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IMPLICATIONS OF CLIMATIC CHANGES ON THE EBRO DELTA

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BACKGROUND

Scientific interest has concentrated on the Ebro delta in recent years, producing many important research programs which have been carried out or are still under way on such topics as pollution control, coastal dynamics, marine productivity and agricultural development. Both the Spanish State Goverment and the Catalonian Autonomous Generalitat have promoted these studies as a reply to the challenges this area is facing as a result of its economic development and the modifications in the Ebro river output.

This report is based on the available results of these programs, specially those related to the study of coastal erosion, the development of agriculture, aquaculture, tourism and the sanitary and economic infrastructure of the Delta.

INTRODUCTION

Trace gases concentration in the atmosphere has been increasing in recent decades as a result of human activities. Many of these gases interfere with the Earth temperature balance by absorbing some of the radiation that the Earth emits back to space like any other black hot body. If the present trend persists, it is likely that the combined effects of these "greenhouse gases" will produce a global warming of a few degrees by the middle of next century (UNEP, 1987).

Carbon dioxide is the most abundant of the greenhouse gases and its concentration is increasing at a rate of 0.5% per year. Methane, nitrous oxide and other trace gases in the atmosphere also produce this effect. Although their concentrations are much lower than that of carbon dioxide, by the year 2030 they would be equivalent to it, as far as the greenhouse effect is concerned. This effect can be estimated to be equal to the one produced by a doubling of present CO_2 levels.

The impacts of the CO_2 buildup on climate and other ecological parameters of the planet were discussed at the WMO Villach Conference, where increases of 1.5 to 4.5 'C in the average temperature were assumed to be likely to occur as early as 2030, together with a sea level rise in the order of 20 to 140 cm.

There is a great deal of uncertainty in these predictions as the role of the oceans in the CO_2 build-up are not completely understood (Crane and Liss, 1983), climatic models need extra developments, temperature equilibrium and stratification of the oceans are often vague approximations, the estimates of CO_2 uptake by vegetation vary greatly and the calculations of the rate of melting-growing of polar and glacial icecaps are extremely dependant on assumptions which are not accepted to a large extent by the great majority of experts.

Nevertheless, the possible negative impacts of the climatic changes associated to such an increase in greenhouse gases justify the study of the situation which would result from one of the most commonly accepted scenarios, such as that adopted in the Villach Conference for the 2030's, or in the UNEP Meeting on Implications of Climatic Changes in the Mediterranean, were it was agreed that this report should be based in the assumption that by the year 2025 there could be an average global increase of 1.5 °C and a 20 cm rise in the sea level, while by the end of next century these figures would be 4.5 °C and 140 cm respectively.

Although these figures seem to be of little relevance compared to natural variations when one considers the relatively long time it will take to reach them, they have to be evaluated in relation to known changes already occurred. UNEP (1987) points out that the Earth's temperature has very seldom varied by more than 1° or 2 °C over the last 10000 years and that the global average temperature during the last glaciation was only about 5 °C colder than it is now.

During the last interglacial period (127kBP-75kBP) temperatures in Western Europe were 2-2.5°C higher than today and the sea level was 5-7 m above the present one. Also, at the end of the Younger Dryas a temperature rise in the order of 8-9°C within a timespan of less than 250 years has been estimated (Janssen and Kunh, 1987). It is clear then that a global warming in the range of that assumed would both be possible and have greater consequences on the Earth's climate than any other change that has occurred during the historical past.

Most models suggest that the increase in the average temperatures will be felt mainly in the higher latitudes and during the winter. Climatic changes will consist of a shortening of the cold seasons, increase of evaporation rates and rainfall, especially in the tropics, and more frequent peak events.

In Europe the main expected effects in Europe of this change will be the extension of dry summer periods, slight changes in vegetation and crops, increased erosion and coastal dynamics, deeper saline water intrusion in aquifers and modification of general hydrological regimes, together with an increase in the occurrence of catastrophic climatic events (floods, droughts, etc.).

MEDITERRANEAN SETTING

The Mediterranean setting is rather different from that of the rest of Europe. Apart from climatic considerations, in the Mediterranean region the erosion processes and the loss of agricultural land is already a common problem and forest fires are, unfortunately, not infrequent during the summer season, especially those of introduced tree species. Water available with adequate quality is scarce and salinization together with sea water intrusion are normal problems in many aquifers, mainly on the coast, where agricultural, residential and industrial developments tend to concentrate. Superimposed on these activities, the touristic flood of every summer exerts an additional demand that exceeds available resources in many of the new coastal resorts.

Because of this already strained environment, it is expected that the predicted increase of temperature and the related changes in the climatic conditions will accelerate the present erosion and fire hazards in the Mediterranean lands and will aggravate the problems of quality and quantity of available water.

The rise in temperatures will also extend the ecological range of some pathogenic organisms or their hosts and vectors, so that the re-introduction of malaria and other illnesses, such as schistosomiasis, in the Southern European countries, can not be ruled out. An increase in the use of pesticides and other fighting methods against these pests will then be necessary in the near future, together with a reassessment of the main health objetives for these areas (see Noordwijkerhout Conference results)

Most of these changes will take place gradually, allowing for an adaptation of ecological, social and economic elements. Furthermore, it is envisaged that technical transformations in the near future, even if they only stay at present rates, will make the necessary modifications in the economic, social and productive structures of the region more feasible and will affect society to a much deeper extent. General drastic consequences of the climatic change will therefore be felt mainly after the 2050's, that is three generations from now.

In the meantime climatic change effects will be felt mainly through the predicted increase in the occurrence of peak events, which would certainly lead to more catastrophic situations. This applies especially to the occurrence of droughts, forest fires, winter storms, sea surges and both river and marine floods.

Gradual and episodic sea level rise and the increase in coastal dynamics and erosión associated with it will be of special significance on the Western Mediterranean coast due to four main factors:

a) In many of the Mediterranean countries the littoral strip of land holds most, if not all of the main economic activities, lacking the inland development common in other European countries. Also, some of the most important areas of natural interest are located on the coast, as is the case of the wetlands where many of the European migratory bird species find sanctuary.

b) There is less tradition of coastal defense in the Western Mediterranean countries than in Northern Europe, and the economic capacity to undertake them is normally insufficient,

c) The most productive areas are located in low-laying lands like deltas and lagoons, where a rise in the sea level would have definite effects, either by the flooding of these areas or by the alteration of the quality of the water used for irrigation,

d) Apart from their agricultural value, the lowlands and the shore-lines of the Mediterranean have acquired an increasing value for recreational activities based on the development of beaches, dunes and coastal lagoons, with huge investments in the form of residential complexes, on the assumption of a continuing stability of the coast.

Recent history of the Mediterranean offers many examples of changes in the coastline that have caused the decline of areas dedicated to agriculture or commerce (i.e. Rosas, on the Catalonian coast). People have adapted to these changes by moving their activities inland or to other more advantageous places; natural areas were substituted by new ones formed elsewhere in the process.

This flexible response is not as easy nowadays. The pressure on the coast has increased dramatically, reducing the available land and raising the value of property on the littoral. This, together with the lack of fertile areas inland, leads to a population which is unwilling to move and puts the emphasis on coastal defence, now technically more feasible.

The new situation will especially affect the natural reserves, as the defence infra-structures will be concentrated in the areas of greatest economic value, not allowing for the transformation of actual lowlands into wetlands, while the existing wetlands disappear after the sea rises and the changing dynamics of the coast resulting from it act on them.

On the other hand, it is expected that the main ports and engineering works in the Mediterranean will be adapted as the sea rises, in a gradual way, with no disruption for their working capacity. Although the total investment will be high in the long run, as it will be applied gradually, in partial steps probably associated to catastrophic events, the effects of the climatic change will be treated more as a natural event, rather than as a man-induced modification.

THE EBRO DELTA

1. GENERAL ASPECTS

The Ebro delta is located on the Mediterranean coast of NE Spain, between lat. 40°30' and 40°50' N and long. 0°35' and 0°55' E. It is a triangular-lobate delta, with a surface area of about 285 square km, 123 on the left side and 162 on the right, which makes it the fourth largest delta in the Mediterranean. The whole deltaic system covers about 40,000 ha (fig. 1).

Together with the delta of the Guadalquivir River, the Ebro delta is one of the most valuable coastal ecosystems of Spain, with wetlands that are essential to a great number of migratory birds. As in the case of the Guadalquivir, it also sustains a very important agricultural activity, which is based on the quality of the soils and the amount of available, regulated waters for irrigation, and a very productive fishing fleet and aquaculture development; up to 20% of the Spanish rice production and up to 25% of the fish and 40% of the molluscs obtained in Catalonia come from this area.

The main contemporary problems of the Ebro delta are associated with the reduction of the river sediment and water output. The sediment load decrease is considered to be one of the main reasons for the progressive erosion of the frontal parts of the delta. The need for a safe supply of irrigation water of adequate quality also makes the delta vulnerable to future reductions decreases in water resources, due to the planned Ebro river and aquifers pwater abstractions for industrial and residential uses.

Although the levels of mercury and PCB's in some sediments indicate the existence of industrial discharges into the river, there are no serious pollution problems in the area at the moment (Mariño, 1983); high water temperatures in the bays during the summer periods are thought to be the main cause for the occasional high death rates which occur in the mussel farms located in the area.

Most of the points mentioned for the Mediterranean situation with regards to the predicted climatic change can also be felt in the Ebro delta. As a result, the main important impacts of this change will surely be the flooding of the low lying wetlands, a worsening of the need and dependance for fresh water and an increase in the existing coastal dynamics, both because of a further decrease of river output and because the sea level rise will modify the present equilibrium profile of the shoreline.

2. THE PRESENT SITUATION

2.1. The Socio-economic Setting

The population of the municipalities comprising the delta reaches 70,000, while around 19,000 people live in the delta itself; 10,187 in Deltebre, 3,446 in Sant Jaume, 3,390 in Aldea and 2,914 in Camarles.

The major economic activity is agriculture, with rice, wheat and vegetables as the main products; 77% of all delta surface is cultivated under irrigation, while the rest is unproductive. Rice, with around 17,000 ha (69% of the delta surface), represents 18% of the whole Spanish production; orchards cover 2,400 ha and cereals, mainly wheat, other 4,700 (Seró and Maymó, 1972, Anuario del Ministerio de Agricultura, 1986).

Fisheries around the delta and in the lagoons are also very productive. The port of Sant Carles de la R pita is the fourth in importance among the Catalonian fishing ports due to the value of the catches and the port of l'Ametlla occupies the sixth place, while L'Ampolla, Deltebre and Las Casas d'Alcanar also contribute to the total fish production of the area. Crustacean, mainly shrimps, are one of the most important products of the Ebro delta marine waters.

In the bays protected by the delta lobes there is also an increasing number of mussel and oyster farms, especially in "Puerto de los Alfaques" in the south, with a very important production.

Total fish discharges in the Delta ports during 1986 (Anuari de la Comisió de Ports de Catalunya, 1986) reached 10,218 metric tons (molluscs 1,570, crustacea 990, fish 7,650), with a commercial value of 2,860 million pesetas (260 mill. dollars). This production represents 28% of that of Catalonia (for molluscs, crustacea and fish the Delta contributes respectively 43%, 71% and 24% of the catches). Fisheries in the lagoons are very important too, producing 84 tons of highly valuable species. Also important is the fast growth of aquaculture facilities, using both sea water from the bays and ground water from the saline aquifer (surface water has temperature problems, with important oscillations, and pollution episodes resulting from the overflow from the cultivated areas).

Industry is limited to two saltworks producing sea salt through evaporation of sea water in shallow ponds. They are located in the South, in the Alfaques bay. The largest (Salinas de la Trinidad) has a yearly output of 25,000 tons, which are mainly exported to northern Europe (Gran Enciclopedia Catalana, 1979). Smaller saltworks have been abandoned and are now being transformed into fish farms.

Two tourist resorts have recently been opened in the delta, one on the northern shore (Ruimar), the other in the south (Els Eucaliptus), just in front of the white sandy beaches that surround the whole area. Although nowadays they do not account for more than a small proportion of the whole Delta coast, there are plans for the construction of 1,000 new apartments and houses in the Els Eucaliptus area (Loaso, pers. comm.). Three port facilities have also been installed for recreational boats in Tortosa, Amposta and Deltebre and a navigational channel between Tortosa and the sea is under study by the Generalitat (C. Canals, pers. comm.).

The main economic activities in the delta will presumably continue to be agriculture and fisheries. The tourist development is expected to remain limited to the two areas already urbanized, especially that on the coast above the Trabucador isthmus (Els Eucaliptus), where the main investments are planned.

The only expected change in the economy of the delta is the further expansion of the shellfish cultivation in the bay behind the northern and southern lobes, where high water productivity and natural defence against the sea allow it. These areas will thus become one of the most productive and valuable ones in the delta and in the whole Spanish Mediterranean coast.

2.2. Physical and Ecological setting

2.2.1. Climate

Rainfall ranges from a minimum of 18 mm in July to maxima of 78 in September and 69 in October, with an annual precipitation of 548,3 mm as average for the last 73 years. Average daily temperatures go from maxima of 25°C in July and August to minima of 9.3 in January and February; the average annual temperature is 16.6°C. Humidity remains rather stable around 60% through the year, while evapo-transpiration varies in the range of 90- 170 mm/month, with an annual loss of about 1400 mm. Annual sunshine hours are over 2,700 (Seró and Maymó, 1972, Observatorio de Roquetes data cited by Riba et al., 1976, cited by M. Canals, pers. comm. and MOPU, 1978).

Winds blow rather strongly in the Ebro delta area. During September and October the "mistral" winds, coming from the N, NW and W, reach their highest velocities (wind speeds over 200 km/h are frequent), while "vents marins", mainly from the East, predominate during spring, pushing the sea waters into the river mouth, elevating the sea surface and obstructing drainage operations from cultivated areas. Storms from E and NE during winter and spring months are also frequent ("llevantades"), causing surges that flood the Trabucador isthmus for a number of days. During the summer months the predominant wind comes from the SW ("garbi") with lower velocities (Font, 1983).

2.2.2. Oceanography

The oceanographic features of the Ebro delta margin are dominated by the river discharge, the general currents in the sea and the dynamics of the bays.

The river discharge controls most of the balance of nutrients and productivity. Alvarez and Masso (1983) studied the basic oceanographic parameters of the area, where stratification during the summer season is common (see figure 2), with temperatures as high as 25 °C outside the delta (it reaches 32 °C inside the bays, Loaso, pers. comm.)

Nutrients are abundant due to the river discharge. Phosphorous concentration reaches 1.79 µg PO4-P/L and ammonia 13.7 µg NH3-N/L. Secchi discs depths ranged between 1.8 m in front of the river mouth and 10 m at the 20 m depth contour. Chlorophyl had its peak in February with 5.0 µg/L. The dissolved oxygen content in the waters remained over 4.0 mg/L, even in the bays, where minima were measured during the summer periods.

General water circulation in the inner shelf in front of the Ebro delta is dominated by the flow imposed from offshore in the Catalan sea, which is in turn influenced by the flow coming from the Balearic sea. Winds perturb the overall current, modulating the larger, externally forced flow, which can be felt mainly in the bottom, with velocities in the range of 12 cm/s towards SSE.

The average current in summer is in the range of 7 cm/s, although flows as high as 25 cm/s running for 70 days southwards have been measured (Han et al., 1983). Summer stratification produces an upper layer which moves under wind fluctuations, while the botton layer flows independently southwards (Font, 1983). Wind effects can also be felt in winter, when the surface and bottom currents seem to go northwards during the time of strong NW winds, with an average velocity of 2,5-3,0 cm/s. This can be due to the blocking of the strong mistral winds by the coastal mountain ranges, which produces a concentrated jet centered in the Ebro delta. This local wind maximun creates an Eckman suction through the curl of the wind stress and this torque is compensated by a pair of centro-rotating gyres in the flow (Han et al., 1983). This situation has been modelled by Mariñas and Tejedor (1983), whose results are shown in fig. 3.

The oceanography of the bays has been extensively studied by Camp and Delgado (1987) from the Instituto de Ciencias del Mar. They describe them as salt-wedge estuaries in which the sea water penetrates as a salt wedge along the bottom while the low salinity water tends to flow outwards over it.

The northern bay (Fangar) has a surface of about 12 km² and an average depth of 2 m, with a connecting channel with the sea of 1 km in width. These figures for Alfacs, in the South, are respectively 50 km², 4 m and 3 km. The total volume of Fangar is in the order of 16 cu.Hm, while Alfaques reaches 200 cu.Hm.
Fresh water enters into the bays laterally from the lagoons through a serie of channels and from the aquifer, causing a preferential low salinity distribution in the landward margin.

Stratification tends to predominate in the bays, until wind induces the mixing, or fresh water input produces the instability of the water masses (for salinity increments of 1%), which are then renovated by sea water in periodic fluctuations that take place after 1-2 days in Fangar and after 10-20 days in Alfaques. These frequencies seem to be related to the ratio between the fresh water inflow and the total volume of the bay, which controls its average residence time (Camp and Delgado, 1987). As these fluctuations persist in winter, when the irrigation channels are dry, Camp and Delgado (1987) also suggest the possible existence of a large groundwater inflow into the bays and the importance of this inflow in their renovation frequency and stability.

Also related to the fresh water inflows are the nutrient and phytoplancton distribution in the bays, that tend to show higher values around the channel discharge points (Delgado, 1987, Delgado and Camp, 1987). However, as nutrient inflow through the irrigation channels explains only 25% of the high primary productivity, Delgado and Camp (1987) mention the organic mineralization processes in the sediments as a possible source of phosphorus to the water column. This high productivity coupled with the regular renovations in the bays result in a periodic carbon outflow towards the sea in the order of 100 tons/week (J. Camp, pers. comm.).

Nutrients and productivity are also influenced by seagrasses, whose spatial distribution and biomass in the bays were studied by Pérez and Camp (1986). Seagrasses cover in Fangar reaches 65% of the total bay surface and 100% of shallow areas, while they are only present in 26% of the Alfaques bay shallow parts, representing a total biomass of 3,600 tons.

2.2.3. Coastal physiography

The development of the Ebro delta bagan at the end of the last glacial stage. At the maximum of the Würm glaciation, about 20,000 years ago, the sea stood 85-90 m below present sea-level. Durent the subsequent transgression due to sea-level rise thick overlapping fluvial gravel deposits were laid down in the fluvial valley. Later, transgressive sequences were deposited extending across the shelf over the gravel and Pleistocene deposits. During this initial stage, because the shore-line was located near the present edge of the shelf, most of the sediments borne by the river were carried by turbidity currents and deposited on the deep submarine Ebro fan (in fig. 4 there is an schematic representation of the delta structure).

With the temporary stabilization of the sea level al -10 m, the prograding delta actively built an extensive deltaic plain. Later, with the continuing rise in sea level, this former deltaic plain was covered by the sea and shallow marine sediments were formed.

The small extent of these marine deposits points to a sharp decrease in the rate of sea level rise and indicates that the fluvial supply of sediments was sufficient to prevent an extensive marine drowning of the delta plain.

Most of the deposits of the present deltaic complex have been laid down during the last 8,000 years; there has been therefore a sharp increase in the effective rate of sedimentation in this final stage of the delta building, concurrent with the slowing down of sea level rise.

The present deltaic plain of the Ebro is formed by the lobate deltas shown in figure 3. The southern delta lobe is the oldest, dating until nearly the 16th century. The northern delta lobe mainly developed through the 17th and 18th centuries extending into the early 19th century. The active period of the central delta lobe coexisted with that of the northern delta lobe during its final stage of development. Initially the central delta lobe had a northern distributary active throuhgout the early 18th century. The eastern distributary reached its maximum development about 1946.

The present Ebro deltaic plain consists of three pronounced delta lobes extending 26 km seaward. The development of these lobes has notably increased the delta plain during the past four centuries until a major flood in 1937 produced a fourth lobe, as the river opened a new mouth (Gola de Sorrapa), abandoning the older lobe in less than 20 years (Maldonado, 1977) (see fig. 5). Older mouths of the river have also been abandoned or closed artificially; Gola de Midgorn in 1915 and Gola de Tamuntana in 1957 during the 20th century, la Platjola, el Galeró and Sol de Riu in the 19th century (Loaso, 1988, pers. comm.).

During historic times the Ebro delta has undergone remarkable modifications, growing from an estuary which reached Tortosa in Roman times, to the modern delta of today (figure 6). From 1970 onwards the growth of the delta has almost stopped, while the front and south lobes are subject to quick erosion due to the damming of the Ebro and to modifications to the discharge mouth and the hydrographic system.

The river damming has resulted in the loss of a great part of the solid discharge, which has been reduced from 15/20,000,000 tons per year in the XIX C., to less than 2,000,000 tons per year now. Maldonado (1983) has given a different figure (19,500 t/y) for the decrease in the sediment load that is deposited in the delta after the second half of this century. However the study of the bathymetry of the Ribarroja and Mequinenza dams shows that just the second one accumulates 8,800,000 t/y which is 96% of the river load (Varela et al., 1983). Although these figures have to be taken with cautions because of the methods used to obtain them, as M. Canals point out (pers. comm.), they nevertheless give an indication of the effect of the dams on the Ebro solid load output (C.E.H. reports measurements made in January 1975 of a solid load output of 86.26 tons/day for a flow of 94.7 cu.m./s, M. Canals, pers. comm.).

The discharge point has shifted from the Gola Midgjorn, on the East, to the Gola Nord and then to its present location, pointing northwards (the latter was closed artificially and is presently occupied by a baby eels nursery).

As a result of these modifications there is now an active reshaping of the delta shore line by the sea, relocating the materials that form today's Isle of Buda and the former Migjorn mouth, along the southern and northern shores. A schematic representation of the main processes of coastal dynamics acting on the Ebro delta is shown in fig. 7 (Maldonado, 1983).

As it is pointed out in this figure, the loss of sediment is not uniformly distributed along the delta, but is concentrated at those points where the dynamic equilibrium is more precarious, as in Cabo Tortosa, which is being eroded at great speed. The Alfaques lobe, in the south, is also under erosion as is the Trabucador isthmus, now in danger of being disrupted by the sea, while, on the other hand, the northen lobe (El Fangar) is growing, although at a much slower rate.

2.2.4. Surface and ground waters

Average monthly River Ebro flows at Tortosa (basin surface of 85,500 km^2) ranged from 120 cu.m/s in August to 800 in January-February for the period 1951-1965, with a yearly average discharge of 600 cu.m/s (Gran Enciclopedia Catalana, 1979). The River sediment output for the same period was in the range of 17,000 cu.km/y, with maxima of 31,300 and minima of 8,000. These figures represent a decrease of almost 20% with respect to the 1912-1935 period, before the dams situated in the lower Ebro were constructed.

There is an irrigation channel system of more than 1,000 km that covers most of the delta and an important drainage network with several pumping stations which discharge through the lagoons to the bays, as only less than 10% of the irrigation flow goes back to the river or to the sea (Camp and Delgado, 1987). Two main irrigation channels follow both river banks, starting from the Xerta dam, 27 km upstream from the delta; they transport 21 and 17 cu.m/s each. Total guaranteed regulated flow in the Ebro is in the order of 60-70 cu.m/s

The groundwater in the Ebro delta area has been studied by Loaso and Herr n (1988). It is a multilayer aquifer, in which gravel and clays contain water with very different salinities. (Figure 8)

The system has a very low hydraulic gradient which produces a slow flushing of the original saline waters. It is only partially conected with the alluvial aquifer located upstream (salinity under 2,000 uS/cm) and with the "piedemonte" (foothill) aquifers of Montsi and AIdea- Camarles which emerge in the "ullals", small ponds located along the contact line between these aquifers and the peats and clays of the delta. (Figure 8)

Apart from the planned extraction for aquaculture, ground water use in the Delta is very limited, as irrigation depends almost exclusively on surface water; only a little was pumped until recently during the winter to water the orchards, when the irrigation channels used to be drained for repairs. Nowadays, ground water is produced at a small rate out of the Aldea-Camarles aquifer (8 Hm3/Y) and out of the alluvial aquifer (15 Hm3/y), which represent an important resource for the future (Loaso and Herr n, 1988).

2.3. Ecological Importance

Two of the lagoons in the southern part of the delta (Tancada and Encanizada) are classified as protected areas because of their value for many migratory birds which either stop there on their route or come to winter (see fig. 9). Isla de Buda, which is located on the eastern front of the delta, is also another important area for aquatic birds.

Natural vegetation is maintained mainly in the lagoons and along the coastal sand dunes (Ammophiletea, Phragmitetea and Arthrocnemetea communities are described by Camarasa et al., 1976 in the "Landscape vegetation map of Ebre Delta", which is summarized in figure 10).

Forty nine square km of the northern part of the Delta are declared "Parque Natural". Five sectors of the Parque Natural are qualified as "Areas de Especial Interés Natural" (Isles of Buda and San Antonio, Canal Vell and Olles lagoons and Fangar peninsula) comprising 25 km^2 (56% of the Parque Natural), as is shown in figure 11. These legal classification aim at "the efficient conservation of the natural ecosystems, making them compatible with the maintenance of the traditional activities and the promotion of the contacts between man and nature".

3. Evaluation of Climatic Change Impacts

3.1. Physical Environments

3.1.1. Climate and oceanography

The first step in the evaluation of the possible impact of the climatic change on the Ebro delta is, evidently, the evaluation of the climatic change itself. In order to make a barely acceptable assessment of possible impacts it is also clearly necessary to evaluate this change using models which deal with a regional, or even subregional scale and that not only include the Mediterranean, but also predict the changes which will occur in the Cantabrian and Pyrenees mountain chains, as most of the Ebro river water originates from there.

This information is not entirely available yet, therefore, the analysis has to be made at the moment on the basis of general climatic models which have a resolution in the order of 5-10°, or of extrapolations of paleoclimatic and recent climatic data.

For most of the assumptions on climatic change made in this paper, the results of the GISS model and those derived from instrumental data (Pitovranov, 1987a), which were presented at the Noordwijkerhout Conference, have been used. Although Wigley (1987) discusses the climatic scenarios for Europe based on the results of GISS model, mainly because of its resolution (8° in latitude and 10° in longitude) and its inability to resolve cyclonic features which bring most of Europe's rainfall, as the Pitovranov (1987b) results based on the data from the last one hundred years and those of GISS model for a doubling of actual CO2 concentrations seem to coincide, the following climatic scenario patterns for the Ebro delta and for the Cantabrian and Pyrenees mountains have been assumed:

- In Spring, cold and wet weather conditions will be more frequent in the warm world period than in the cool period.

- Summers will be larger and dryer

- There will be an increase in rainfall in the order of 0,2-0,4 mm/day during spring and between 0 and 0,2 in winter, it will remain similar to today's rate for autumn and will decrease about 0,2 mm/day for the summer period.

- Precipitation variability will decrease slightly, especially in winter.

- Evapotranspiration will increase over the whole basin.

It can be assumed too that the temperature change will mean an increase in the frequency of episodic events associated to storms and floods.

It can also be accepted that total rainfall in the catchment area will similar to today's, or even higher, although with a different pattern. This can be deduced too from paleoclimatic data for the first part of the Holocene, which shows that during the climatic optimum around 6,500 BP, when temperatures were 2-3 °C higher than today, humid condition predominated in the present day subtropical zone, with the existence of large lakes in the Sahara (Janssen and Kuhn, 1987)

The general sea circulation in the W Mediterranean region is not expected to be affected by this climatic change as it it mainly dominated by general currents, only partially modulated by the strong winds that flow through the Ebro river opening in the coastal mountains (Mariñas and Tejedor, 1983, Han et al. 1983). Summer stratification, on the other hand, will be enhanced, raising the water temperature in the bays and affecting water renovation.

Hydro dynamics by the coastwill be more energetic than now, especially during storms and sea surges associated with high easterly winds. Wave action on the shore is also expected to increase, speeding up the reshaping of the delta, which is now wave dominated as a result of the decrease in the sediment transport.

3.1.2. Erosion and coastal stability

Although the studies of the coastal dynamics of the delta are far from being completed, a preliminary assessment of the possible problems can be made out of the description of the present day situation. It seems clear that the main impact of the expected sea level rise will come through the increase in the coastal dynamic processes.

This increase will probably lead to the retreat, erosion and more regular drowning of the Trabucador isthmus which is only 50-100 m wide and 0.5 m above the average sea level. Should this happen the erosion processes now acting on the Alfaques peninsula to the south would surely be accelerated, exposing the Alfaques bay and the southern lowlands of the delta to the sea and contributing materials to the mouth of the bay. In the long run it is not pessimistic to assume that important parts of the delta could be eroded, returning to the shape they had in early days, as this is a very flat and new geological formation.

In the shorter term it is likely that low lying areas as the peninsulas, Isla de Buda, Balsa del Pall in the north and lagunas de la Tancada and la Encanyissada in the south, will be regularly invaded by the sea, changing the characteristics of the water. Peninsula del Trabucador and Isla de Buda will surely recede in the face of the sea action, moving the delta front backwards.

All these changes would take place in a very gradual way, as the sea level rise is expected to be in the order of 1- 4 cm per year (about 1 m in 50 years). This rate is similar to the fastest rise occurred during the Holocene (10.000 BP to now), when the eustatic rise was of 1.5 cm/year, as the sea level increased about 65 m in 4,000 years, between 10,000 BP, at the end of the last glacial period, and 6,000 BP, at the beginning of the Atlantic phase (Aloisi, 1986).

This slow sea level rise will produce a gradual retreat of the Delta shore-line of the Delta as the beach equilibrium profile would be displaced landwards from its present situation. This will especially affect Cabo Tortosa as no protective measures are planned there and, apart from an increase in wave action, the rise of sea level will reduce the erosion that the Ebro River produces on its bed, decreasing even more the sediment output at the mouth (M. Canals, pers. comm.).

Díaz Guerrero (pers. comm.) suggests that due to the retreat of the coastline, the Alfaques bay in the south and the Fangar bay in the north, would gradually become closed, to the state of restricted lagoons whose communication with the sea would be reduced to small channels, mainly controlled by storm surges. This closing of the bays would take place because of the displacement of the peninsulas, which would be faster than that of the main body of the Delta. Finally, depending on the river discharge situation and characteristics, the deltaic plain could grow over these lagoons, reducing their surface or, even, filling them.

Díaz Guerrero also points out that, although the present state of the Trabucador isthmus does not favor its migration, the progressive destruction of the Isle of Buda in the north, which will be incremented by the sea level rise, could originate an important drift of eroded materials that would control its stability. Nevertheless, these situations would certainly become more common when this narrow strip of sand is covered by the sea, and only during long periods of good weather will it fully emerge.

3.1.3. Surface and Ground Water

As most surface water in the delta comes from the Ebro through the irrigation system, the quality of surface and, to a large extent, ground water, will be governed by the quantity and characteristics of the river water.

Because of the longer dry summer periods it can be assumed that the water balance in the delta will get further into the negative, although this could be offset in the short term by the also expected maintained precipitations in the Ebro catchment basin (Pyrenees and Cantabrian mountains) which can be regulated by the existing network of dams and the irrigation system of the delta.

Consequences of this water disbalance will be mainly felt in the areas surrounding the delta, leading to more water abstractions from the river upstream of it and to more severe forest fires in the upland areas. Water abstractions from the aquifers will also surely increase, needing careful management, in order to avoid salinity intrusion.

In the long term, water management will need to be reassessed as a result of the predictable filling up of most of the dams of the basin and the loss of their regulating capacity. This filling up could be accelerated if soil erosion in the basin increases with the expected increase in evapotranspiration and floods occurrence (Kwadijk, 1987) and remedial actions are not undertaken to control it.

Water quality, in terms of salinity, can decrease if actual trends do not change. However, as this is mainly due to a mismanagement of irrigation, it can be accepted that given the necessary conditions, water salinization will be controlled well before it presents a problem for the delta.

Other difficulties could arise from a rise in the sea level, both gradual or due to episodic climatic conditions. It could mean that either drainage from cultivated land will be more difficult, needing more frequent use of pumps, or that periodic flooding of low lands during storms affects the quality of ground water and soils in those areas.

Fresh-salt water mixture penetration in the estuary would move upwards too, from its actual normal situation between Isle of Gracia and Amposta, to Tortosa; this would affect lateral aquifers (the alluvial and the Aldea- Camarles) with serious consequences for their actual exploitation, which is important, and for the overall future use of this most important aquifer of Catalonia (Loaso, pers. comm.).

A sea level rise would also affect the flow of ground water in the Delta, which is governed by a very low hydraulic gradient (Loaso y Herr n, 1988), reducing the flushing of saline water and favoring salt intrusions.

3.2. Ecosystems

Effects of the climatic changes on the Ebro delta ecosystems can arise from modifications of marine and bays oceanographic conditions, alteration of lagoons and marshes location and changes in the distribution of species because of the increase in temperature.

Oceanographic conditions are expected to remain as they are now, except for the bays, where increased stratification and higher water temperatures are likely to occur. As a consequence of these changes a more frequent oxygen depletion in these bays will be encountered and some loss of productivity can be envisaged. As ground and surface water characteristics will surely change due to higher abstractions and better water management techniques, the renovation mechanisms of the bays will also be modified.

Apart from its direct impact on the cultivation of molluscs in the bays, it is difficult to assess now the possible repercussion of these changes on the general productivity of the whole area or on the species living there. Nevertheless, it seem possible that chlorophyl loads from these bays will be reduced as will be the conditions for mussel cultivation, which could need to be changed to other bivalves or to fish farms. It also seems possible that the importance of these areas as nursery grounds for many of the species of the area will remain as it is now.

Present erosion processes are already reshaping the delta coastline, with a tendency to retreat at Cabo Tortosa and the break down of Isla Buda behind it. If the sea level rises, most of these ecologically valuable areas of the delta will be covered by sea water. Conservation of these natural areas will depend greatly on the defence actions that could be taken and on the stability of the Trabucador isthmus, but its future is undoubtly compromised as priorities will surely be given to the agricultural lands. Water management schemes and shoreline protection works will surely be needed to preserve these important ecological lagoons and marshes.

Finally, the impact of expected changes in temperature and rainfall patterns on species distribution is, so far, unpredictable. Speculations can vary from changes in the flora of the main wetlands to reintroduction or proliferation of pests and parasites as of mosquitoes, which have already been a great barrier for the delta development in the past. Nevertheless, from the available data it does not seem probable that there will be significant and rapid changes in the ecology of the delta.

3.3. Social and Economic Structures

The main impacts of the climatic changes on the social and economic structures of the Delta are grouped into the following areas:

a) **Residential**. Most of the towns in the delta are located in its central part which is also the highest (3-4 m above sea level). Therefore the main effect of the expected sea level rise will be suffered by the tourist developments on the coast which, nevertheless, represent a minor proportion of these existing on the Mediterranean coast of Sapin and only a marginal value for the economy of the delta.

b) **Agriculture and Fisheries**. The main activity in the delta is agriculture. In the short run the effect on agriculture will consist in the loss of front low lands and in the increase in salinization (this can be offset by better irrigation practices using the Ebro water, if its quality remains as it is now and the actual salinization trend is discontinued). Crop changes are not thought to be necessary.

The activity of fisheries are also not expected to change so long as the Ebro discharge, which is the main source of nutrients, will remain unchanged. The possible effects on stocks could derive from the loss of nursery grounds in the northern and, specially, in the southern bays.

Also, the actual aquaculture development in the southern bay will be in jeopardy if it is opened to the sea by the Trabucador isthmus and exposed to wave action, or as a consequence of higher summer water temperatures and increased stratification associated with a reduction of the renewal rate because of the progressive closing of the bays.

c) **Infrastructure**. There are no main infrastructures in the delta at the moment and the only important engineering work is the San Carlos de la Rapita port, in the south. As the sea rise will be gradual and as this port is located just off the delta, no major structural problems are expected there, as defences will surely be adapted in time. The problems for this port could come from the movement of the sediments that form today the Alfaques peninsula, so that, depending on it, the port could be silted out, or would need important extra dredging to keep it open. There are not main roads in the delta and those which cross it are rather inland.

The saltworks are the only important activity that will certainly be affected by climatic changes. Nevertheless, with adecuate protection measures for shore regeneration or stabilization, these works could be saved, adding an extra protection to the southern bay in the short term. In the long term it is doubtful that their conservation is feasible in the face of a higher sea level and with the expected increase in stormy actions of the sea.

CONCLUSIONS

In the preceding lines a quick summary of the Ebro delta characteristics and problems has been presented. The main points stated are the following:

- The Ebro delta represents an important agricultural and natural resource in the Western Mediterranean.
- Present coastal dynamics is already reshaping the delta coastline, eroding the front lobe in Cabo Tortosa and the southern peninsula and isthmus.
- A climatic change and sea level rise in the predicted range would accelerate the actual trend, endangering the front parts of the delta.
- The southern part of the delta is the most threatened one, mainly from the possible rupture of the Trabucador isthmus and from the erosion and reshaping of the peninsula.

- A proper understanding of the processes and dynamics that are acting on the delta is necessary for a better assessment of the problem and to decide on the more effective ways to reduce the negative consequences on society.

- Climatic changes will be mainly felt in the short term by an increased occurrence of episodic peak events, such as storm surges and floods. More frequent stratification in the bays and oxygen deficits in these areas during the summer season can also take place as a consequence of the changes and the modification of the general hydrological system.

- Water quality and quantity in the delta is not likely to change as the increase in evaporation can be offset by better management of the irrigation and the aquifers and by the adequate regulation of the Ebro basin in the short term. For the long term it could be necessary to redesign the present water management approach.

RECOMENDATIONS

In order to evaluate and control the main negative effects of the expected climatic and sea level changes the following activities could be undertaken:

a) Basic research work about the delta should be continued, with data collection, especially with regards to the following subjects:

  - coastal accretion and erosion rates and mechanisms

  - sea level rise and fluctuations, with the installation of adequate instruments in the area

  - river liquid and solid discharge rates and fluctuations

  - historical effect of dams and impact of planned water abstractions

  - sediment transport modelling

  - the quality of ground water and irrigation water

  - the dependance of ecological areas on water characteristics

- the fisheries dependance on the northern and southern bays.

- the sanitary situation in the delta, with special attention to insect borne diseases

b) Planned and expected developments in the near future should be studied taking into account the expected climatic change. This applies especially to agriculture, aquaculture, transport (mainly port facilities), salt production and tourism infrastructure.

c) Detailed mapping, using social geography methods should be done on the delta, both of the emerged area (differentiating according to the main uses) and in the submerged surrounding belt. Adequate leveling of high precision should be incorporated in order to evaluate relative sea level rise and the influence of possible subsidence in these areas.

d) Coastal reshaping and sediment transport should be studied and control measures adopted, taking into account the sea level rise and the consequent flooding of low lands during storm surges.

e) Based on the predicted temperature increase, insect population changes should be studied. Possible health and agricultural consequences need to be analyzed, together with the side-effects of necessary control actions (i.e. increase in the use of pesticides and herbicides and the runoff of these products into the lagoons and the bays).

f) The Ebro basin and the dams system management should be studied and prepared to react to the predicted changes in soil erosion, sediments transport and water demands. Ground water management and resources allocation in the delta need to be reassessed taking into account the possible future conditions.

g) Continuous long data series are essential on sea level changes, nutrients and phytoplancton concentration and dynamics in the bays, river output and shore-line modifications to evaluate and correct the possible negative effects of the expected climatic change. They should start to be collected as soon as possible.

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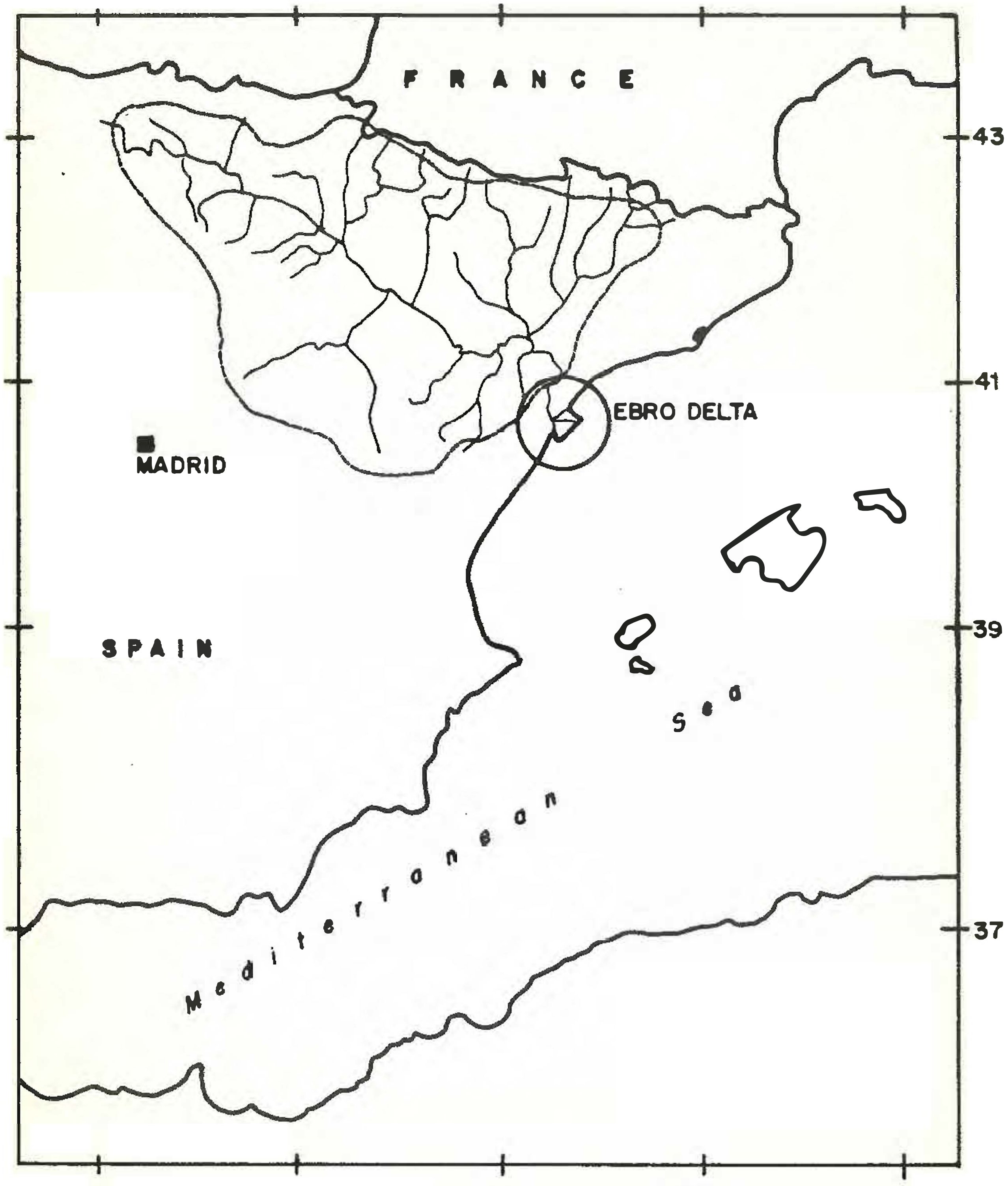

FIGURA 1.- Index map of Ebro delta wita Ebro drainage basin.

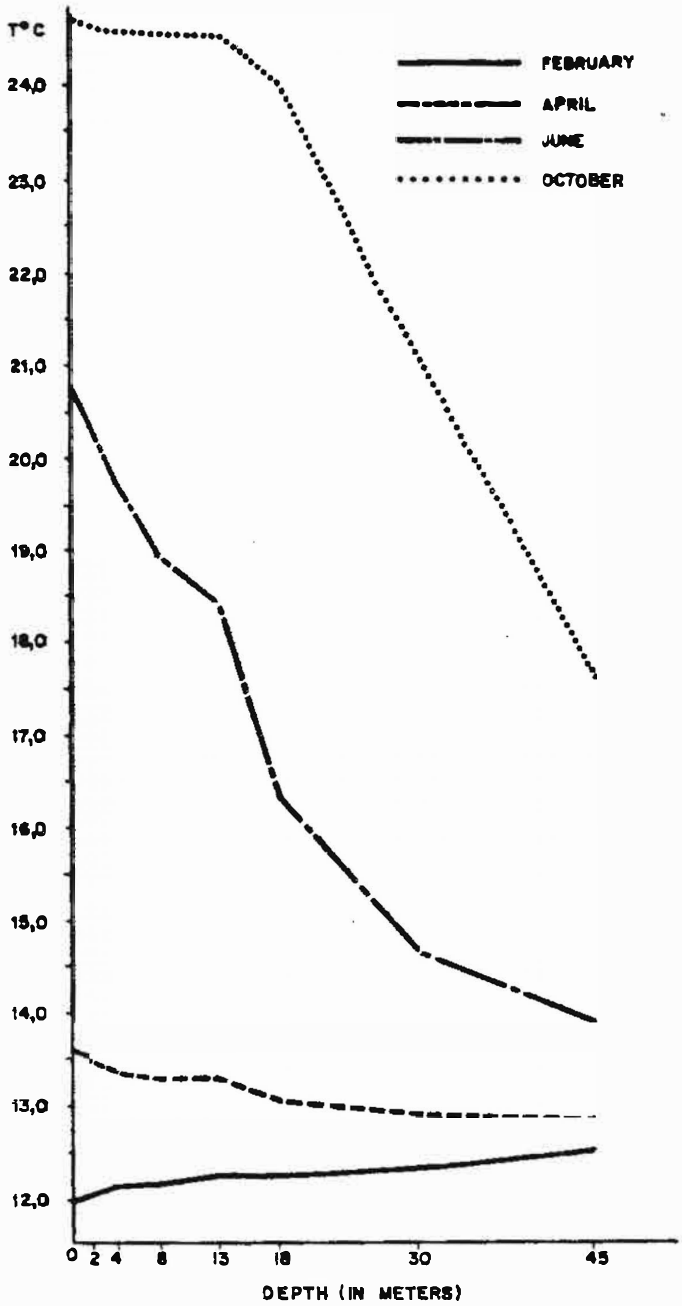

FIGURA 2.- Temperature profiles.

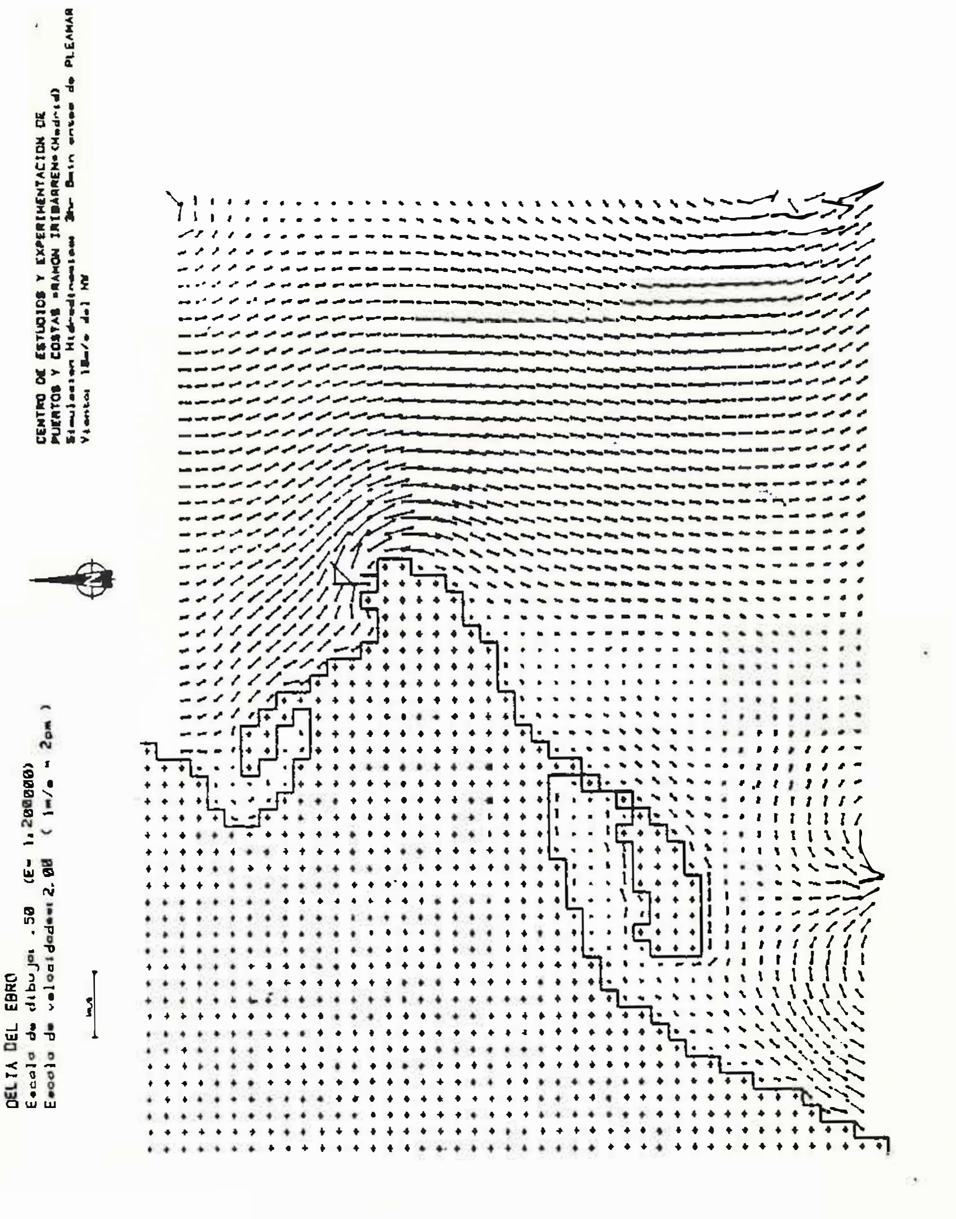

FIGURA 3: Current field as modelled by the CEDEX

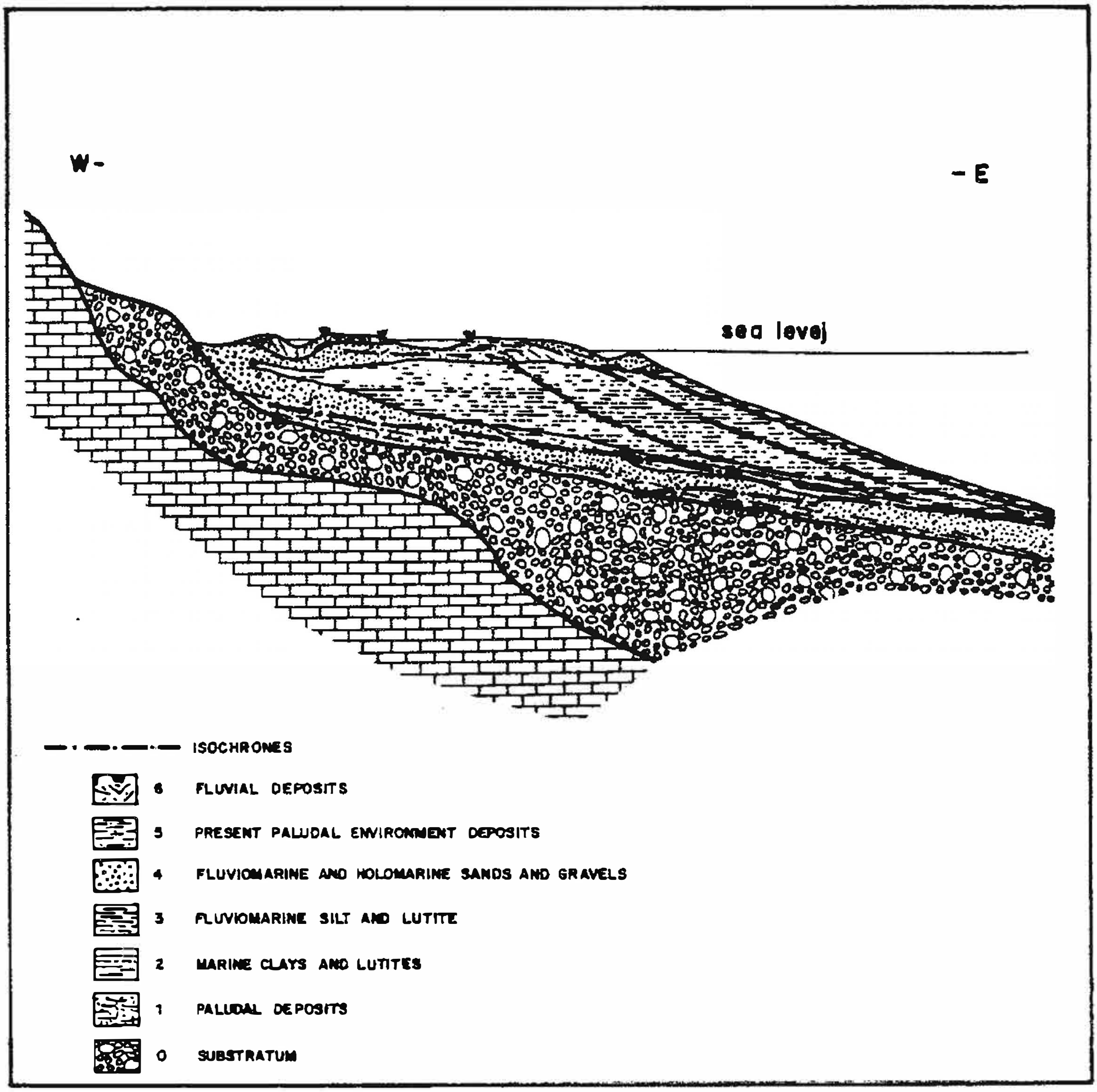

FIGURA 4.- Schematic profile W-E through the axis of the delta complex.

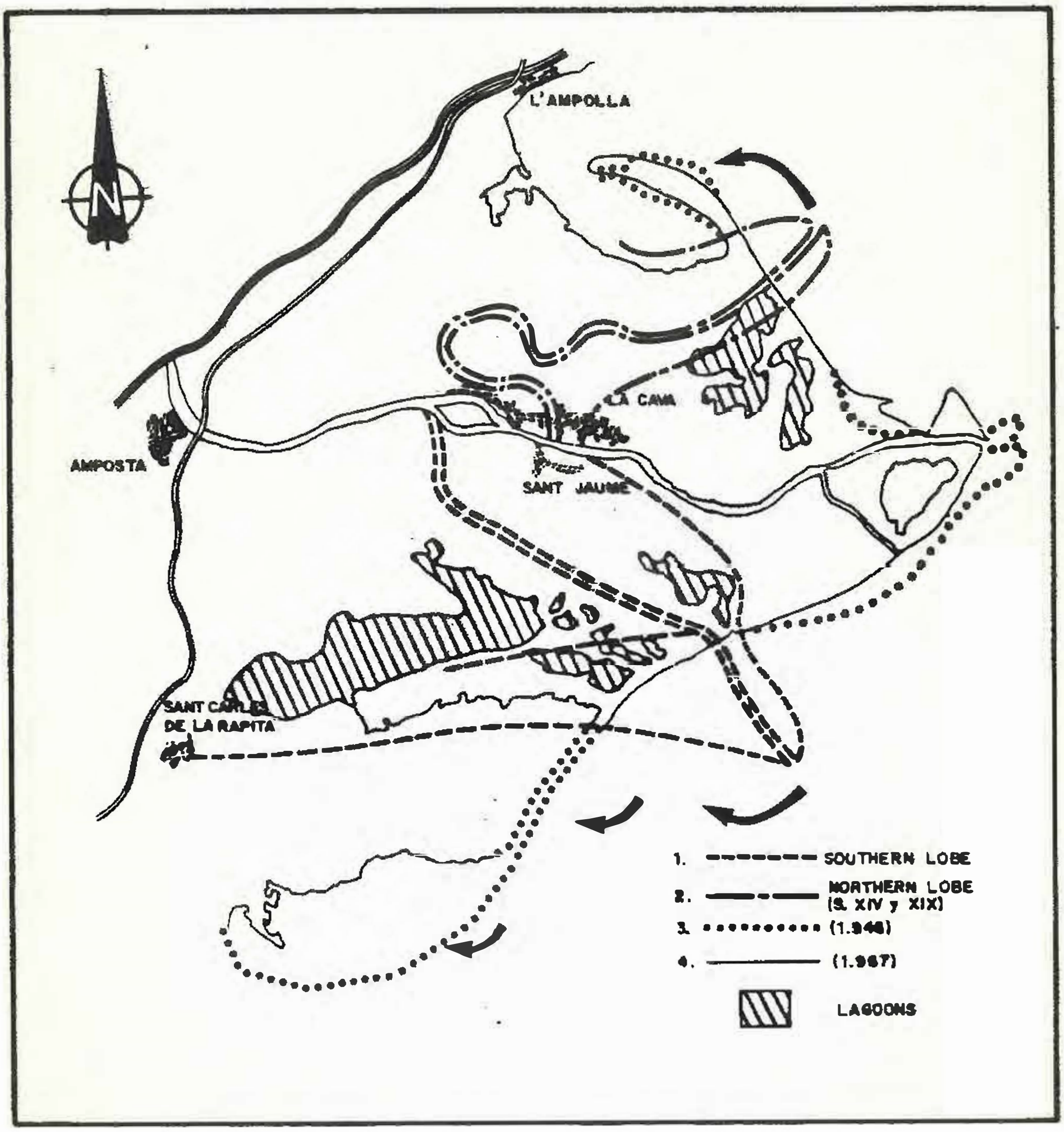

FIGURA 5.- Formation process of lobes in the deltaic plane.

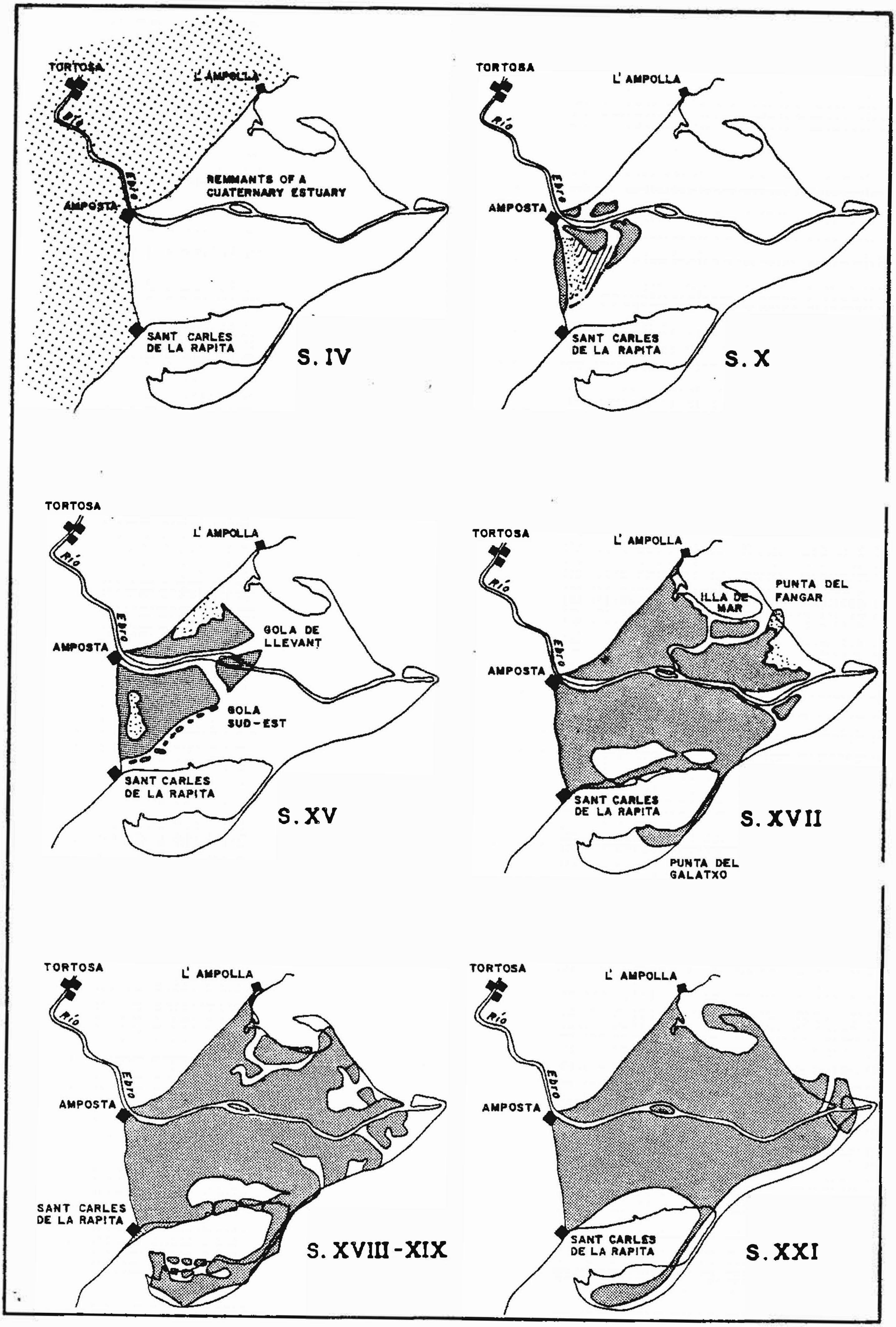

FIGURA 6: Evolution since roman times

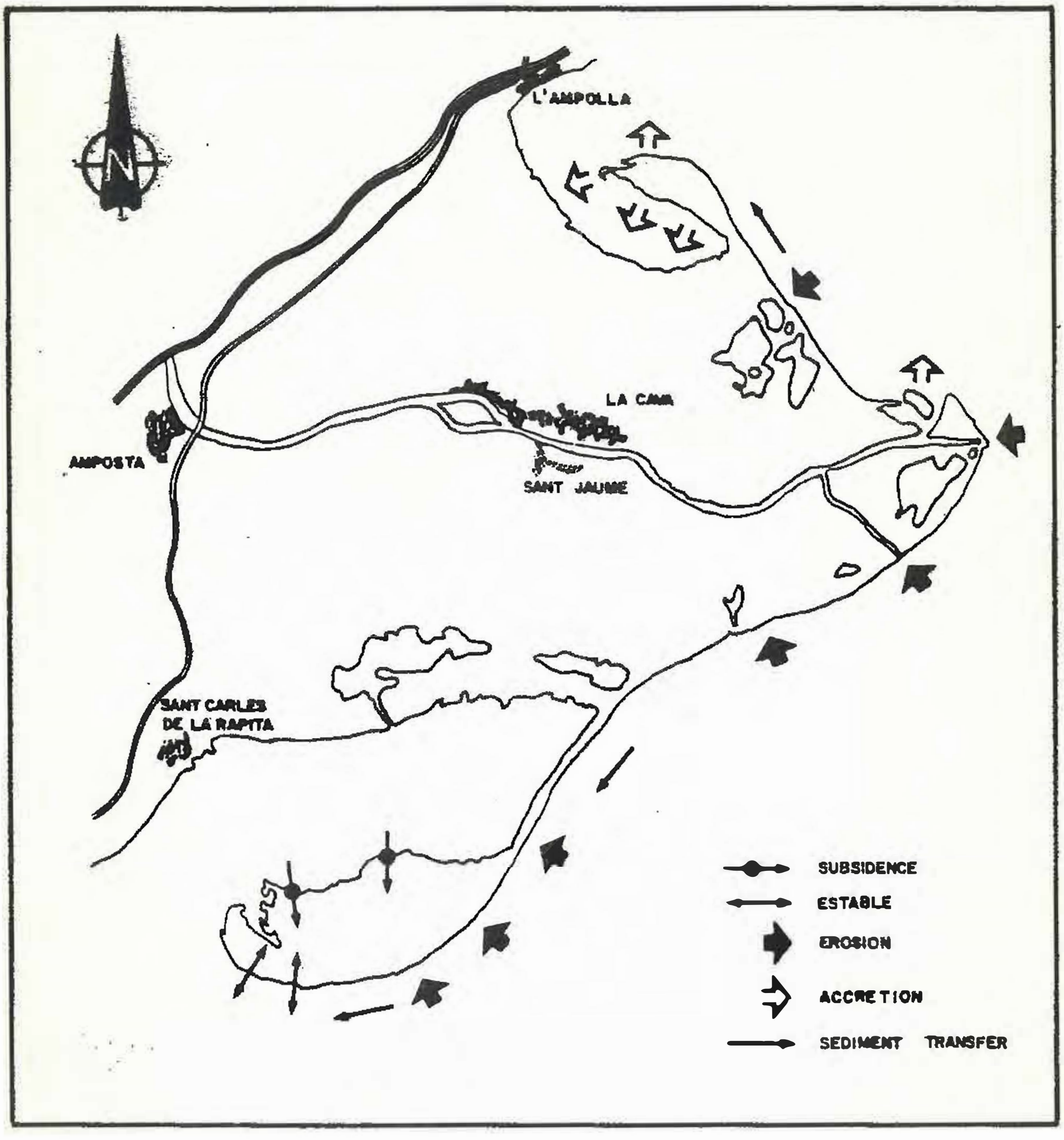

FIGURA 7.- Main coastal dynamic processes.

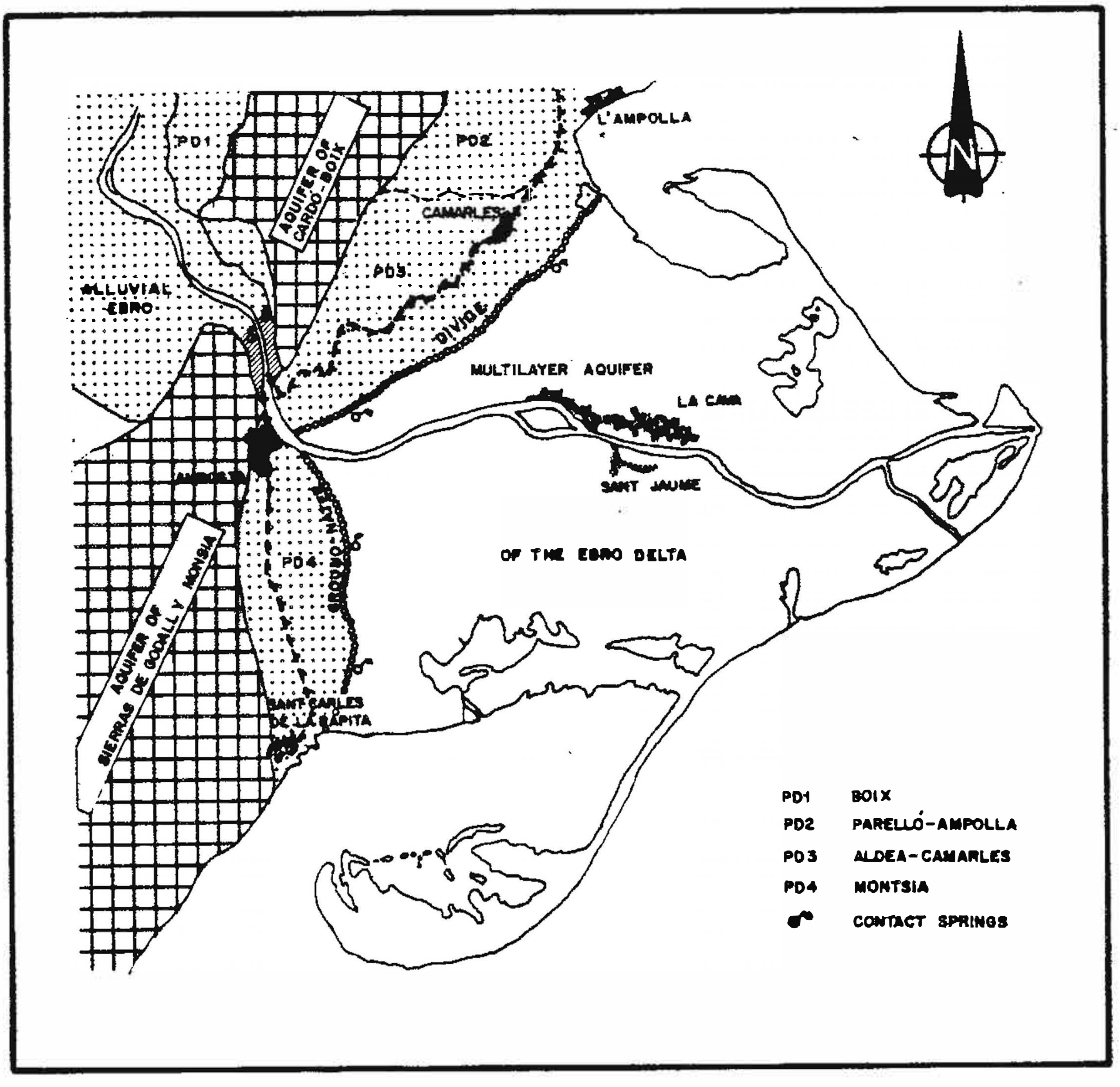

FIGURA 8.- Aquifers.

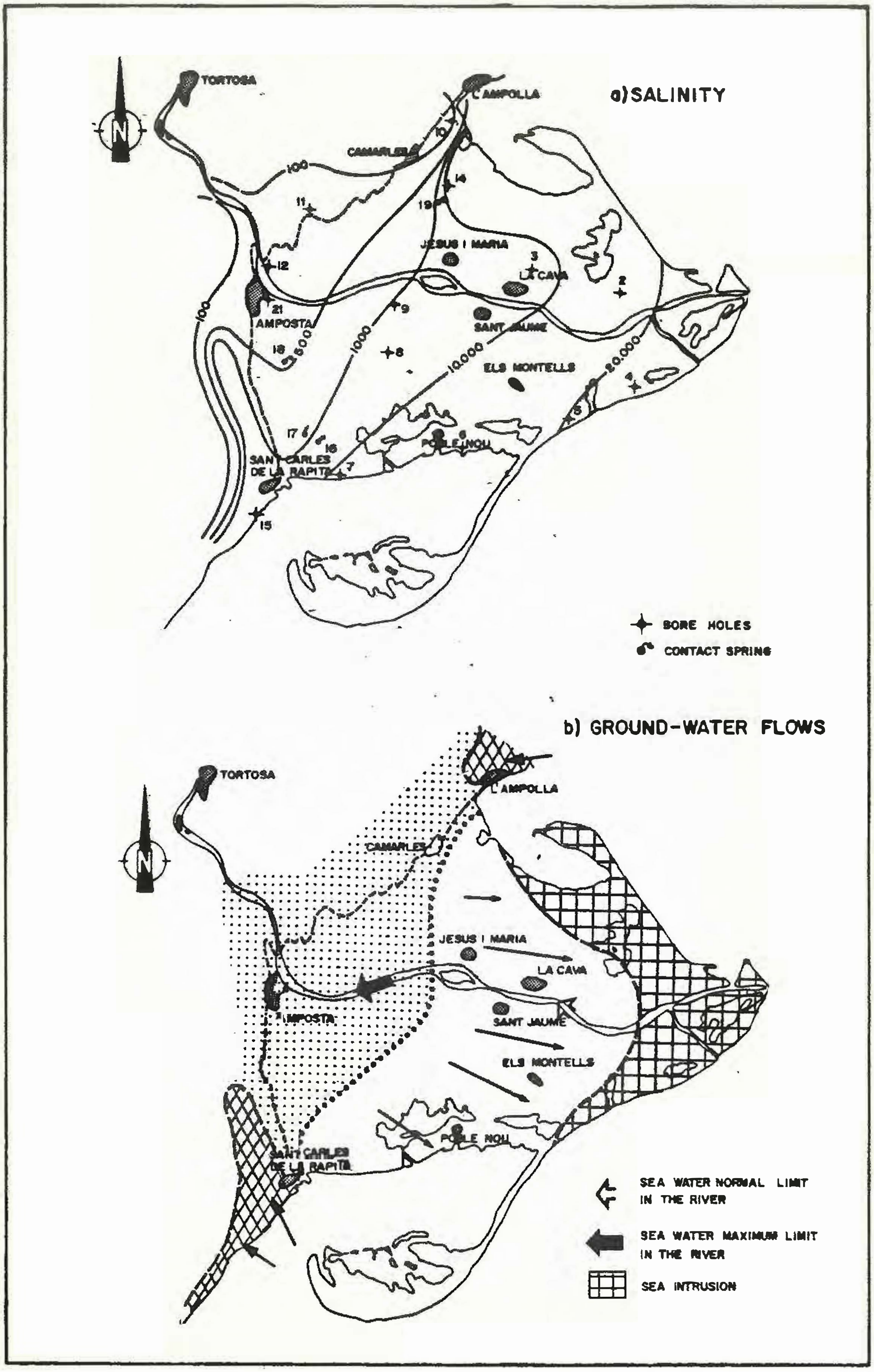

FIGURA 9.- Ebro delta ground-waters.

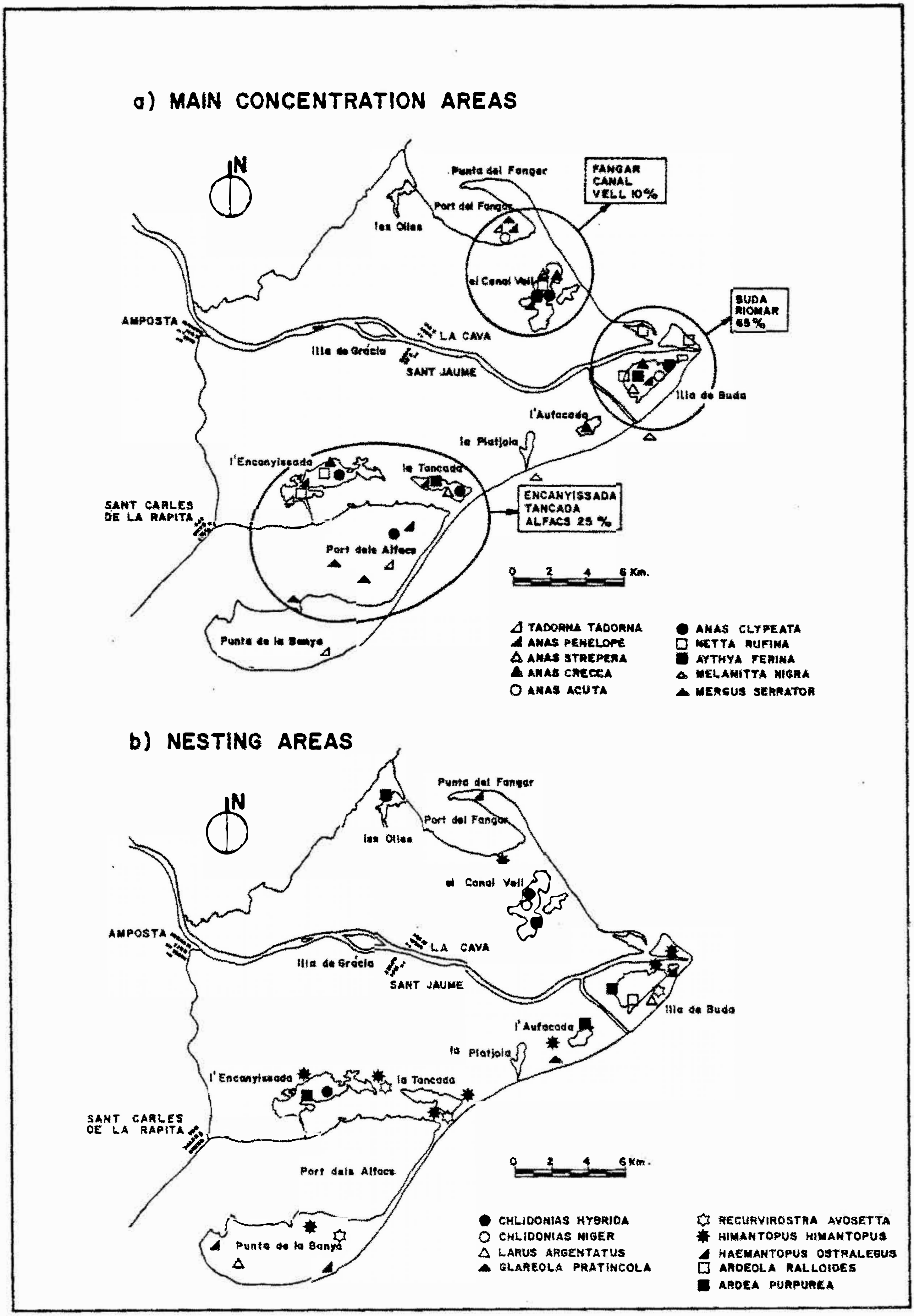

FIGURA 10: Birds nesting and main concentration areas.

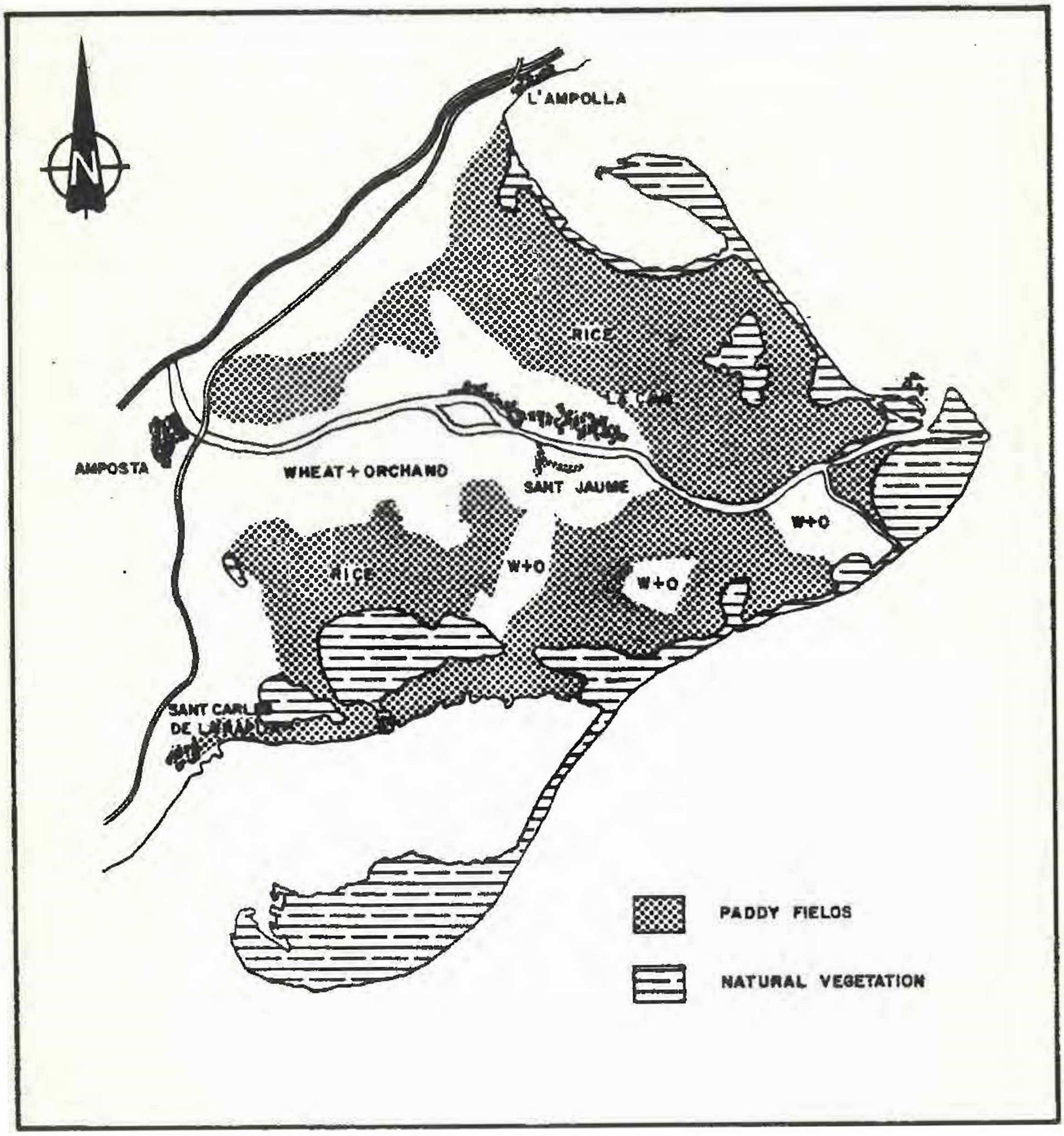

FIGURA 11.- Vegetatión map.

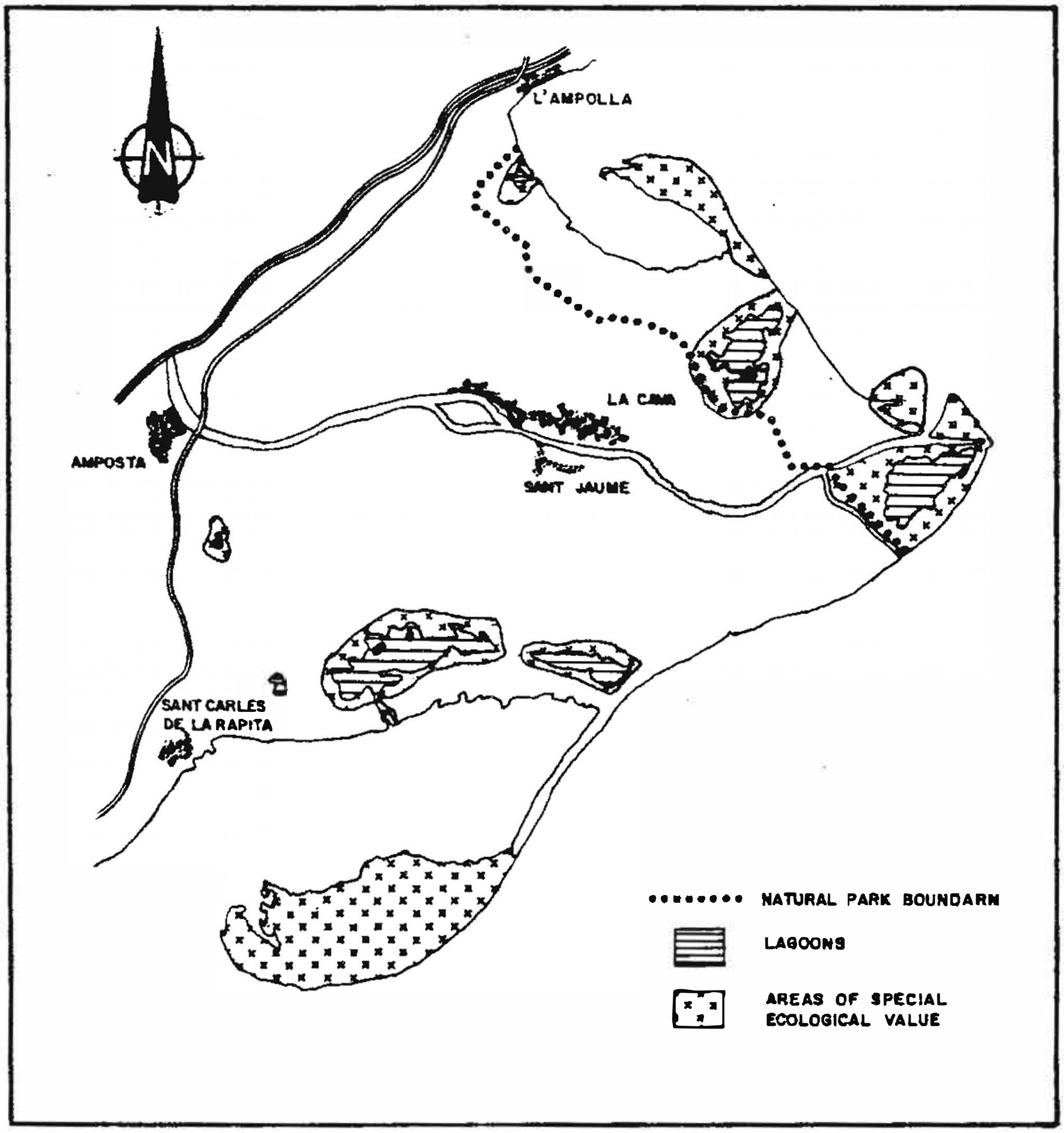

FIGURA 12:- Natural park of the Ebro Delta.