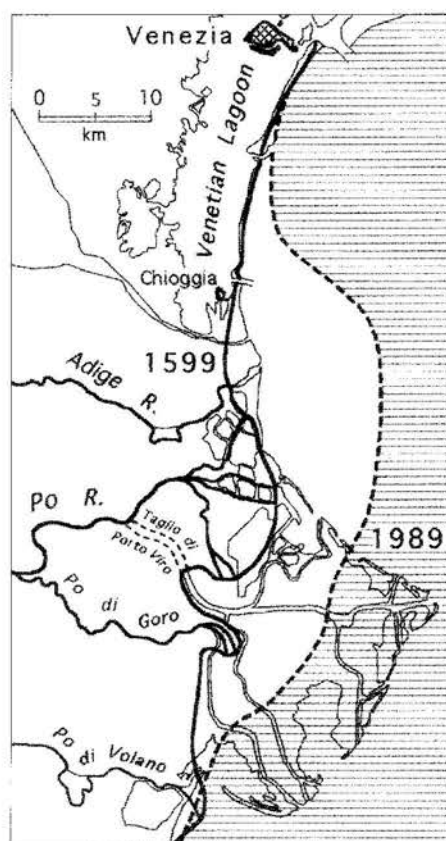


Figure 3 – A comparison between the Po delta in 1599 (marked in black) and 1989. The dotted line delimits the hypothetical form which the coast would have had if, in the 17th century, the main branch of the Po had not been deviated towards the south-east (Taglio di Porto Viro).

Other examples from the coast of Emilia-Romagna (IDROSER, 1994) show the response of the coast to the illegal constructions of numerous wells for the extraction of water and gas both in the river basins and on the coastal area. A comparison of two coastal surveys carried out in 1984 and 1993 shows that in total there have been beach volumetric changes, between +1 m and -6 m depth, of about  $-3.8 \text{ Mm}^3$ . The loss of material as a result of subsidence has been calculated as  $-19.8 \text{ Mm}^3$ . These data show that the volume which has been lost as a result of subsidence, of which the velocity has been markedly accelerated by anthropic activity, is greater than that deposited by the rivers.

Another approach allows one to calculate indirectly the sediment transport of the river Po on the basis of the volumetric variations registered in the area of the delta. To justify the variations which took place in the period between 1900 and 1940 the average bed-load required is  $4.5\text{-}5 \text{ Mm}^3/\text{y}$ ; in the subsequent periods, and taking into account the subsidence, decreasing values have been estimated, from  $3 \text{ Mm}^3/\text{y}$  around 1950,  $2 \text{ Mm}^3/\text{y}$  around

1960 and 0.8-1.0 Mm<sup>3</sup>/y in the early 1970s. For the 1980s, bearing in mind the notable interventions which have been carried out along the courses of the rivers, the increase in excavations and the reduction in the subsidence, the bed-load is 0.75 Mm<sup>3</sup>/y (IDROSER, 1994). Given the closure of the quarries, the estimate for 1990 rises to 0.95 Mm<sup>3</sup>/y and one can hypothesise that it will rise to 1.1 Mm<sup>3</sup>/y in the year 2000 and 1.25 Mm<sup>3</sup>/y in 2010. These data indicate a tendency after the 1980s to recover the sediment supplies of the rivers, although it is equally clear that these can never return to the levels of the first half of the century. Once again these values are only indicative, since they were obtained on the basis of hypotheses which are plausible but which also involve a high level of extrapolation.

Anthropic activity, with the changes caused by cultivation, construction of roads and railways, interventions in the catchment basins, extraction of material from the river channels and construction of barriers of various kinds, has violently changed the natural conditions of sediment transport to the sea. It is not our intention to criticise or advise against these interventions, which can often be indispensable and urgent, but only to emphasize that the evolution of the coast depends on factors which originate a long way from the sea. In these cases it is necessary to intervene on the basis of the balance between both economic and social costs/benefits.

In the Adriatic the basic problem of coastal management policy appears to be mainly a cultural one. It regards the capacity to manage at an institutional-administrative level an environmental resource and its compatibility with respect to the productive processes and the urban settlements. In fact by disfiguring nature in a short time the economic value of the coastal area is notably reduced and by building inefficient structures one provokes accidents of which the costs markedly outweigh the benefits. In the field of economics this soon determines bankruptcy.

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