Plate 1. The wide protuberance referred to as the Po delta represents only the present-day delta, while the whole territory affected by the various outlets of the Po during historical time is much wider. The ancient Po delta approximated 1300 km^2 while the modern delta covers only 730 km^2 and extends along 130 km of low sedimentary shores, forming a crescent around the northwestern Adriatic Sea.

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Physical Processes and Human Activities in the Evolution of the Po Delta, Italy

Carlo Cencini

Department of Economics, Section of Geography
University of Bologna
Viale Filopanti 5, 40126 Bolgna, Italy

ABSTRACT

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The Po delta covers a surface of about 1300 km^2 of reclaimed lands, fresh- and salt-water lagoons, low sedimentary shores and emerging sandy banks. Its evolution has been extremely complex and several historical deltas have been recognized. Up to the end of the Middle Ages, the coastal morphology of ancient cuspidate deltas appears to have been shaped basically by natural processes. On the contrary, the formation of the modern lobate delta has been largely the result of human intervention. The Po delta is one of the largest in the Mediterranean. It contains areas of great natural beauty and monuments of historical interest and has been recognized as an internationally important wetland.

In order to improve the habitability of the area and exploit its resources, man has altered the fluvial sedimentation, controlled the river network, reclaimed marshy lands, and developed agriculture, fishing, tourism and industry. The concentration of population, settlements and economic interests along the Po delta has resulted in a drastic change in existing ecosystems, together with a general decrease in the standards of environmental quality, such as beach erosion, dune degradation, land subsidence and pollution. Today the greater part of the delta lies below sea level and, to prevent flooding, several defence structures protect the deltaic coastline.

The complexity and the diversity of the problems that affect the delta clearly require a unified approach. Unfortunately, the management of the Po delta depends on numerous administrative competencies. This is one of the main ob.tacles to the full realization of the Po delta becoming a natural park.

ADDITIONAL INDEX WORDS: *Po delta, Italy, Mediterranean, coastal processes.*

INTRODUCTION

The Po River delta is usually identified as a wide protuberance (evident in maps, air photos and satellite images) that stands out from the Italian shore of the northern Adriatic Sea (Figure 1). This prominence represents only the present-day delta (herein referred to as the "modern delta") while the whole territory affected by the various outlets of the Po during historical times (here labeled the "ancient delta") is much wider and extends from Venice Lagoon to the province of Revenna. This deltaic area extends as much as 30 km to the oldest dune ridge, which stretches from Chioggia to Cervia (Figure 2).

So defined, the ancient Po delta approximates 1300 km^2, while the modern delta covers only 730 km^2 and extends along 130 km of low sedimentary shores, forming a crescent around the northwestern Adriatic Sea. Along this boundary the Po delta contains the outlets of some minor rivers (such as the Brenta, Adige and Reno), as well as reclaimed lands and various types of both freshwater and saltwater lagoons, marshes and swamps, with foreshores and emerging sandy banks. The area may thus be considered, in its entirety, as a single "hydro-geomorphological unit" (BONDESAN and COCCHI, 1996; MARABINI, 1985) (Figure 2).

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GEOMORPHOLOGICAL EVOLUTION

The Origin

At the end of the Tertiary, the Adriatic Gulf extended over the entire Po plain. The Gulf has been gradually filled by alluvial deposits brought down by the Po, Adige, and other minor rivers that flowed down from the Alps and the Apennines mountains during the Quaternary. Brief mention is made of the severest phases of negative eustacy and the marked erosion and siltation that formed the great morphological lines of the deposition. These deposits have been covered by the most recent sediment, first deposited during the post-glacial climatic optimum and then throughout the Holocene period up to present day. After the last post-glacial significant rise in sea level (flandrian transgression), and above all during the last 5000 years, this sedimentation has resulted in the eastward development of the Po plain, which has grown under general regressive conditions. This is primarily the result of the predominance of fluvial sediment supply over marine erosion than of eustatic factors. The natural phenomena that affected this development include subsidence, climatic variations and human activities.

In short, the Po delta has remote origins, but the most intensive periods of development occurred relatively recently when its natural history evolved coincident with human settlement. During the last few thousand years, and even more so in the last few hundred, human activity has accelerated

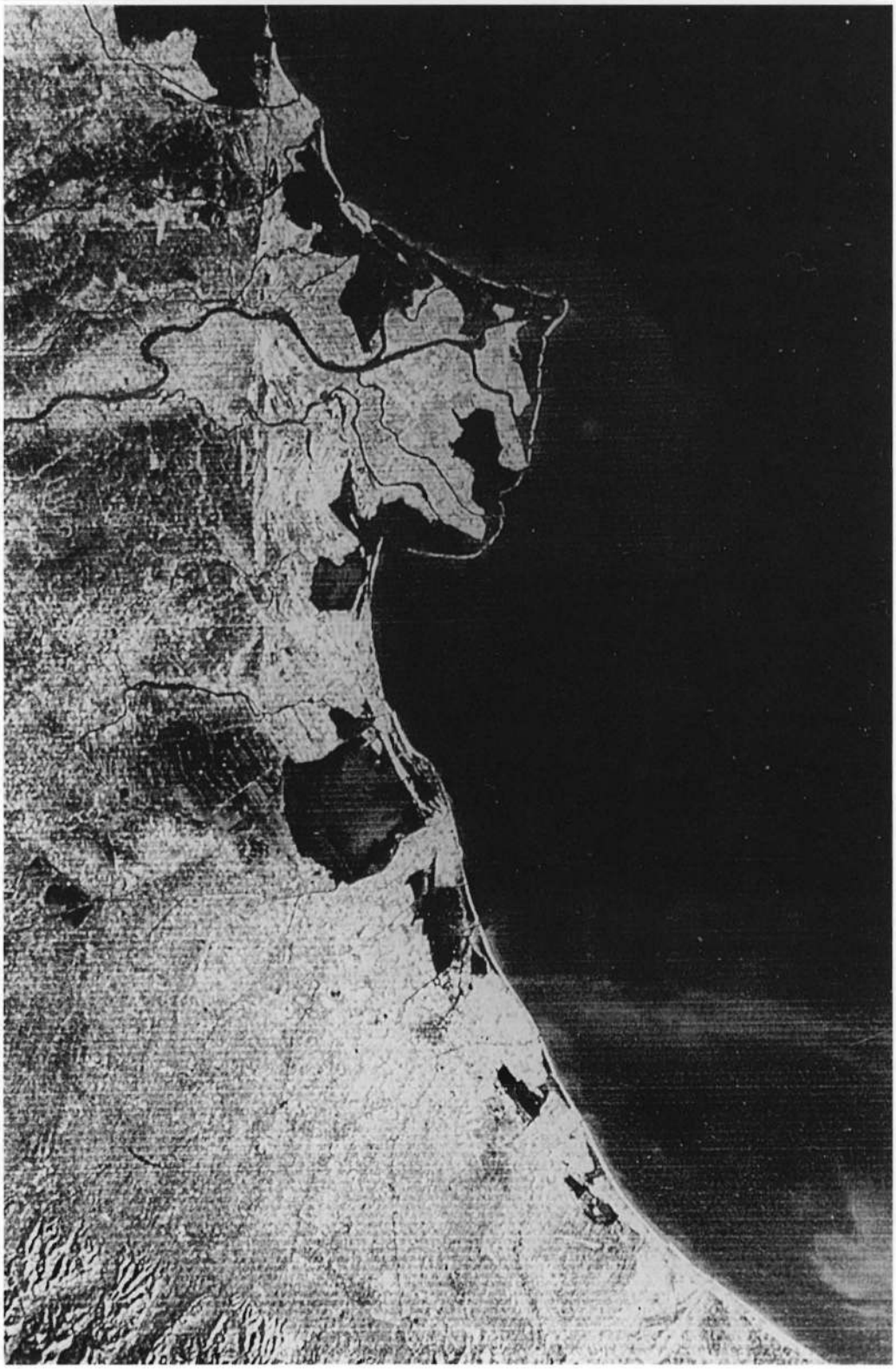

Figure 1. The wide prominence of the Po delta along the Italian coast of of the Northern Adriatic Sea.

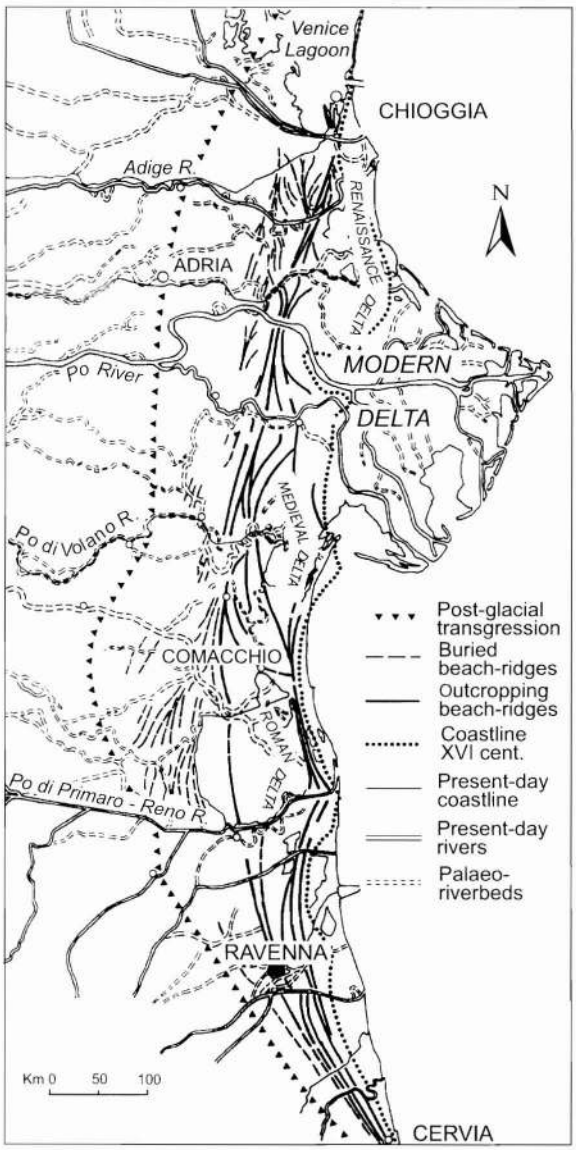

Figure 2. Geomorphological map of the study area with the modern and ancient deltas of the Po River.

the processes of coastal sedimentation and has often managed to alter the delicate hydrographic balance of the delta system. This has occurred commensurate with physical processes favoring delta formation.

The processes of formation and the main stages of deltaic growth have been studied by numerous experts in different fields. Earth science researchers (geomorphologists, hydrogeologists and sedimentologists) have supplied much information, in addition to the valuable contributions of archeologists, historians, human geographers and toponymists, the latter having assisted in a more profound comprehension of the physical development of the delta.

The coastline variations of the Po delta may be traced through a variety of data mostly related to human presence, such as archaeological findings or relict structures, including harbor works and other artifacts typical of coastal areas. The earliest reliable documentation of human action in the area can be traced back to 2500 BP. Valuable data also are found in descriptions by classical authors of ancient coastal sites or regions, especially when reference is made to features of known locations. For the Po delta the most ancient sources are the descriptions of Polybius (150 BC), Strabo (66 BC–AD 21) and Pliny the Elder (approx. AD 65–75) (ALFIERI, 1981; CIPRIANI, 1988). Old cartographic documents are a valuable source from the 16th century onward, although the reliability of distances and angles may be regarded as satisfactory only from the 18th century. For the last four or five centuries, however, the use of available cartographic documentation usually proves to be a satisfactory way of tracing coastline evolution (FABBRI, 1985, 1994). In recent decades, a significant contribution to the identification of old coastlines and associated features has emerged from air-photographs and satellite imagery and measurements.

The evolution of the Po delta is extremely complex. Sand beaches or dune ridges testify to the complex progradational phases the system has experienced, each set corresponding to different stages of accretion (Figure 3). Other important morphological features are the abandoned riverbeds, some of which lie at a depth of several metres (Figure 4). These paleodunes and paleo-riverbeds have intrigued scientists since the 19th century. Early researchers concluded that the Po delta did not develop in an open sea, but rather in a primitive large lagoon (including the Venetian one) that was sealed off by a littoral barrier corresponding to the old dune ridge extending from Ravenna to Chioggia. It was in this lagoon that the Po, Adige and Apennine rivers were to have formed their deltas (LOMBARDINI, 1869; MARINELLI, 1924; VISENTINI and BORGHI, 1938; ORTOLANI, 1956; ALFIERI, 1959, 1960; DONGUS, 1963; ORTOLANI and ALFIERI, 1965).

However, research carried out in the last 30 years (CIABATTI, 1967; BONDESAN, 1968, 1986; BONDESAN and BUCCI, 1973; BONDESAN and SIMEONI 1983; VEGGI and RONCUZZI, 1970, 1973; VEGGIANI, 1974, 1985; ZUNICA, 1984; FABBRI, 1985, 1994) and especially that during the last decade, which includes ^{14}C analyses of the most comprehensively interpreted cores (BONDESAN *et al.*, 1995a, 1995b), contests the earlier primitive evolutionary model. This research has provided maps of the different coastlines of the last two millennia and an outline of the area's ancient hydrography.

The Ancient Deltas

Until the 12th century AD, the deltaic area was located south of the present one, in the lowlands known as the Valli di Comacchio. A coastline that existed at the time of the founding of the town of Spina (*i.e.* 6th-4th century BC and therefore called "Etruscan") can be traced for about 80 km, from Chioggia to Ravenna (Figure 5a). Recent research, carried out after the discovery of Spina, has confirmed, through archaeological findings and interpretation of air-photographs, the dating of this coastline (ALFIERI, 1959, 1960; UGGERI 1985). At this stage the Po flowed into the sea through a main outlet close to Spina. A more northern outlet, referred

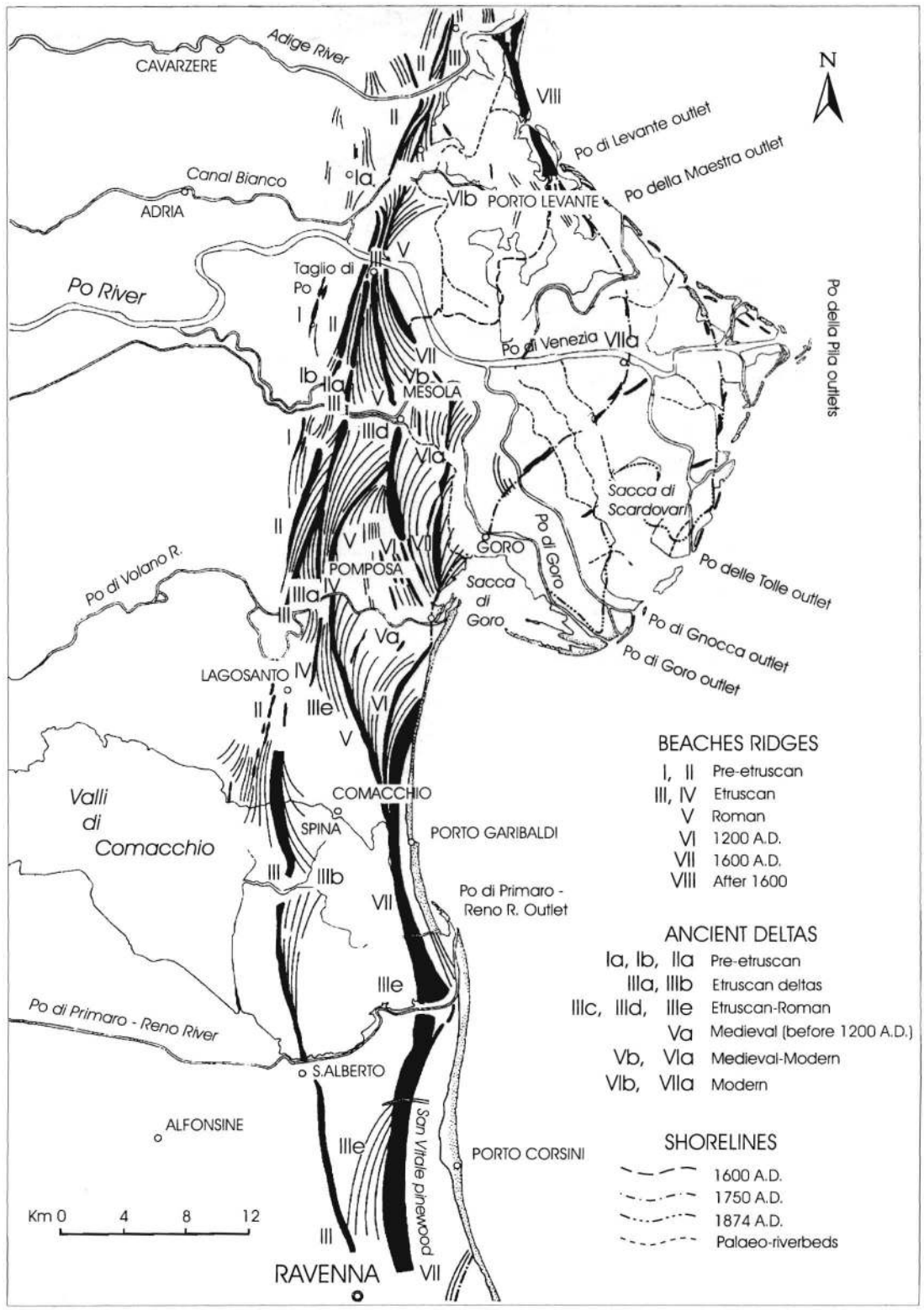

Figure 3. Palaeo-beach ridges and paleo deltas in the Po delta area according to Ciabatti (1966).

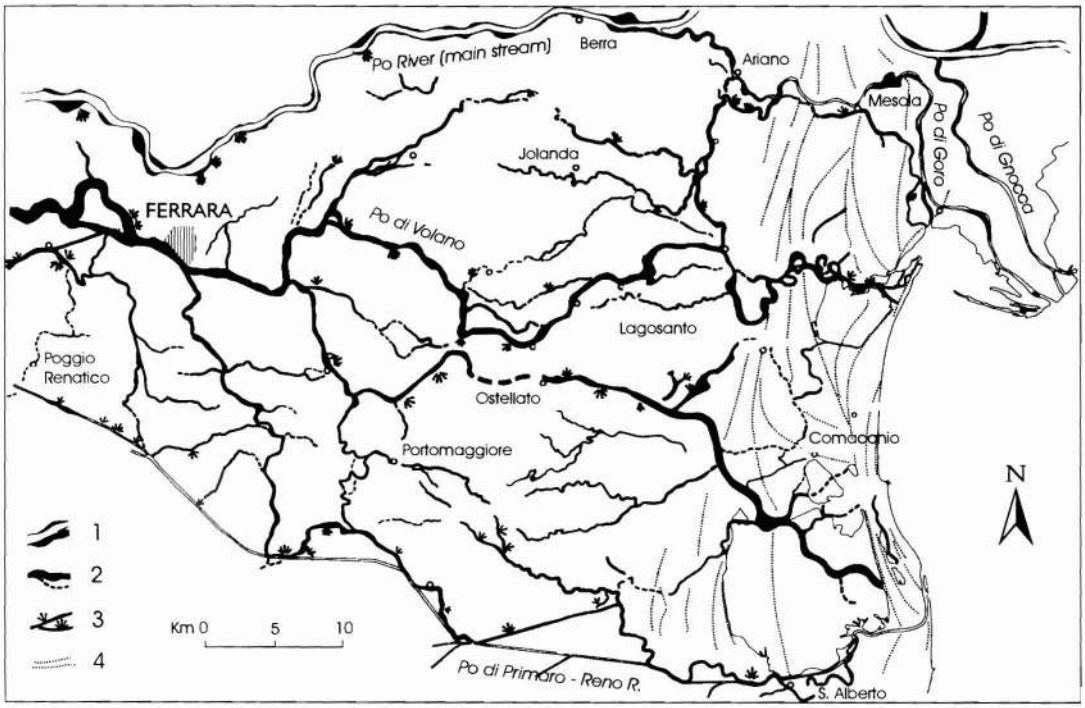

Figure 4. Palaeo-riverbeds in the southern part of the Po delta (Ferrara province) after Bondesan, 1986; (1) present-day rivers; (2) palaeo-riverbeds; (3) breach cones; (4) main beaches-ridges.

to as Po di Adria and later mentioned by Pliny as Fossae Philistinae, may be regarded as secondary. Water probably flowed to this outlet through the town of Adria and eventually from rivers now no longer connected to the Adige river.

A more recent alignment of sand ridges, discovered on air-photographs, has been dated at approximately the 2nd-5th century AD (Figure 5, insert b), on the basis of its position with regard to the ancient harbour of Ravenna (VEGGI and RONCUZZI, 1973). According to the descriptions by Polybion and Pliny, it can be inferred that at this stage the Po flowed into the sea through three well-marked cuspidate deltas, corresponding to old main distributaries. The first outlet, named by Pliny Carbonaria, was very close to marshlands or lagoons, which he called Hadrianae. The second outlet was that of the Po di Volano, an outlet that still exists. The third outlet was that of the main course of the Po during the Roman age, which Polybion called Padúa, and Pliny mentioned as Padus or Eridanus, also recalling the previous name of Spineticus, from the town of Spina. Strabo in his "Geography" states that Spina was by this time 90 stades (about 15 km) from the sea. Progradation of the Padúa outlet suggests an increase in the rate of fluvial deposition accelerated by human intervention, which may be interpreted as the outcome of extensive deforestation in the Po basin carried out by the Celts and the Romans in previous centuries (FABBRI, 1985).

During the early Middle Ages (7th-10th century), a major event was the formation of a new branch of the Po, called the Primaro, with its mouth a little further south than the Padúa. The latter no longer existed but was frequently mentioned in later documents as Padus vetus or Padovetere (*i.e.* Old Po). The Po di Volano (old Olana) also developed in these centuries with the building of a large delta as outlined in Figure 5, insert c. Its position has been reported on account of associated archaeological findings, such as the Abbey of Pomposa, discovered a few centuries earlier.

The Making of the Modern Delta

In the middle of the 12th century, an important event, the "breach of Ficarolo," occurred near Ferrara and caused the Po's main course to move northward. The formation of the new distributary, named Po di Ficarolo, may be regarded as a key event in the evolution of the delta. In fact, within a few centuries, the new stream became the main branch of the Po, thus starting the formation of the "Renaissance delta" that has been largely the result of human intervention (Figure 5, insert d).

During the 16th century, the Po delle Fornaci and the Po di Goro became the two main outlets of the new stream and were artificially embanked. Until the end of the 16th century, these main outlets were farther north than they are now, and closely approached Venice Lagoon. In the years 1604–1607, the Venetians, fearing that discharged sediments might close the mouth of the lagoon, diverted the Po to the southeast, excavating a canal 5 km long at Porto Viro (thereafter called Taglio di Po) to discharge water into the Sacca di Goro (Figure 6). After the new canalization, the Po delta began to show its present configuration accreting offshore at significantly

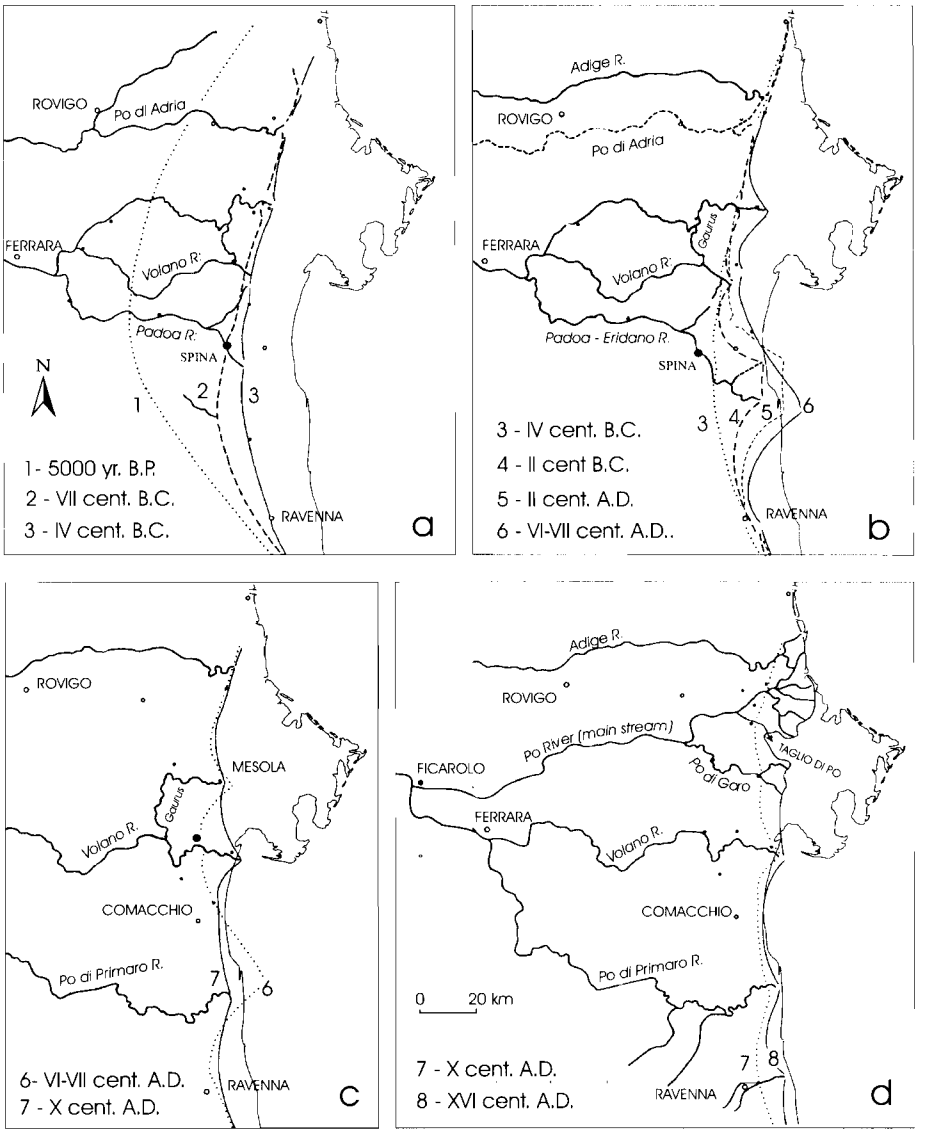

Figure 5. The evolution of the Po delta area from 5000 BP (flandrian transgression) to present time (after Bondesan, 1986).

higher rates than before. Old maps (Figure 7) show the complete filling of the ancient Sacca di Goro and further accretion of the southeastern lobe, where the new course of Porto Viro reached the sea through a number of distributaries. Along with the formation of this so called "modern delta," the ancient delta of Po delle Fornaci underwent erosion by wave action, because of the reduction in output of fluvial sediment to the sea.

During the 18th and 19th centuries, the newly formed multi-lobed delta showed an average growth of about 70 hectares/year, much greater than the previous rate which approximated 10 hectares (Figure 8) (ZUNICA, 1981; BONDESAN, 1982). Such an acceleration may be related to extensive deforestation and intensification of tillage carried out in the uplands over these centuries, which increased fluvial siltation, and to land reclamation schemes, which led to the embankment of the distributaries and a consequent increase of sediment loads to the river mouths (FABBRI, 1985).

The different rate of advancement in these periods has also been related to climatic changes and, in particular, to the cold and wet weather conditions, which during the "little ice age" from 1735 up to 1836, may have contributed to the large advancement of the Po delta building (MARABINI, 1986). Another cause for the expansion was likely the reorganization of the dike system in the low Po basin, following the two extraordinary floods of 1872 and 1879. Henceforth, the lateral discharge of water containing suspended sediments diminished and more material was carried to the river-mouth (VISENTINI and BORGHI, 1938).

At the same time, the old branches of the Volano and Pri-

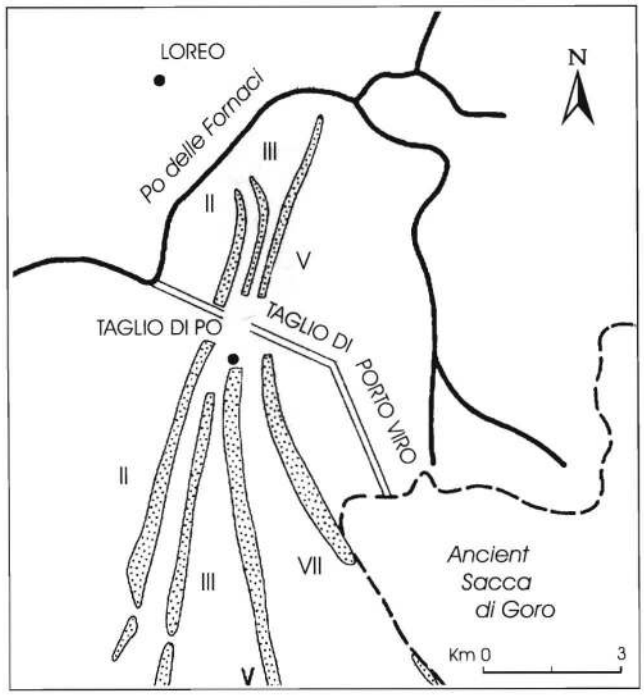

Figure 6. The diversion of the Po (*Taglio di Porto Viro*) made in 1604 by Venetians fearing that the Po sediments might close the mouth of the lagoon.

Figure 7. An old map (De Rossi, *Lagazione del Ducato di Ferrara,* 1709) showing the progradation of the modern Po delta caused by the new course of the Po after the diversion at Porto Viro.

maro were disconnected from the active network of the Po. The former was used both for navigation and to convey water from wide areas inland. The Primaro branch was later used to lead Reno river water to the sea.

Recent Trends

During the 20th century, progradation has generally been less rapid than that of the 18th and 19th centuries. The Po delta reached its maximum extension between the 1930s and 1940s. In recent decades, the delta has been retreating and yet the Po continues to transport the largest yields of sediment to the upper Adriatic. During the period 1954–1978 significant retreat of 250 m (more than 10 m/year) occurred, particularly evident among the different outlets of the delta (Figure 9).

In the modern delta, the area between Albarella Island and the Volano Outlet is devoid of beaches. Here the erosional trend was dominated by large-scale land subsidence, as a consequence of the extraction of water and gas between 1938 and 1961. The present main deltaic outlet, the Po di Pila, which supplanted the Po di Tolle, is an exception to the general trend. Because of extensive embanking of the river, sediments are transported directly to the outlets. The latter have gained depositional land and the formation of adjacent spits and elongated barrier islands has occurred. During 1934–1979 a pronounced triangular-shaped sandbank developed, indicating a significant amount of sedimentation had occurred at the river-mouth (BONDESAN and SIMEONI, 1983; POSTMA, 1989).

The beaches south and north of the delta are eroding, and it has been necessary to protect them with artificial defenses. Here the retreat is mainly the consequence of a marked reduction in the sediment supply to the coast. The Po, similar to its neighbouring rivers (the Adige, Brenta and Reno), transports only a very small quantity of sediment to the coast. The reduction in sediment yield is the result of reforestation policies, the decrease of tillage on slopes, the construction of dams, and sand extraction from river beds, all of which have been particularly severe since World War II (VISENTINI and BORGHI, 1938; ZUNICA, 1971, 1981; CENCINI et al., 1979).

NATURAL ENVIRONMENT

Lagoons and Marshlands

With respect to the remainder of the Po plain, the climate in the Po delta is mitigated by the presence of the sea. The Mediterranean's influence is greater between March and October, when east winds are strongest. Toward the end of winter and the beginning of spring, storms caused by north-east

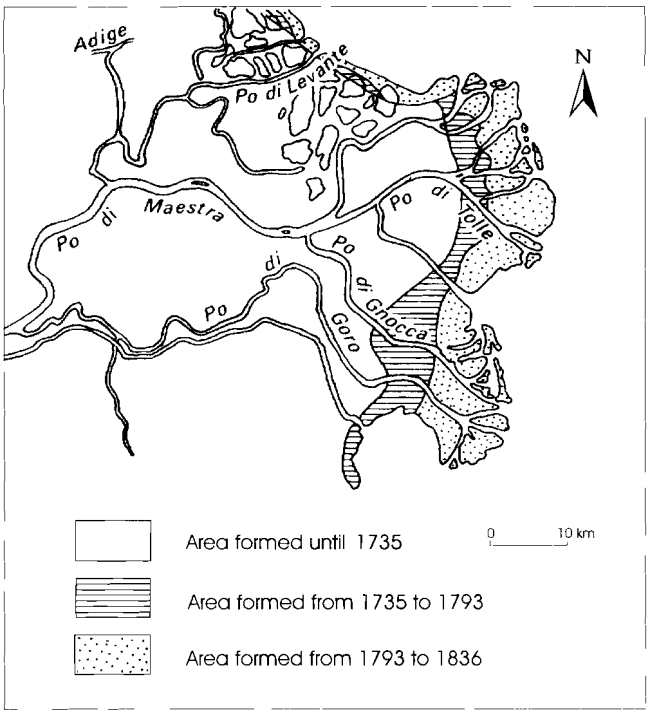

Figure 8. The progradation of the newly formed multi-lobed delta from 1735 to 1836.

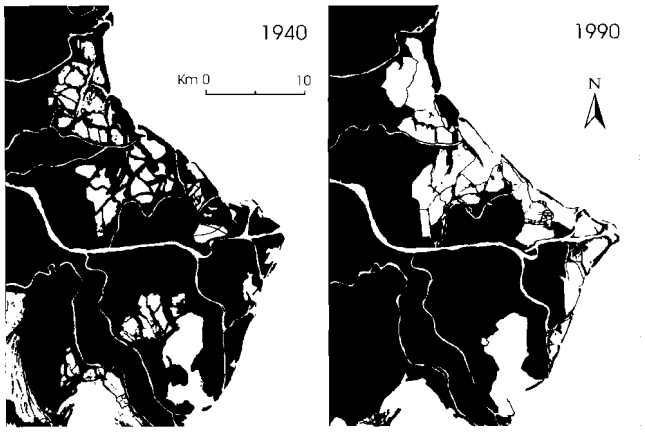

Figure 9. Recent trend of the m odern Po delta from 1940 to 1990.

winds from the Russo-Asiatic anticyclone may occur. However, these rarely reach speeds of greater than 50 km/h, and their average speed is 30 km/h. The "scirocco" (south-east wind) as well as the tide often result in the phenomenon referred to as *acqua-alta* (deep water). During such an instance in November 1966, sea level rose by 2.2 m with respect to the average level. The annual temperature range is about 23.4° C (1.3° C–24.7°C), *i.e.* lower than that of the inland plain. Average rainfall is about 600 mm/year, snow is rare, humidity is high, and fog frequently occurs early in the morning or late at night.

During ancient times, the deltaic coastland was described as a continuous, almost impassable sequence of lagoons, marshes and rivers. Most of the wetlands have subsequently been filled by sediment or reclaimed by humans. Today, even if reclamation has strongly reduced the extension of marshlands, the area remains rich in important naturalistic and environmental features. More than 50,000 hectares of fresh or salt-water marshlands exist, placing the Po delta among the largest wetlands in Italy and among the most important in the Mediterranean basin. The Po delta contains many areas of great natural beauty and monuments of historical interest. The vast and levelled plain, slow rivers, wide outlets, beaches, dunes, ancient coastal woods, marshes and lagoons create a unique and wonderful scenery (Figure 10).

The southern part of the delta (the Emilia-Romagna portion) presents several distinct nuclei of salt and brackish marshes: Valle Bertuzzi, Valli di Comacchio, Pialasse Ravennati and Cervia saltpans. These marshes formed either because of the closing of the mouth of previous lagoons or as a result of seawater flooding inland. Subsidence and temporary sea level rises caused by climatic changes also greatly affected the origin of these environments. The environment situation is diversified and ranges from the almost pristine Valli Bertuzzi, where traditional fishing activity has contributed to the maintenance of the natural ecosystems, to the Pialasse, seriously affected by pollution emanating from the nearby Ravenna harbour and related industrial zone.

Marshes have been strongly affected by humans through embankment and other engineering endeavors. Water exchange with the sea and, in some cases, with the surrounding rivers is accomplished through canals, although significantly affected by modifications as a result of dismantling the tideway network. In the northern sector (Veneto region) marshlands are largely exploited by modern aquaculture and the emerged vegetation is scattered and limited to a few canebrakes, Salicornia fields and Spartinetum.

The open lagoons (the so called "sacche," such as Sacca di Goro and Sacca di Scardovari) are bodies of seawater partially enclosed by paleo-riverbeds, deltaic peninsulas or large sandbanks (the so called "scanni"). The origin of the other lagoons is associated with depressed areas near the coast, often previously occupied by marshland. Saltpans show special characteristics derived from high water salinity and the vegetation is limited, being favoured by a few specialized communities, mainly Salicornia species.

Vegetation Outlines

The Po delta shows a highly varied vegetation pattern that is influenced by some environmental factors, such as distance from the shoreline, soil type and ground-water level. In spite of the alterations caused by anthropogenic influences, several plant communities are clearly characterized and well-defined in their ecology. Their distribution confirms the importance of the Po delta salt marshes as a transition between Atlantic and Mediterranean vegetation complexes.

The coastal vegetation of the Po delta has been investigated by many authors (PIGNATTI, 1959, 1966; CORBETTA *et al.*,

Figure 10. Air photograph of the Po di Tolle outlet in the modern delta.

1984; GÉHU *et al.*, 1984; GERDOL and PICCOLI, 1984; FERRARI *et al.*, 1985). According to the "phytosociological method," three main vegetation complexes have been recognized: (a) the sand dune vegetation; (b) the coastal mudflat and salt marsh vegetation; and, (c) wood vegetation.

(a) The vegetation of sand dunes has been strongly modified by human impact and coastal erosion. Only a few sites show the natural zonation from the foreshore communities to the fixed dune communities. The typical foreshore community is characterized by sea rocket (*Cakile maritima*) and the prickly saltwort (*Salsola kali*). The development of the first rank of embryo dunes is the result of the colonization and establishment of the sand couch, i.e., the grass *Agropyron junceum*. More mature higher dunes are colonized by a community dominated by marran grass (*Ammophila arenaria*). Fixed dunes are very rare in the Po delta region as they have been largely destroyed by human activity. Near recreational areas the few remaining dunes are often covered by plantations of pines.

(b) The coastal mudflats and saltwater marshes are colonized by some communities dominated by the glassworts (*Salicornia species*), which very slowly result in surface level increase. Inland they are followed by the communities formed almost exclusively by the saltmarsh-grass (*Puccinellia maritima*). In permanently flooded areas, the plant communities are dominated by the sea-club rush (*Scirpus maritimus*) and the reed (*Phragmites australis*).

(c) The coastal woods are important relics of mixed oak forests, characterized by a complex mosaic of plant communities, settled on ancient fixed dunes which date back at least to the Medieval age. Within small areas, the landforms are a cause of a high spatial turnover of species. The Po delta region is at the boundary between the Central European and the Mediterranean phytogeographic regions. Thus, it is possible to observe a very original mixture of species, either from the phytogeographic viewpoint or from the ecological one. These woods contain Central European species, as the penduncolate oak (*Quercus robur*), the hornbeam (*Carpinus betulus*) and the eastern hornbeam (*Carpinus orientalis*), as well as Mediterranean species such as the holm oak (Quercus ilex), the southern ash (*Fraxinus angustifolia*), the fragrant *clematis (Clematis flammula*) and *Phyllirea angustifolia*. Bosco Nordio, northwards, Bosco Mesola and Ravenna pinewoods (San Vitale and Classe), southwards, show the only remains of the Po delta coastal woods.

Fauna

The Po delta is one of the largest deltas of the Mediterranean. A wide portion of it has been recognised as an internationally important wetland, according to the Ramsar Convention and as a Special Protected Areas (SPA), according to the Bird Directive. It has been entirely designated as an Important Bird Area (IBA) by BirdLife International.

HUMAN ACTIVITIES

Human Presence in the Past

For some time humans have played an increasingly important role in Po delta evolution becoming the most important geomorphological agent. In order to improve the habitability of the area and exploit its resources, humans have altered the fluvial sedimentation patterns, controlled the river network, reclaimed marshy lands, developed agriculture, fishing, tourism and industry. As previously mentioned, the first settlement in the the Po delta dates back to the Graeco-Etruscan foundation by Spina, when the coast was bordered by dune ridges running from Ravenna to Adria, the first

Graeco-Etruscan commercial port in the Northern Adriatic sea (ALFIERI, 1960; VEGGIANI 1974; FABBRI, 1985; VARANI, 1985, 1987). With the expansion and consolidation of the Roman Empire, the Po delta began to be populated and economically exploited, but in an area characterised by the alteration between land and water. Too often marshy and unattractive for habitation, the first settlements were established along the river banks or on the dune ridges that fringed the shoreline (ORTOLANI, 1956). The area appears to have been populated along the axis running from north to south, the via Popillia, which developed on the dunes of the Etruscan ridge.

Through the centuries following the fall of the Roman empire, the economic organization of the delta fell into a state of decay. The natural processes of sedimentation took over, and deposits accumulated quite quickly. Lacking any cultural center, the delta became an area of hunting, fishing, extraction of salt, and some marginal form of grazing. Until the Medieval period, there was little evidence of human presence along the Po delta, and natural processes dominated the moulding of the shoreline. The only exception was the Abbey of Pomposa, founded in the vicinity of the coast between 7th and 8th centuries.

The dawn of the modern age saw humans increasingly interested in works aimed at water conservation and regulation. Since the 17th and 18th centuries great hydraulic works of embankment diversions have taken place (*e.g.* the diversion of the Po made by the Venetians), and efforts have been carried on to drain the marshes in the most inland areas of the delta plains. Drainage works, which were initially carried out by individual inhabitants and limited to small areas, ended up involving whole communities and extending to increasingly wide areas.

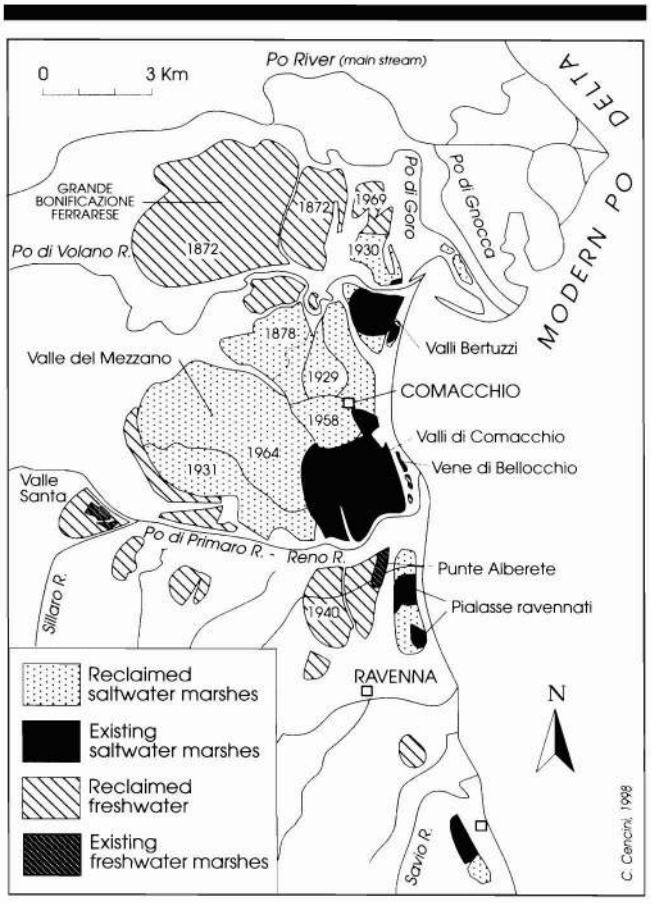

Figure 11. Reclaimed and existing fresh- and saltwater marshlands in the southern part of the Po delta (noted by the year of reclamation).

Reclamation Scheme and Agriculture

A first important phase in human-induced modification of the deltaic plain was brought about by extensive reclamation which started in the 1870s. The intention was not only to improve the hygienic conditions of the marshland and eradicate malaria, but also to gain new farm land. In 1882, the Italian Parliament passed an act that classified reclamation as works of "public utility." Seventy-five percent of the total cost was to be supported by the government, and the remainder by the private citizens who had been assigned property rights. The presence of great landed property estates favoured the growth of capitalistic farming that specialized in wheat, rice, sugar beets, and forage cultivation. Besides public funding, other factors that encouraged reclamation were the newly-available water-lifting plants, which proved to be essential for the drainage of the deltaic lowlands.

The first works involved the modern delta (Polesine) where reclamation was accomplished by the early years of the 20th century. The progressive colonization of the lands of Polesine was made by noble Venetian families who became grantees of the reclaimed lands and whose names are still recalled in the toponomy. In about 1930 the Fascist Government developed important projects for the reclamation and colonization of extensive marshlands in the Po delta. After World War II, under demographic and social pressure (the so-called "social question"), the Republican Government completed the reclamation with an agrarian reform carried out by the Ente Delta Padano, including the creation of roads, aqueducts, rural dwellings and farming villages. In the reclamation districts (*comprensori*), works started with the embankment of the rivers, the excavation of an artificial drainage network and the installation of water-pumping plants. The newly-gained lands displayed a regular grid pattern created by canals and roads.

Reclamation works ended by the 1960s owing to social and economic changes. The social question found a solution in the strong migration of peasants from the delta area toward the industrialized cities of the Northern Italy. Nowadays, in a radically different economic and social context, and a greater awareness of the need to respect the environment, past decisions have become widely regretted. The almost complete elimination of marshes irreversibly changed the hydrological and agricultural assets of the coastal plains. Today, in the ancient delta, 98% of the freshwater marshes and more than 70% of the salt marsh that existed at the beginning of the century has been reclaimed (Figure 11). In the modern delta, reclamation have not been so intensive, and large wetlands have been kept flooded for fishing or recreational use.

Fishing, Aquaculture and Saltworks

Many human activities in the Po delta are linked to water. Marshes and lagoons have generally been exploited for fishing. Traditional fishing (in particular, eel farming) has been one of the most important economic resources of this area for centuries. Salt marshes were transformed into fishing lagoons (the so called *valli*) by bringing in seawater through artificial canals (some of them were excavated many centuries ago), in order to keep the lagoon mouths active and to favor the circulation of the water. The tidal range is approximately 80 cm (average), and marshes were regulated in order to obtain favourable condition for fish breeding. Salinity varies considerably in connection with management. The average values were 15–25% in winter and spring, 25–35% in summer and fall. At present, little remains of this ancient and poor economy. The old building (*casoni*) and the eel traps (*lavorieri*) are a rare tourist attraction. The development of new techniques of mollusc cultivation allows intensive fish-farming, in particular eel and mullet in some basins of the Valli di Comacchio and of the Venetian sector of the delta, clams and other shellfish in the Sacca di Goro, Sacca di Scadovari and other smaller lagoons. In the past saltworks were also important economic activities for the locals.

Tourism and Industries

Tourism has been one of the main factors that has most incisively transformed the beaches of the delta in the last fifty years. After World War II the spread of mass tourism transformed the flat coast south of the Po delta (the "Adriatic Riviera") into the most extensive coastal conurbation of the country. By the 1960s, with the saturation of the "riviera," the urban growth impacted the nearby beaches, mainly those to the south of the delta.

The seaside resorts, which already existed in 1950 (Cervia, Milano Marittima and Marina di Ravenna to the south, and Sottomarina di Chioggia to the north), were joined by new marinas on both sides of the delta. Today urbanization extends from Chioggia to Cervia for nearly 46 km (32 km to the south of the delta and 14 to the north) corresponding to an area of more than 2000 hectares. The only tract that has been completely spared is the modern delta area between Albarella and Volano. The new urbanization is particularly heavy along the Ravenna coast, with Lido di Savio, Lido di Classe, Lido di Dante and Lido Adriano (Figure 12), and along the Ferrara coast, with Lido di Spina, Lido degli Estensi, Porto Garibaldi, Lido di Pomposa, Lido degli Scacchi, Lido delle Nazioni and Lido di Volano. In the northern sector (Rovigo province) urbanization is fragmentary (Rosolina Mare, Porto Caleri and Albarella). The new settlements have been largely managed by real estate companies, who have bought agricultural lands at low prices and resold them in lots after having built roads and condominiums. This urbanization scheme has produced a heavy concentration of buildings behind the shoreline, particularly "second-homes," resulting in an imbalance between permanent and seasonal dwellings. Only recently has urbanization recorded signs of stagnation as a result of saturation and increasing specific control (CORNA PELLEGRINI, 1969; CAMPI, 1970; MENEGATTI, 1979; CENCINI, 1996).

The flux of tourists toward sea-side resorts has developed on a mass scale during the last thirty years. An indication of the trend of tourist development is provided by the beaches of the provinces of Ferrara and Ravenna, where in 1995 more than 1 million arrivals and about 12 million overnights have been estimated. Most beaches are heavily used. A wide range of infrastructure, such as the *bagni* (beach houses or bathing establishments) is provided along with all possible facilities, including restaurants, coffeeshops and hundreds of umbrellas and deck-chairs placed between the *bagno* and the shoreline (Figure 13). Figure 14 shows the density of the beach equipment measured by the number of umbrellas per hectare of beach.

Currently tourism is mainly related to beaches. A future re-evaluation of some activities not strictly combined to sea-side tourism could induce the recovery of the local identity of the delta, where wilderness alternates with a discrete civilization. The area is rich in cultural heritage from the past in the form of many archaeological sites, small towns and cities (including Comacchio, Chioggia and Ravenna), churches and monasteries (such as the ancient Romanesque Abbey of Pomposa), castles (such as the castle of Mesola), patrician villas, and other historical buildings or structures connected with the reclamation scheme, saltworks, traditional fishing, and sea-related activities. With sound planning, this attractions could reduce beach congestion and environmental stress.

Since the 1960s some industries have been developed near or in the delta. In particular, the oil and chemical industry has located near the Ravenna harbour, other activities connected with energy production, such as off-shore extraction of methane from the deep strata, and the building of a large thermoelectric power station in 1978 at Porto Tolle (in the midst of the delta) with an installed capacity of 2500 megawatts. These industries have often produced heavy levels of local pollution and minimal integration with the deltaic socio-economic structure. Other activities present in the delta include fish-harbors, fish and mollusc-farming, sugar refining, and dock- and repair-yards. More recently, several new small industries, craftworks and tertiary enterprises, linked to beach tourism, have taken place along the Romea road. Included are furniture production and shopping centres.

THE ENVIRONMENTAL IMPACT

Dune Degradation and Beach Erosion

The concentration of population, settlements, and economic interests in the Po delta, has resulted in a drastic change in existing ecosystems, together with a general decrease in the standards of environmental quality.

A first impact has involved beaches and dunes. The recent spread of tourist development has stimulated a very heavy demand for waterfront land. Buildings and roads were located directly over back dunes, which were thus removed from the coastal system. In order to provide space for the bathing establishments and other recreational facilities, front dunes were also levelled. Dunes not directly involved with housing also suffered from other human activities: many were mined, scarred by footpaths and vehicular traffic, devegetated by uncontrolled camping and parking, and excavated to provide

Figure 12. Heavy concentration of buildings behind the shoreline at Lido Adriano, south of the Po delta.

sand for concrete. At present, relict foredunes are lowered and affected by numerous breaches and rarely provide good protection for the shore. Even where it remains, the dune front has lost its continuity and does not offer protection against winds or the sea flooding related to the phenomenon of *acqua alta* (high tide). Since, in the delta, dunes can no longer supply sand to the system, part of the sand irreversibly disappears into the sea during storms. This process results in erosion until a new equilibrium has been established (CENCINI *et al.*, 1988; CENCINI and VARANI, 1989).

Another form of human impact on environment is related to beach erosion. Shoreline recession, caused by the general processes discussed previously, has been particularly severe in the Po delta and adjacent beaches. In ignorance or in disregard of this trend, tourist development concentrated very near the beaches and in some cases upon them, although evidence of erosion abounds (Figure 15).

Along the ancient delta shorelines (Ravenna and Ferrara provinces) the development of the urban waterfront was particularly intense in the period 1950–1970, notwithstanding a shoreline recession rate of 5–10 m/yr (CENCINI *et al.*, 1979). The coincidence between a prograding urbanization and a retreating coastline has emphasized (and often dramatized) the erosional trend and has led inevitably to the establishment of a substantial system of protective works. In 1968 along the 67 km stretch of beaches of these two provinces, more than 45% was eroding and only 7.5% was protected.

Land Subsidence

Areas more than 2 m below sea level are widespread around the Po Delta (Figure 16), and in the central area of the delta some areas lie at −5 m (CASTIGLIONI, 1994, 1997; BONDESAN *et al.*, 1995b). Long-term natural subsidence has been estimated between 0.8 and 1.2 mm/year (ELMI, 1984). In addition, the entire territory suffers from heavy human-induced subsidence. Reclamation has produced negative effects as sediments have been compacted by reduced hydrostatic pressure. Also, heavy pumping of ground water for agricultural and industrial use in newly developed areas has increased subsidence in the Po delta. Since the 1950's, the extraction of methane-bearing water from Quaternary strata

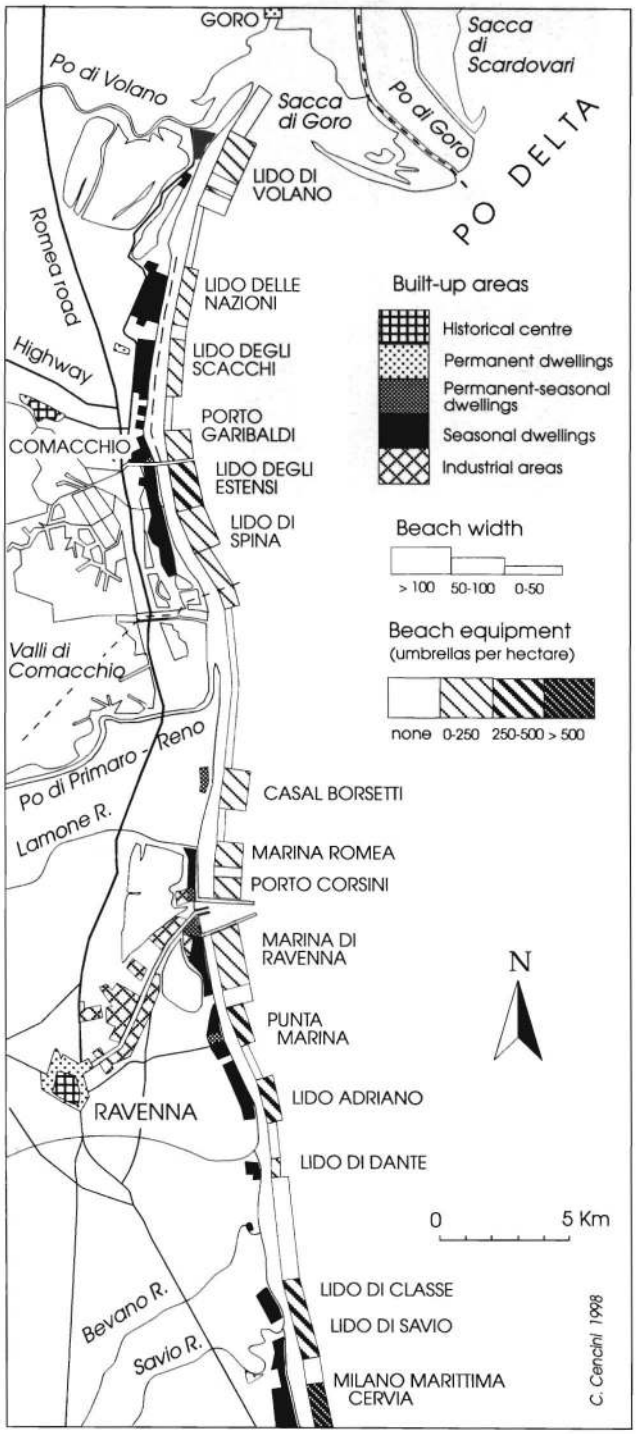

Figure 13. Built-up areas and density of beach equipment in the southern part of the Po delta.

has become the predominant deteriorating factor. Methane extraction, which started in 1938 and continued until 1964 when it was forbidden, largely contributed to an increase in the subsidence phenomenon.

When the first levelling network was established in 1957, subsidence values ranged between 70 and 100 mm/year (CAPUTO *et al.*, 1970; BONDESAN and SIMEONI 1983; CARBOGNIN *et al.*, 1984; BONDESAN, 1989). Since 1964 subsequent levelling indicated a decrease in the subsidence rate, but in the 1970s the southern part of the delta was experiencing subsidence rates varying between 5 and 20 mm/year (BONDESAN *et al.*, 1986). More recent information suggests that subsidence rates decreased very little in the 1980s and even increased in some cases, probably in relation to the present land use, which requires copious irrigation and forced drainage. On the whole it means a total subsidence of 2 m in 30 years, with peaks of 3 m.

Artificial Structures

At the turn of the century, limited sectors of the delta were protected by artificial structures. Now different coastal defence structures protect over 60% (82 km of 130 km) of the delta coastline, resulting in its almost complete artificial stabilization. (CENCINI and VARANI, 1988; CNR, 1976) (Figure 17).

Artificial structures are of many types. A rough classification includes: (a) dams or dikes to prevent flooding of land by sea; (b) artificial structures related with river-mouth and channel-harbours; (c) artificial structures to prevent coastal erosion.

Today the wider portions of the delta are embanked and protected by seawalls or dikes, 75 km long to prevent flooding of the land by the sea. Moreover, the lagoons and the river branches not directly facing the sea (such as Sacca di Goro and Sacca di Scardovari) have been embanked and protected by sea walls. For instance Isola Camerini—an intensivly cultivated land between Po di Pila and Po di Tolle—is surrounded by high banks and is subdivided into three "polders" by two inner artificial banks (Figure 16). The building of artificial embankments along the rivers, in order to contain floods, has forced the deposition of new sediments capable of compensating subsidence.

The entrances to lagoons, as well as the mouth of some harbors, built at the outlet of rivers or canals, are usually protected by two paired jetties that act as sand traps and help in the maintenance of the canal. The 3 km-long paired jetties of the Ravenna harbor are protected by riprap or concrete armour units of different shapes and sizes, similar to tetrapods and cubic blocks. Frequently, the jettied canal-harbors interfere with the longshore sand migration. This effect is evident in the cases of Porto Garibaldi where, because of the erosion caused downdrift by jetties, it has been necessary to protect beaches with offshore detached breakwaters for a length of 10 km from the northern pier.

The spread of tourist urbanization along some of the deltaic coast has led to the establishment of defensive structures in order to protect the beach-front from erosion and to prevent the destruction of buildings, roads or recreational facilities. South of the delta, 24 km of beach are protected. Several kinds of defence works are being used: the most common form of defence consists of offshore detached breakwaters, constructed from large blocks of limestone, 50–120 m in length,

Figure 14. Hundreds of umbrellas on the beach of Lido delle Nazioni, south of the Po delta, in summertime.

2–4 m in depth and 100–200 m from the shore. These structures are usually oriented perpendicular to the prevailing winds (CENCINI and VARANI, 1988).

Such breakwaters are usually effective in protecting beaches but present some disadvantages. They do constitute the major factor in deteriorating the standard of coastal waters, which become stagnant between the structures and the shore. Their maintenance costs are high, since breakwaters tend to sink into the substrate and demand periodic additions of new material. Finally breakwaters interfere with the longshore drift and can accelerate erosion of the nearby unprotected beaches. Such disadvantages led recently to softer defences such as sacks or pipes of plastic material filled with sand which have been submerged offshore along the Ravenna coast in 2–3 m water depths, 300–400 m from the shoreline.

Sea Level Rise and Flooding Risk

The greater part of the delta is drained by a dense network of canals. The water management of the delta, carried out with numerous pumping stations (more than 100), in order to control the excess waters, is a most necessary aspect of the management of the delta. The drainage system of the delta is extremely vulnerable and this threatens the integrity of the territory. Since many pumping stations are exclusively powered by electricity, the interruption of mechanical drainage can cause severe risks of flooding, as occurred during a storm in 1979 (BONDESAN *et al.*, 1995b).

Between 1951 and 1966, Isola Camerini was flooded 10 times and Isola Bonelli 6, in spite of frequent bank reinforcements. Reclamation operations in Isola Bonelli, less densely populated and more difficult to protect, were finally abandoned in 1956. The waters of the Po di Tolle entered this lagoon through various breaches, and the area is now and again invaded by the sea and is referred to as the Lagoon of Bastimento.

These problems could be exacerbated as a consequence of climatic change. Any future rise in the sea level would certainly lead to a danger for the existing overall equilibrium and security near river mouths, in the lagoon and along the eroding coastline. The main risks are the result of (a) the rise of the salt-water wedge in rivers and of the salt-freshwater interface, both making it more difficult to procure fresh water for irrigation and other uses; (b) the increasing vulnerability of the area to invasion by the sea and flooding by rivers, leading to the need to raise the height of existing dikes, dams and river banks.

For the next century, and even in the absence of additional human-induced subsidence, projections indicate innundation of between 0.5–1.5 (BONDESAN *et al.*, 1995b). Most coastal lagoons will probably be engulfed by the sea and new and stronger defences will be required along the remaining delta, in a scenario more and more similar to an "Italian Netherlands" as acutely defined by Bondesan *et al.* (1995b).

MANAGEMENT OF THE DELTA

Environmental Planning

Both physical and human problems are particularly varied and severe in the Po delta. The maintenance of delta equilibrium requires ongoing hydraulic management and periodic addition of new structures to protect the territory from coastal erosion and from the risk of flooding by the sea. These works, if carried out in a disorganized way, can have a heavy impact on the environment, even to the point of destroying its morphological equilibrium.

New projects for exploiting the territory continue to be

Figure 15. Beach establishment (*bagni*) damaged by erosion ot Lido di Dante, south of the Po delta, in the 1980s.

planned and carried out in the Po delta: enlargement of tourist resorts and ports, construction of leisure parks, more intensive fish-farming, addition of other industrial sites (*e.g.* at Porto Levante), large waste dumps, new roads, widening of the existing roads (such as the Romea road which now supports intensive heavy traffic), and restarting gas extraction in the Valli di Comacchio. Recently (1991) expansion of the power station at Porto Tolle was approved, to increase the output capacity of by 300 megawatts.

The need for environmental equilibrium is intimately linked with the socio-economic activities of this densely inhabited area (70 inhabitants/ km^2). The conservation of the natural beauty not only necessitates protection of the existing natural and historical features, but it also represents an occasion for producing new wealth, strengthening the cultural services, creating a new kind of qualified eco-tourism, and providing incentives for compatible economic activities, such as biological agriculture, fish-farming and craftwork. According to the principles of sustainable development, the management of the delta must provide ecosystem integrity and, at the same time, realize economic efficency as well as social equity. On the other hand, sustainable development is a target that has to be territorialized in order to be pursued in practice. In this sense it is necessary to reformulate development on the basis of specific characteristics and of local ecosystems (CENCINI and MENEGATTI, 1997). The conservation, management and use of wetlands may assume a central role in establishing sustainable development based on traditional territorial processes and respect for the coexistence between man and water. This should extend to the point of restoration of wetlands that have been already reclaimed but are no longer used for agricultural purposes.

The complexity and the diversity of the problems that affect the delta clearly require a unified approach. Experience has shown that it is impossible to successfully protect the territory by applying fragmentary measures at the local level. On the contrary it can be managed only by well-organized territorial policies based on national and regional acts.

Unfortunately, a unitary strategy for the Po delta is very hard to achieve. Its management depends on several political and administrative authorities and different technical boards, such as the State, two Regions (Emilia-Romagna and Veneto), four provinces (Ravenna, Ferrara, Rovigo and, partially, Venice) and at least 15 municipalities. Furthermore the management of the river bed of the Po is carried out by the "Magistracy for the Po," which depends on the Ministry of Public Works, while a regional organism (*Genio Civile*) is responsible for the other rivers and the coastline. Reclamation consortia, which are old private organizations, are responsible for drainage and irrigation in the various delta sectors. The consortia are responsible for the building and the management of inland canals and pumping stations.

Protected Areas

It was in the 1960s, when the largest marshy area of 17,700 hectares (Valle del Mezzano) was being reclaimed, that the idea to conserve the natural beauties of the Po delta began to circulate. During the last 25 years, several projects for the creation of a natural park have been formulated, some of which contrasted with each other (ZUNICA, 1981; CERUTI, 1981, 1983).

The establishment of the regional authorities at the beginning of the 1970s, has accompanied the emergence of a new environmental culture and has given new hopes and new instruments for protection. The Emilia-Romagna regional authority acted well in advance, recognizing the international value of the Po delta, according to the Ramsar Convention.

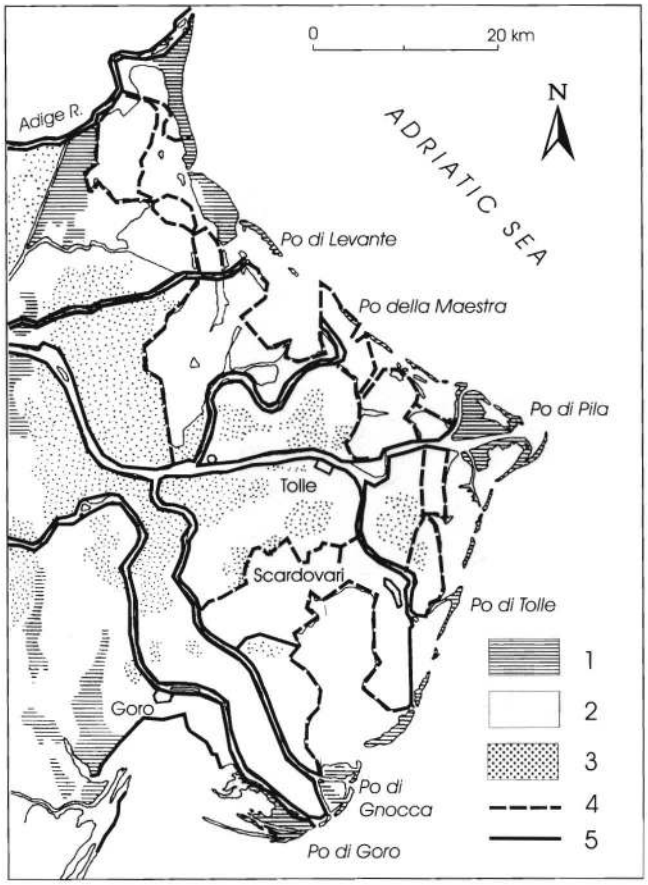

Figure 16. Depressed areas and artificial structures in the modern Po delta: (1) areas above sea level; (2) areas 0–2 m below sea level; (3) areas more than 2 m below sea level; (4) river embankments; (5) seawalls and dykes.

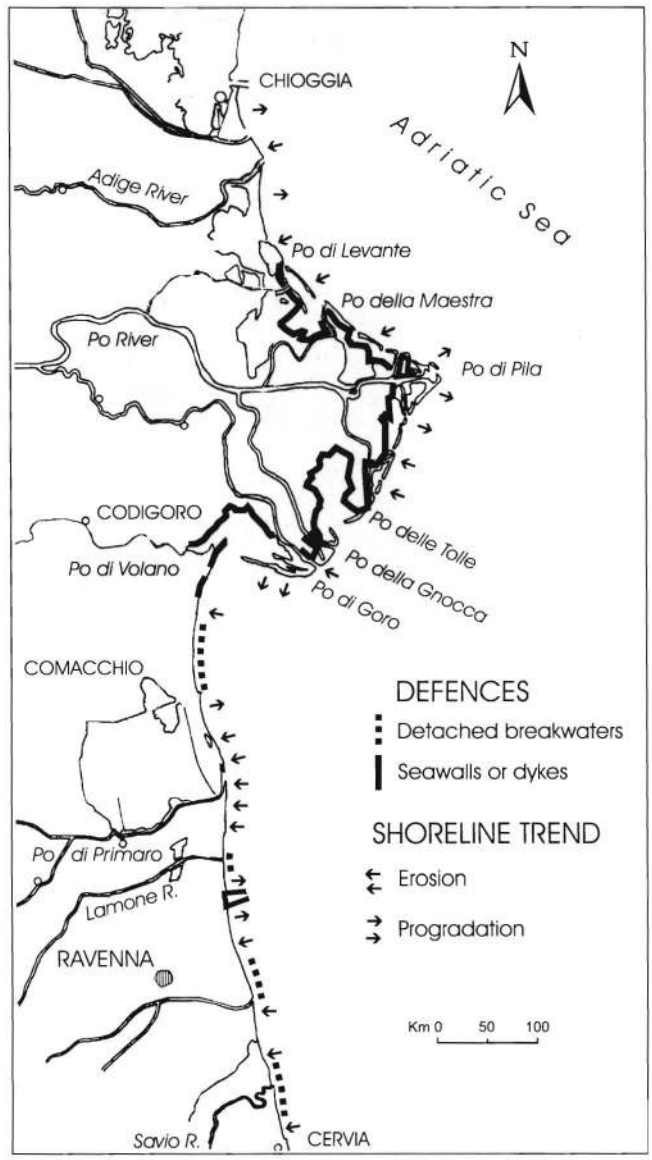

Figure 17. Shoreline trend and srtificial structures in the Po delta.

Fundamental instruments of urban and regional planning were the Regional Territorial Plan and the Regional Landscape Territorial Plan, which have identified lines of development for the region and established the contents of single sectorial plans. By means of these instruments, human activities have gradually been regulated and cultural, historical and natural values have been preserved.

The situation differs completely in the Veneto region where there is no landscape plan and, since the very beginning, the idea of a park was immediately opposed by the local population as well as regional authorities, both worried about seeing their possibilities of development limited.

After various proposals in 1988, Emilia-Romagna Region passed a regional act establishing the Po Delta Natural Park, obviously limited to the regional territory, south to the Po di Goro branch. The relative territorial plan, carefully defining the characteristics of the park and its boundaries, came into force in 1991. The official inaugutation date, however, was not until 1996 (CENCINI, 1996).

The institution of the park involves the creation of a "management consortium," that is a supra-municipal coordinated level of policies for protection, restoration, and enhancement of natural and historical features and for qualification and promotion of local economic activities and employment. The park extends over 60,000 hectares: one third occupied by wetlands, one third by agriculture, and one third by woodlands and built-up areas. It is divided into six "stations," *i.e.* homogeneous territorial units: Volano-Mesola-Goro, the historical centre of Comacchio, the Valli of Comacchio, Campotto di Argenta, San Vitale pine-wood, and Cervia saltwork. This structure represents the result of a well-balanced policy of environmental defence, as well as a rare example of net-like system of protected areas (Figure 18). The examples of ecological corridors that link the various stations of the Po delta park are particularly interesting.

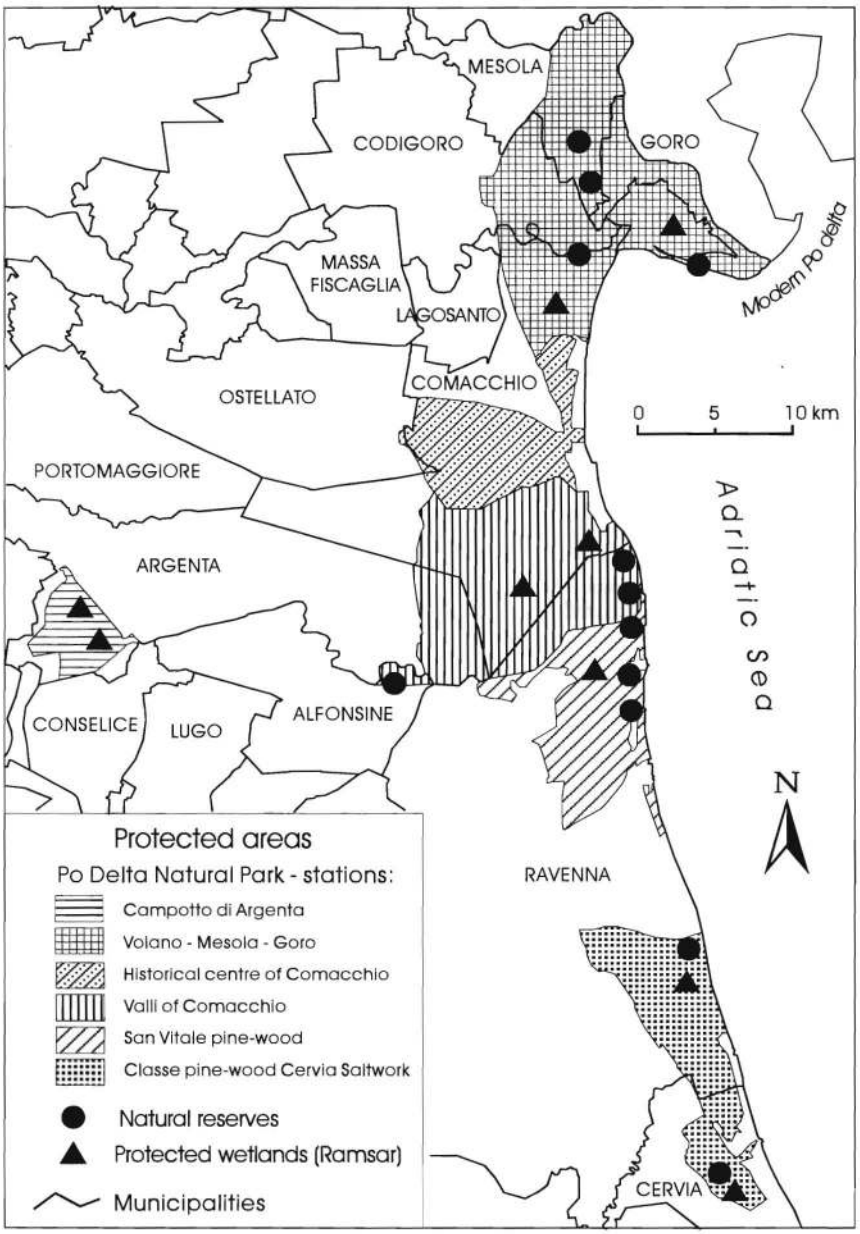

Figure 18. The regional park and other protected areas in the Po delta.

A national law (no. 394, Protected Areas), approved in 1991, has provided for the constitution of a "national" park covering the whole delta (a perspective being particularly favored by many environmental associations) in case the two regions involved do not come to an agreement in order to set up an "inter-regional" park.

After must hesitation it appears that the two Regions have come to an agreement to set up an inter-regional park, so avoiding the creation of a national park. In fact, both regions agree on one point: they do not want the national park. The situation remains very uncertain, and this makes the achievement of the goal of unitary management of the delta even more difficult. The Po delta has experienced, since ancient times, a common history under the influence of physical processes and human activities. Today, this unity has been lost and it appears increasingly more difficult to regain it.

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