Environmental evolution in the Lagoon of Venice (Italy)†

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Bonardi, M. & Marabini, F. 1993. Environmental evolution in the Lagoon of Venice (Italy). *Geophytology* **23** (1) : 159 — 165.

The Lagoon of Venice was formed about 6000 years B. P., and is quite unique since it evolved not only by natural events but also because of human intervention which has played a major role in recent times. Man's activities that started during the 14th century, drastically affected the natural development of the Lagoon and led to its present marine characteristic. This study is a preliminary attempt for a more detailed investigation that will try to correlate geological, lithological, climatological, palaeobotanical, mineralogical and archaeological parameters that contributed to the formation of.the different environments of the Lagoon of Venice during the Late Quaternary. Well dated evidences of different nature, from stratigraphy, sea level and coastline changes, pollen, palaeobotanical and archaeological findings, have been considered to describe and compile environmental sequences in the Lagoon of Venice and the northern Adriatic Sea.

Key-words—Venice Lagoon, palaeoenvironments, climatic changes, Venice (Italy).

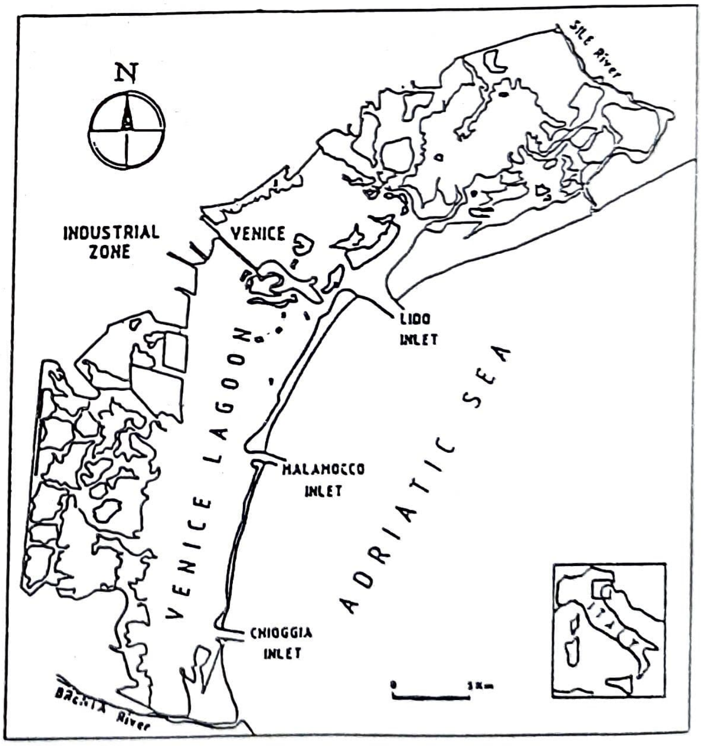
INTRODUCTION

THE Lagoon of Venice is the most developed of the series of lagoons in the northern part of the Adriatic Sea (Text-fig. 1). Its development during the Late Quaternary has been affected first by natural factors then, more recently by man's activity. It is important therefore, to recognize not only the natural events but also the human impact on the landscope. The sedimentary column records most of the factors that have affected the lagoon during its formation and development. These factors are: the sediments and the fresh water from the mainland; the salty waters, currents, tides, waves from the sea; the deviation outside the lagoon of the main rivers; and the digging of canals for internal navigation done by man.

This report represents a preliminary phase for a more detailed correlation of the lithological, palaeontological, palaeobotanical and archaeological informations available to date, that can be used to reconstruct the environmental evolution in the Lagoon of Venice and the Northern Adriatic Sea during the past 40,000 years.

THE LAGOON OF VENICE

The arch shaped Lagoon of Venice (Text-fig.1) located at the northern end of the Adriatic Sea, communicates at present with the open sea by three openings that allow water exchange and maintain the marine character of the lagoon. Its formation and evolution can be briefly summarized as follows:



Text-figure 1. The Venice Lagoon. Areas submerged during Flandrian trasgression.

† Paper presented at the Birbal Sahni Birth Centenary Polaeobotanical Conference, Lucknow, November 20-22, 1991.

(a) a period of continental sedimentation during the Pleistocene Würm glaciation,

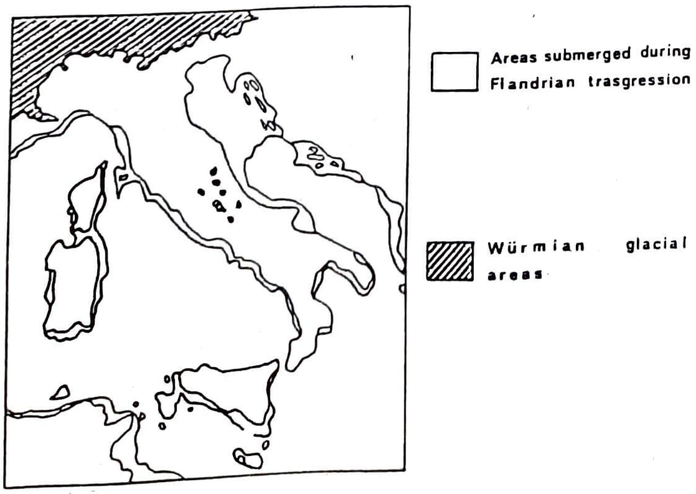
(b) a period of emergence of about 11,000 years (18,000-7,000 B.P.) during the end of the Pleistocene period with almost no sedimentation and characterized by the compaction of the argillaceous continental deposits,

(c) the Holocene Flandrian transgression during which the continental sediments of the Adriatic palaeoplain were partly eroded, reworked and dispersed by the intense fluvial activity and by current and wave motion of the sea that was progressively moving northwards until it reached approximately the present position, about 6,000 years B.P., and

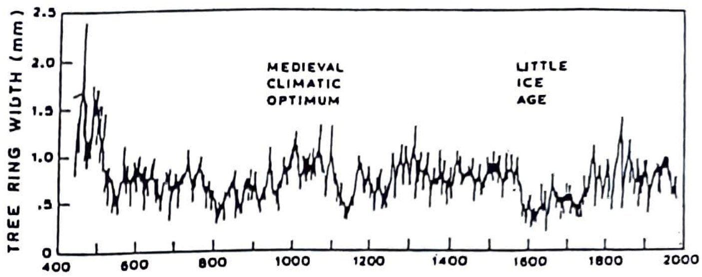
(d) finally the period from the Roman times to the present, during which the influence of man's activity on the mainland and on the Lagoon itself prevailed over the natural evolution of the Venetian basin.

THE PLEISTOCENE CONTINENTAL SEDIMENTATION

During the Pleistocene Würm glacial period about 20,000 years B.P. the Adriatic Sea level was from 90 to 130 m lower than the present and the coastline was about 300 km further south (Text-fig. 2) leaving an emerged plain in the northern part of the Adriatic region. The Late Pleistocene continental complex is formed mainly by interbedded layers of clay, sand and peat; the continental origin of which is confirmed by the textural characteristics of the sediment layers and their palaeontological contents. Important studies by Bortolami *et al.* (1977) on pollen obtained from samples from different cores in the Lagoon of Venice and the Lower Po Valley provided important information on the subsidence and climatic fluctuations in the northern Adriatic region. Their study briefly indicates:



Text-figure 2. The Upper Adriatic Palaeoplain during the Würmian glaciation (after Gatto & Carbognin, 1981).



Text-figure 3. Dendrocronological standard curve : Northern Sweden from 436 A.D. up to day (Bartholin, 1984).

(1) following a continuous subsidence and sedimentation rate of about 1.3 mm/yr from before 40,000 to 22,000 years B.P., the least glacial peak, the sedimentation rate increased drastically to at last 5 mm/yr, probably caused by an accelerated downward movement of the basin, i.e. an isostatic effect,

(2) a sedimentation gap ends the Pleistocene (18,000-7,000 years B.P.), and

(3) an episode of emergence that corresponds to the compaction and overconsolidation of a clay layer considered as an indicator of the Holocene/Pleistocene boundary.

Borotolami *et al.* (1977) also found that the Pleistocene peat samples consist of the same type of Cyperaceae peat throughout the stratigraphic column indicating that the growth conditions, i.e. the hydrologic situation, must have been approximately the same during each period of peat development. Furthermore the authors suggest that a good correlation betweeen age and depth of the sediments implies that the sedimentation was strictly related to the subsidence of the basin floor. Table I summarizes the palaeogeographic events that characterized the northern Adriatic region.

Palynologic analyses gave important indications on the climatic variations and on the related vegetational phases for the time span between 40,000 and 18,000 years B.P.

A study by Bortolami *et al.* (1977) on pollen from peat samples from the Northern Adriatic basin gave a C14 date of 39,000 B.P.and indicates the following five climatic phases:

(1) a Gramineae steppe period with *Juniperus, Artemisia, Ephedra* and some scattered pine trees indicating a cold and dry climate,

(2) sixty percent increase in tree pollen percentage such as oak forest elements, traces of beech (*Fagus*), fir (*Abies*), pines (*Pinus*),birch (*Betula*) and spruce (*Picea*),

Table 1. Palaeogeographic reconstruction of the Venice area (Bortolami *et.al.*, 1977)

Age (years B.P.)	Vegetal cover	Climate	Sedimentation	Crustal movement
Present			lagoonal	relative stability
3,000	mixed oak forest	warm; humid		
			littoral	<1.3 mm/year
7,000			Flandrian transgression	
	?	?	erosion	isostatic rebound
15,000			calcareous paleosol	
	?	?		
18,000			emergence	
	Gramineae steppe	very dry; cold		> 5 mm/year subsidence + isostatic effect
23,000				
	pine forest	dry		
32,000				
	Gramineae steppe	cold; dry	lacustrine fluviatile	
34,000				
	pine and birch	warm; dry		1.3 mm/year
38,000				
	pine and some mixed oak forest	temperate warm; humid		
39,000				
	Gramineae steppe	cold; dry		
>43,000			emergence	
	?	?	marine transgression	?
>60,000	(?) mixed oak forest	warm; humid	lacustrine fluviatile	?

between 38,000 to 34,000 years B.P. could be attributed to warmer and more humid conditions with some climatic changes within the same period,

(3) with the occurrence of steppe vegetation such as Gramineae, Chenopodiaceae and few pines at 33,000 years B.P. a change to cold climate could be recorded,

(4) between 32,000 and 23,000 years B.P., 50% increase in pine pollen with fairly high value for Graminceae, *Artemisia*, *Ephedra* and *Juniperus* indicates an open pine forest in the steppe with a dry climate. But between 31,000 and 29,000 years B.P. more humid condition were developed as indicated by the presence of oak (*Quercus*), elm (*Ulnus*) and poplar (*Populus*), and

(5) a steppe type vegetation with up to 70% Gramineae, *Artemisia, Juniperus* and Chenopodiaceae characterized the 22,000-18,000 years B.P. period with very dry and cold climate.

The authors also report a striking resemblance, despite the great distance, when they correlate the vegetation phases of the Venetian region with those from other locations in the Mediterranean area.

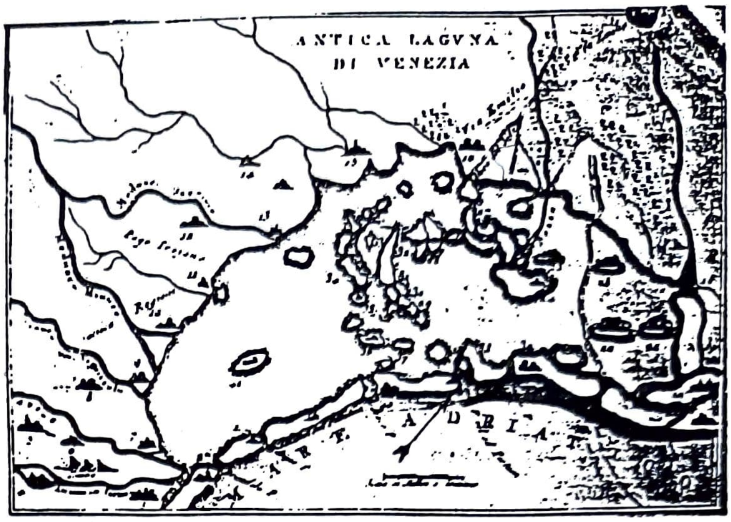
PLEISTOCENE EMERGENCE

The Pleistocene period ends with a phase of no sedimentation (18,000-7,000 B.P.) in the Venetian lagoon. In fact no Pleistocene continental deposits younger than 17,800 B.P. have been recorded in the region. During the final phase of the Pleistocene period the shallow argillaceous deposits are drained, compacted and oxidized to form the overconsolidated levels known in the Venetian lagoon as "caranto" and representative of the Holocene/Pleistocene limit. The lack of sedimentation corresponds to the beginning of the deglaciation, the Flandrian transgression.

THE FLANDRIAN TRANSGRESSION

With the climate improvement that started about 17,000 B.P. and reached its maximum about 6,000 B.P., the sea level began to rise and the coastline moved progressively northwards over the Adriatic palaeoplain until it reached approximately the present position about 6,000 B.P. That period was characterized by an intense and prolonged alluvial phase. Wave motion and sea current reworked and dispersed the fluvial sediments carried to the sea and formed the sandy littoral bar which delineated the primordial Venetian lagoon (Carbognin *et al.*, 1984).

We must remember that every lagoon is an extremely unstable ambience that can become a swamp or a plain if either a transgression of the sea or the solid material carried by the sea prevails.



Text-figure 4. The old Lagoon when Venice was founded (a reconstruction by Teodoro Viero, 1799).

Five rivers flowed into the Venetian basin (Text-fig. 4) and guaranteed the brackish water, but threatened to make the whole lagoon a marshland and silt it up, leading to the disappearance of the lagoon that became a permanent emerged area joined to the Venetian plain. The natural land sinking process (subsidence) caused by the compaction of the late alluvial deposits and the eustasy (rising of the sea level) were not sufficient to counterbalance the natural silting-up of the Venetian lagoon (Carbognin *et al.*, 1984).

Records of this unstable character of the Venetian lagoon are the beachrock formations as described by Stefanon (1966) on the edge of ancient lagoons now disappeared after the sea transgression, and the "barene" (intertidal flats). Braga and Stefanon (1969) described several outcrops of submerged beachrocks, at different depths and distances from the coast, typical of warmer areas. Theses outcrops have been formed through the cementation by carbonates of sediments in the intertidal zone and they have been C14 dated to about 3,850 B. P. The "barene" are tabular structures periodically submerged by high tide. They are quite unique of the Lagoon of Venice and their very existence depends on the extremely unstable equilibrium of the Venice Lagoon ambience.

Among the extensive number of studies done on the palaeoecology of the Upper Adriatic Sea and, in particular on the Venetian ambience, worth mentioning is the research done by Marcello and Pignatti (1962) on the characteristic phaenoanthesis of Venice Lagoon tidal flats. They concluded that the plants present in the "barene" belong to two groups very distinct in origin and phaenoanthesic rhythm. One group formed mainly of halophile and hydrophile entities is of Atlantic-American affinity; the other group is composed of entities with Central-Asiatic affinities (true halophile or thermophile)

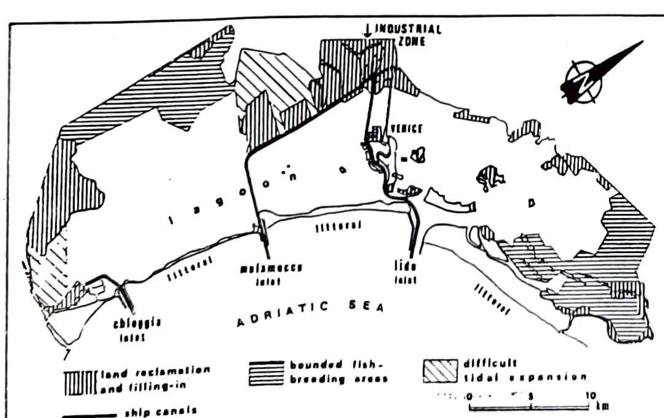
(Marcello & Pignatti 1962).

MAN-INDUCED CHANGES IN THE NORTHERN ADRIATIC SEA ENVIRONMENT

Recent archaeological discoveries such as a floor of a domus (house) of the Roman period, about one century A.D. and the base of Roman bridges on the "Via Attinia" (Favero, 1991 personal communication) about 1.5 m under the present sea level, indicate that the area, at the time of construction, was dry and about 2 m higher than present. These evidences are contradictory with the commonly accepted opinion that, the "Veneti"(the inhabitants of the region) during the 14th century, under the attack of the Uns and the Longobards, left the mainland and escaped to the lagoon and founded what is now called Venice. The land sinking was about 1.5 m and the sea level raised about 40 cm during the last 1000 years.

Neither the natural process of land sinking (1.3 mm/year) caused by the compaction of late alluvial deposits, nor the eustasy could counterbalance the continuous silting up of the Lagoon of Venice and of the eight openings to the Adriatic Sea (Text-fig. 4).

Venice was built in the middle of the Lagoon and considering the surrounding environment as the best defence against the barbaric hordes, the Republic of Venice "La Serenissima" decided, during the 14he century to divert into the open sea the five major lagoon tributaries, responsible for the silting-up, and started digging canals for inland navigation. The diverting of the rivers (Text-fig. 5), completed in four centuries, (1400-1800 A.D.) accomplished the conservation and the enlargement of stretches of water and induced an abrupt reversal on the natural evolution of the lagoon. The characteristic brackish water of the lagoon became, after the diversion of the major tributaries, more and more saline with the direct consequence that the electrochemical compaction of the sediments due to salt water seepage



Text-figure 5. Map of the Venice Lagoon showing the man-made changes from 1800 until today (after Gatto and Carbognin, 1981).

also increased.

The Venetian lagoon's natural evolution towards a continental environment was inverted and as a consequence of this four century-long intervention, it assumed a more marine character. The well known phenomenon called " acqua alta" (high water) was also increased by the combination of land subsidence, eustasy and high tides. The digging of deep canals for internal navigation, the reduction of the sea entrances from 8 to 3 m and the deepening of their depth from 3 to 15 m spurred the lagoon hydrodynamic causing increases of the tidal flow and of erosive processes.

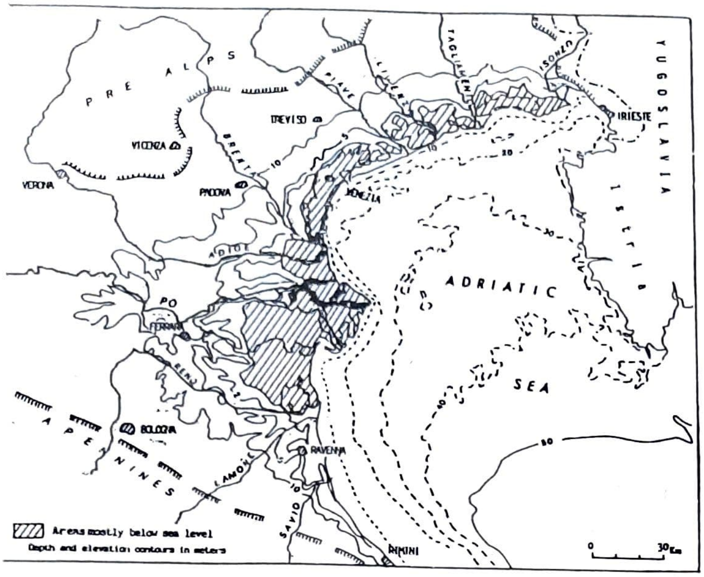
The lagoon ecosystem has again been intensely modified by man since the beginning of 1800 A.D. Land reclamation claimed 40 square Km, 32 more square K. were filled up for industrial and urban use, 85 square Km were bounded off to form fish breeding areas. In total the original 586 square Km surface of the Lagoon of Venice at the beginning of the last century were reduced by a total of 187 square Km equal to about 32% . A rash exploitation of underground water, mainly for industrial consumption, that interested 6 strata of the aquifer system from ground level to—250 m, between 1950 and 1970, closely relates to the -12 cm subsidence in the industrial area and -10 cm in the town of Venice. At present the Lagoon, compared with the original conditions, is smaller and deeper, the brackish characteristics diminished and sea characteristic have become more and more prevalent (Text-fig. 5).

CLIMATIC VARIATIONS

In addition to the described long-term climatic variations during the geological times, we have record of recent time's short-term climatic fluctuations. At the end of the last century, Brukner (1890) published a study pointing out a sequence of climatic fluctuations based on the comparison of meteorological data which resulted similar, for the same period, in different parts of the Northern Hemisphere. Using geological, geomorphological, glaciological, palaeobotanical, archaeological and historical investigations, it has been possible to reconstruct the sequence of climatic variations with accuracy for the historical times.

For the last, 3,000 years, five cold and humid periods have been recognized that had a great impact on the Mediterranean basin. The periods were: 1400-1300 B.C.; 900-300 B.C.; 400-750 A.D.; 1150-1300 A.D.; 1550-1850 A.D.

These cold/wet periods were alternated with warm/dry periods and they have been well indentified by the dendrochronological curves (Text-fig.3). Within these " large scale" periods, small climatic fluctuations of 10-35 years continued with cold/wet and warm/dry cycles up



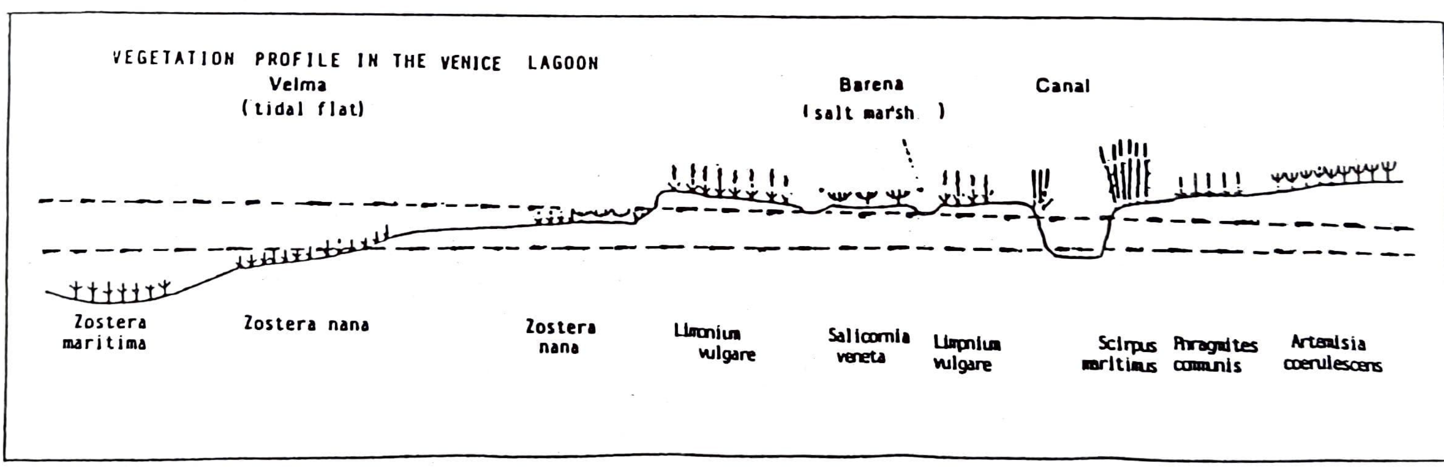
Text-figure 6. Map indicates areas below sea level (after Sestini, 1989).

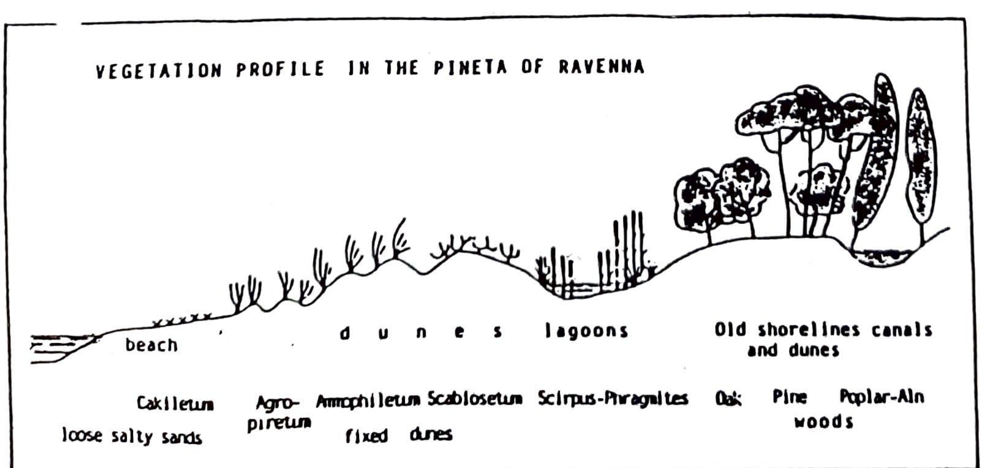
to present time. The influence of these climatic changes on the environmental evolutional trend is obvious.

Man's intervention greatly modified the natural evolution not only of the Venice Lagoon but also, though not so drastic, of the Upper Adriatic coast. Witnesses of the combined man intervention and climate fluctuations are the vegetation changes with time. When the Romans arrived in the Ravenna area they found extensive forests and swamps. The landscape modification started with the land reclamation for agriculture purposes by the Romans. Still at the end of the Roman period the city Ravenna was surrounded by swamps and pinewoods of *Pinus pinaster* and *P. pinea*, and *Quercus ilex*. These forests were kept as natural barriers to control the frequent floods (Text–figs 6,7).

The evolution of the Po River Delta and the mild climate near the sea favoured the formation of the coastal dunes of the Mesola Pinewood 1200-1000 B.P. The wood consists of three types of vegetation:(a) one type mainly of *Quercus ilex* that indicates a humid Mediterranean climate around 1200-1000 A.D.; (b)a mesophile type of *Quercus robus* and *Carpinus betulus* and (c) an igrophile type with *Fraxinus oxycrapa*. During the following centuries an intense forest cutting and marshland reclamation firstly for agriculture use and more recently for industrial activities were witnessed.

At present while Mesola Pinewoods and other woodlands along the coast still exist, in the Venetian lagoon





Figs. 7a,b. Schemes of natural zonation in the coastal zone of the Adriatic lowlands (after Sestini, G., 1989).

Text-figure 7a,b. Schemes of natural zonation in the coastal zone of the Adriatic lowlands (after Sestini, 1989).

none of the original woods remain and only vegetation typical of a marshland environment can be found.

With the disappearance of the coastal woodlands, a natural barrier against the erosion by the sea has also disappeared facilitating a coastline regression (Marabini & Veggiani, 1991). It must be also mentioned that the strong winter sea-storms of the past 30 years along with cold/wet climate during the 1950-1970, period further damaged and depleted the forests along the Upper Adriatic coasts.

It is, therefore, concluded that while for the Venice Lagoon only man-made barriers could be effective against sea-storms, we should perhaps consider a aforestation program along the Upper Adriatic coast to protect the natural ambience with species of plants, such as Olive from Bohemia, more resistant to cold winter weather and salty moisture from the sea.

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