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IMPLICATIONS OF CLIMATIC CHANGES ON THE GULF OF LION

Condensed translation of the French version

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F I R S T D R A F T

N O T T O B E C I T E D

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INTRODUCTION

The international conference of the World Climate Program, held in Villach (Austria) in 1985, forecast that a doubling of the percentage of CO_2 would cause a warming of the atmosphere by 1.5°C to 5.45°C, the lower value being the most likely. In the middle latitudes the warm seasons would become longer, the cold season shorter. In any case, these climatic changes would not emerge above the 'background noise' of the inter-annual variations until the end of the century.

The changes that are hypothetically predicted by the GISS general circulation model for the French Mediterranean coast are a warming of 4°C in January, of between 3° and 4°C in July to the east of Montpellier, and of 4°C to the west, with an annual mean increase of 4°C. Precipitations would increase by 0.5 mm/day) (+ 15.5 month) in January; there would be practically no change in July (a slight increase east of the Camargue, a slight decrease to the west), and the annual mean precipitation would remain the same as today. Evaporation would increase by 0.25 mm/day that is by 0.75 mm/month) in January; it would increase slightly in July, to the east of the Rhône and decrease slightly to the west.

In contrast to these predictions, Wigley (1987) and Pitrovanov (1987) have concluded that the consequences of a general warming could be, in the Mediterranean coastal area, a winter cooling of minor entity (0.5° C), but with greater inter-annual variations. Spring and summer temperatures would remain unchanged, maybe with a trend to an increase, with a warmer autumn. Rainfall should be more important in winter, less in summer.

To this, one should add a cyclonic circulation that could become more active with a global rise of temperature, as was noted in the Atlantic during the last period of warming (Rognon, 1981).

Even if the other changes would not be quantitatively important, they would be very relevant for their incidence on extreme situations (Wigley, 1985), such as a succession of cold winters, of dry summers etc., which would have considerable biologic impacts. The extreme events deserve to be taken quite seriously, as there is a definite risk of a much greater inter-annual variability of climate.

The Gulf of Lion forms an arc about 270km long, open towards the southeast between lat. 42°5' and 43°6' N and long. 3° and 5° East (Fig. 1). It extends between the crystalline massif of the Albères, in the SW, which creates a very dissected rocky coast, and the Estaque calcareous chain in the NE. Most of the littoral is flanked by a low shore, frequently lagoonal,

interrupted by few rocky capes (Cap Leucate, the La Clape Mts, Cap d'Agde, Mont Saint Clair). The Rhône delta is situated at the eastern end of the gulf. It covers an area of 173.640 ha. As much as 40% of the gulf shoreline has been formed by the alluvial deposits of the Rhône river.

It is well known that the shoreline of the Gulf of Lion since the end of the last glaciation and during past historical periods, has been subject to changes on a scale that is certainly not comparable with those that are foreseen. In the absence of human occupation and activities, its evolution would be of no great consequence. In fact, after a long period of neglect, gradually or quite rapidly, according to places, man has become interested in the varied resource of the coast. In view of the present degree of permanent occupation and of the importance of the investments that have been made, the foreseen changes are all the more worrying, as they cannot be entirely controlled.

GEOLOGY AND GEOMORPHOLOGY

From the north of the Albères to the Canet, there is a major subsidence area filled with Neogene sediments. The Flandrian transgression was considerable in the area and led to the formation of a coastal strip accompanied by deltaic and lagoonal sedimentation. The present day lakes are the remnants of lagoons filled by river inputs. More to the north, under the Leucate sand bar, there is a regressive marine facies underlain by sands.

It is known that ca. 500 B.S. there was a sand barrier between the Albères and the Leucate lake. Further north up to the borders of the Herault (pond of Vendres) the coast seems to have been a lot more jagged with gulfs like those of Salses, of Narbonne (occupied by the Bages and Vendres lakes) and bordered by islands (Leucate, Ste. Lucie, Sidrières, St. Martin, La Clape mountain). This part of the coast developed rapidly because of alluvial deposits: 500 years later there is mention of the Leucate sand bar. Through the progressive closing of the bays and fluviolagoonal deposits, the coastline became regularized and the lagoons took on their present form. The dune system has a width of only few hundred meters and at the back of the beach it is mostly limited to a simple ridge.

Further north, the lake of Thau (48.2° lat., 1.4° long.) is an old gulf that occupies a basin closed by a narrow, very flat sand bar.

From Sète to the Grande Motte, the coast does not seem to have developed very much during the Flandrian period. The system

of dunes is relatively thick, with a low altitude (>10m) and greatly altered by the land winds.

From the Grande Motte onwards, the sand bar has an easterly direction and divides into several sandy strips spreading out like a fan: lagoons are integrated among them. This system extends throughout the Petite Camargue and gives a coastal formation which is several kilometres wide. It is abruptly cut off near the Petit Rhône, at right angles to the Saintes Maries de la Mer by a geological irregularity (fault, fold ...?) which lies perpendicular to the coast. Each one of the branches seems to mark out various stages of a considerable forward movement of the coast. These surface units began to form during the Flandrian transgression (Bazille, 1974). They continued to develop until modern times as witnessed by the formation of the Espiguette Cape. The system of dunes is very diversified. Its altitude, even though the highest in all the coast, does not exceed 12m.

Beyond Saintes-Maries-de-la-Mer, towards the east, the landscape consists of a network of ponds, earth banks, remnants of dune strips partially filled in by alluvial clay deposits. This landscape is the result of the combined action of fluvio-swampy deposits, predominant in the north and of the laguno-marine deposits, in the southern areas (ref. Rept. Fig. 4.1).

The substratum of the Camargue consists of gravels, the top of which dips in a SW direction from -5m to -42m. Its topography is rather confused, probably made up of terraces cut by gullies and closed depressions. The Flandrian transgression has left traces of five successive phases separated by stops, if not slight regressions. At its maximum extension it does not appear to have gone beyond the northern tip of the Vaccarès pond. During the first 4 phases, the alluvial deposits were primarily lagoonal or marine. During the period of the 4th stillstand which can probably be attributed to the Boréal-Atlantic transition (ca 7500 B.C.), a big barrier was formed that blocked any further transgression. It seems to have been linked with large terrigenous discharge too early to be considered as the creation of Neolithic farmers (Pons et al., 1979). From then on, a phase of general advance began, due to river inputs. It continued until quite recently, since the coast towards the end of the 4th centruy was roughly 4 to 13 km to the north of where it is today (Greslou, 1984).

The whole recent history of the Camargue, up to the mid 19th century has been dominated by the shifting of the arms of the Rhône river, the successive mouths of which have slowly moved eastward.

On the basis of surface deposits we can distinguish three ecological sectors from north to south: the Haute Camargue, where the altitude varies between 4.5 and 1m CGF, with marshes near zero m NGF; the Moyenne Camargue with a lower general altitude and marshes, in parts lower than the sea level, also comprising the Vaccarès pond; and the Basse Camargue, the third ecological sector. It is located to the south of Vaccarès and is characterized by more or less distinct rows of dunes separated by ponds; altitudes vary between +7m NGF for certain dunes and -0.3m NGF in the ponds.

The Haute and Moyenne Camargue were formed from a network of distributory channels encircling the marshes, the Basse Camargue through laguno-marine sedimentation (sands and salty clay silts).

Today the coast of the delta advances toward the sea through two large blunted capes that shift the west: the Beauduc headland, at right angles to the Camargue, reflects the discharge of the Grand Rhône; the Espiguette headland, normal to the Petite Camargue, corresponds to that of the Petit Rhône.

THE CLIMATE TODAY

The climate of the Gulf of Lion is of the Mediterranean subhumid type with cool to temperate winters according to the Emberger classification or of the IV 3 type according to Walter's classification. It has also been called "transitional", because some years it can display oceanic climate characteristics, more rarely continental climate characteristics (Bordière and Emberger, 1959).

Generally, the rise of the Açores anticyclone in the summer protects the region from the perturbations coming from the Atlantic, but there are years when it settles too low in latitude and this allows the penetration of low pressures from the west.

In the winter, the relief of the hinterland and the continental thermal high pressures displace the perturbated currents northwards; however, the weakening of these high pressures may allow the perturbations of the western circulation to pass through. In any event, 2/3 of the perturbations affecting the region are of local origin caused by meridian circulations of cold polar air reaching the Mediterranean. In particular, they give rise to southeasterly winds which can be violent and bring along rain and storms.

Annual rainfall ranges between 400 and 750mm (540mm in the Camargue) with 50 to 95 rainy days a year. Mean annual temperatures range between 14° and 15°C.

The average of the minimum temperatures (m) is, in this connection, especially important for vegetation, because it localizes the distribution threshold of the various species; from the SW to the NE m it decreases (Rept. fig. 4.16), by +4°C on the Albères coast (Cape Béar); the decrease diminishes to +0.9°C in Montpellier and it increases to +1.7°C in the Camargue and +8°C in Monaco, near the Italian border. The median part of the Gulf is thus relatively cold in the winter and this causes a gap from a biogeographic point of view.

Climatic variability has been studied in detail on the basis of continuous observations from 1945 and 1987, made at the biology research station of La Tour-du-Valet in the Rhône delta. During that period precipitation and temperature have been quite variable. At first sight there seems to be a considerable variation between one year and the other: a wet or very cold year is followed by a dry or hot year. This important variability masks however a very complex general evolutionary trend, though relatively unenventful before 1942-1945.

The trend is subdivided into periods, some are quite obvious, other are masked. However, their interplay does not permit to draw conclusions for periods longer than a few years. Two years after 1944 stand out: 1945, which was very dry, and 1956, which was very cold.

The conclusion, is that as statistical trends cannot be detected, the climatic variations of the last 44 years give no indication on the behaviour of climate in the next decades.

In the region of the Gulf of Lion the prevailing winds have a NW-SE orientation with a strong preponderance in the NW sector. Winds are frequent and at times violent; they blow 208 days year^{-1} at more than 38 km h^{-1} (10.8 m s^{-1}) of which 11 days year^{-1} at more than 74km h^{-1} (20.5 m s^{-1}) with peaks at 135-165km h^{-1} (37.5-45.8 m s^{-1}).

THE SEA

The tides are weak, the amplitude not exceeding 30 cm at average springtide. On the other hand, the variations due to the oscillations of atmospheric pressure and especially to the wind effect are a lot more important. The sea is made to rise by SE winds and to fall by the NW winds. Greslou (1984) reports record values of +1.80m east of the Camargue (toward the Gulf of Fos) and -0.5m NGF at Port-La-Nouvelle (south of the Gulf of Lion).

In the area of the Camargue coastline over a 7-year period (1967-1973) the oscillations ranged between the following extremes: -0.39 m NGF and -0.90 m NGF or a level difference of 1.29 m (Greslou, 1984).

In the northern part of the Gulf (Sète-Camargue), the prevailing orientation of the waves is from the SW or the SE; in the southern part, the main directions are E, SE or N-NE. Maximum wave height, with a probability of a 100-year period, is calculated at 5-10m depending on the site; the annual probability from 3 to 6m.

The general currents circulate far out in the open sea to affect coastline dynamics. On the other hand, the currents caused by the waves that are oblique to the beach, play an important role in the tangential migration of the sediments.

In accordance with French National Geographic Institute data there has been a net sea rise of 10cm from 1885 to 1979 with an acceleration between 1944-1955 and a decrease afterwards (Fig. 2).

THE SOCIO-ECONOMIC SETTING

The past

The coastal zone of the Gulf of Lion had for a long time been considered marginal, because it lies outside the principal currents of economic activity of the region. Thus traditional activities dominated fishing and shellfish growing in the ponds, exploitation of salt, hunting, agriculture, extensive breeding of horses ('manades'), etc. Summer tourism, severely limited because of the mosquito problem, was confined to the vicinity of the urban centres of the interior. The harbours of Sète and Port-la-Nouvelle remained the principal centres of commercial and industrial activity of the coast.

The environment had reached a certain level of balance. When the agricultural or fishing activities made it necessary, the land owners took various measures of protection against the sea. They aimed primarily at preserving the continuity of the dune strip at right angles with the exploited areas and at managing the channels "graus" between the sea and the lakes. In 1867, Régy, a civil engineer working for the government, published an important report in which he set out for the Hérault coastline a management plan for the lagoons, but also a plan for the protection of the coast (a planting programme, creation of artificial dunes, etc.) all of which gives us a clear picture of

the concern of the authorities - already a long time ago - to make the area secure against the aggression of the sea.

In the Camargue, the first attempts to control the environment go back to the 12th century, but the true concern for the protection of the coastline did not rise until the 19th century when those involved in salt production bought back stretches of the Basse Camargue, after an unsuccessful attempt to cultivate them. In 1859, the dyke by the sea was completed.

In 1869, the arms of the Rhône were dammed permanently. This put an end to the shifting of the river and to the risks of flooding.

In 1929, most of the Basse Camargue was made into a reserve. This was done because of the conflict between salters and farmers for the management of water resources and because of the utmost important of the area as a biotope. The status of the reserve gave the delta its natural image and fostered both international tourism and large-scale scientific activities (Biology Station of the Tour du Valet, CNRS laboratory - until 1986, Camargue National Reserve, Regional Park, etc.).

THE PRESENT SITUATION

Currently, the interest of the coast of the Gulf of Lion and the financial stakes concerning it have greatly developed under the influence of several large scale development programmes [Rept. figs. 1.1-1.5].

(a) agriculture: development of irrigation and drainage networks in the Camargue for rice growing and the management of marshes for water fowl. In the Languedoc, the construction of the Canal of the Bas-Rhône and large-scale infrastructure projects of irrigation and drainage for a local diversification of crops;

(b) tourism: for the whole coastline, except in the Camargue, a mosquito combating scheme was the first and prerequisite stage, having made the beaches more attractive, a concerted construction plan was launched (new towns, extension of existing urban areas, etc.) directly fronting the sea, making the whole of the Gulf of Lion one of the new summer resorts of Europe. Currently more than 40% of the coastline has been developed.

(c) - industry: mainly the creation of a new harbour, metal works and oil refining complex at Fos-sur-Mer;

- environment: creation of the Regional Nature Park of the Camargue and classification of the Camargue as Reserve of the Biosphere. These actions underscore the importance of this region both for its role in the preservation of the European avifauna and for the uniqueness of its biotopes (for instance, the Riège forest of Juniperus pheonicea), as well as for the richness and diversity of its wetlands (506 natural stretches of water of 0.5 ha covering 40% of the Camargue and ranging from fresh water to water with high salinity (ref. Britton and Podlejski, 1981).

CONTEMPORARY COASTAL CHANGES

A systematic study of the development of the coast based on aerial photographs and on bibliographical data for the years 1942-46 to 1970-80 has given the following results (fig. 3, 4 and 5).

- Eastern Pyrenees and Aude (from Albères to the Vendres lagoon) 90 km of coast, 27 of which are bordered by dunes. Generally the coast advances, with some recession areas near the mouths of coastal rivers (Tech and Tet) and around rocky headlands (Albères, point Leucate). The picture is as follows: 53% of the coastline advances by 0.5 to 1.5m year^{-1}, in spots up to more than 3m year^{-1}.

  27% of the coastline recedes by 0,4 to 1.2 m year^{-1}, in spots up to more than 3m year-1.

  20% of the coastline is stable (variations 0.3m year^{-1} in one direction or the other, taking into account a margin of error in measurement.

  Hérault (from the Vendres lagoon to the Grande Motte) 84 km of coastline. Of those, 62 are bordered by dune strips. The coast shows the same phenomena of recession near the months of rivers and rocky headlands. This is however less systematic, because of the existing protective works. In summary,

9.5% of the coastline advances
24.4% of the coastline recedes
66.1% of the coastline is stable.

Gard and Bouches-du-Rhône (from the Grande Motte to the Gulf of Fos). 103km of coastline of which for the Gard 17.6km of dunes out of 33 for the department as a whole. The whole coastal dynamics is linked with the slow westward movement of the old present deposits of the two mouths of the Rhône. The Espiguette point advances by 18m year; the construction of dykes at its tip has changed the direction of this forward movement and in spots an advance of 20-25m year has been observed. The Beauduc point advances by 11m year. Near the river mouths the recession of the coast is considerable, approximately more than 4m year-1. This last figure should be correlated with the decrease in the solid discharge of the river, which was 4 x 10*6t year at the end of the 19th century, but had become 4 x 10*5t year in 1970. The displacements of the beach can be summarized as follows:

28% of the coastline advances
62% of the coastline recedes.

The statistics just given correspond to resultants; it seems on the basis of the first observations carried out on the Hérault coastline (Le Dain A.Y., op. cit.) that the resultants are, at least in certain places, the outcome of cycles of forward and backward movements, as has been observed on other coasts over periods of 10 years or more (Bird, 1986).

The big storms have formidable consequences: in 3 days the 1982 storm made the coast recede by several dozen meters in certain spots and brought about several break-ups of the dune strip.

AN EVALUATION OF THE IMPACTS OF CLIMATIC CHANGES

1. Physical Oceanography

The dynamic circulation of the Mediterranean Sea, within the limit of temperature variations that are suggested, is not a function of absolute temperature values, but of the temperature differences between the Atlantic and the Mediterranean. As the changes in air temperatures could only be along latiduninal zones, the Mediterranean will always have a continental climate in respect of the Atlantic. The western basin would continue to be a basin of concentration (water losses due to evaporation, greater than the inputs of fresh waters). A sea level change of few or several decimeters would not, certainly, appreciably modify the flow across the sills of Gibraltar and Sicily. A

similar functioning has already been suggested to have occurred both during the climatic optima and the glacial maxima.

On a seasonal or annual scale, a modification of rainfall (with greater intensity in winter) as well as colder winters, will tend to magnify the Ligurian current, though within ranges already observed, with the exception of cold winters and/or of high autumn or winter precipitation.

In conclusion, the limiting conditions in the open sea are fixed by the Ligurian current, more or less accentuated, and by the residual littoral circulation over the continental shelf, conditioned essentially by wind.

2. Marine fauna

The physico-chemical features of the Gulf of Lion, salinity and temperature in particular, explain a large part of the animal distribution and occurrence, as well as their recent modifications and upheavals. As the gulf constitutes a biogeographic frontier for a number of species, any modification of these factors would have far reaching consequences.

3. Physical effects on the coast (Chpt. 5, 1-2)

The scale adopted for the map that shows a forecast of the coast in 2,025 AD [Figs. 3a and 4.3b], only indicates the major trends of the possible changes.

Taking into account the capacity of this deltaic coast shaped by waves to reconstruct itself after major storms, and to rise gradually in phase with the average rise of sea level, there are no catastrophic changes to be feared during the next 40 years.

Nevertheless, those stretches of the shore that are now already unstable or threatened, will be even more so in 2,025. There are, from east to west:

- the spit of La Gracieuse, which may become detached;
- the Courbe-à-la-Mer and the inlet of La Dent;
- the mouth of the Petit Rhône and the beaches situated on both sides of the promontory that defends Saintes-Maries-de-la-Mer;
- the shore of the Petit Camargue;

- the embayment between the point of Espiguette and the Grau-du-Roi, which risk shoaling and silting up.

There are, however, still several outstanding questions:

- How will the offshore coastal defences behave, like the breakwaters of the Courbe-à-la-Mer in the Petit Camargue.?

- Will the mouth of Grand Rhône shift eastwards? Or, which is most likely, will a new mouth develop towards the SSW?

- Will subsidence continue at Beauduc, creating a real threat of submersion for the lagoons of that sector of the delta?

The coast presents different situations in its response to changes depending on the nature of the coastal and terrestrial environments.

(a) In the dunal areas that are not limited behind by roads, tourist resorts, or by areas of intensive agriculture, and that are in a good condition (e.g. continuous and high dune belt, with homogeneous sand grain size), the whole system will retreat as expected (ref. Chapter 4). It is possible that in the shorter term the retreat will be slower given the inertia of the sand masses involved.

(b) In the dune areas that are damaged and intensively occupied by man in general, the dunes have variable elevations, breaks and anomalous beach slopes (flat or inverted). In these cases there will be an acceleration of the process of degradation, both by removal of the sands towards the sea (where they will be caught in the littoral drift) and landwards by the overwash of the dune belt. There will probably be a thinning of the beaches involved and the progressive formation of inland dune belts, fragmented and oriented parallel with the dominant onshore wind (the Mistral or Tramontane). A transformation of the littoral coastal landscape is then to be expected towards a succession of flat surfaces, with or without wetlands, and of inland dunes, with a general N-S orientation and not E-W as today. The attainment of such morphology will probably take half a century.

(c) In the beach-dune barriers that separate the sea from the lakes, sea level rise and especially storm surges, threaten to lead to the breaking and the opening of new inlets.

(d) In the strongly urbanized areas, there has been in general a decrease of beach slope gradients due to the smothering or removal of dunes for the construction of sea front roads, of buildings, camp sites, and a reduction of beach width, in consequence of the close spacing of defence structures.

These two aspects of coastal degradation will emphasize the risk of washovers by storm waves, and the deposition of sand outside the beach zone, especially where beaches are narrow. Once moved onshore, the sands are lost to littoral drift. Thus the damping effect of the beach for the bigger waves will decrease; beach profiles will steepen and retreat; they become less functional even in the stretches where coastal erosion does not seem to be important (for example the sea front of Valras-plage after the storm of 1982, and the right-hand shore of Palavas, after the October 1987 storm).

In these strongly transformed sectors, it is likely that, in the case of a significant rise of sea level, there will be much greater damage to facilities, because of the increased frequency of storm washovers.

In the event of a clearly identified rise of sea level, it is probable that coastal protection will be focused on the urbanized stretches, and on the protection of the coastal lakes and lagoons, the areas of major economic importance in the Languedoc-Roussillon. The proper identification of the sectors of degradation will permit to reduce and to stagger in time the necessary protective measures. The entity of cost will then be of less relevance in the face of the overall economic stakes involved.

5. Changes in the lagoonal zone

Following the hypotheses that there will be a weakening of the littoral barrier, this should produce, without human intervention, in the 'front-line' lakes, a widening and an increase in the number of inlets, then a gradual return of a certain number of lagoonal basins to a marine environment. In the absence of control in general, one can expect a widespread shifting of the paralic systems. In several cases this should result in a fall of phytoplanctonic productivity (and therefore of shellfish culture) in the lagoonal basins, and a consequent impoverishment of the adjacent marine belt (Frisoni 1984;

Guelorget and Perthuisot 1983; Guelorget 1985).

In the strongly confined lakes, and particularly in most of the lakes of the Camargue, two alternatives can be considered, with or without interventions to the hydraulic system [Ref. Rept. figs. 4.2, 4.13-15].

(a) Without intervention

The system of lakes of the Camargue is separated from the sea by a dyke and communications through a number of sluices. At present only one of these is operational. It has allowed a gravity flow towards the sea of some 60 mill m^3 during the years 1986 and 1987, representing an outflow of 1.5 mill. tons of salts.

The gravity flows to sea are all the more important as the lakes are at a higher level. In this respect the NNW mistral wind, which pushes waters southward, plays an important role. In practice, in the present situation, the outflow to the sea occurs only at the edge of the lower lakes, at elev. of >0.10m NGF. Clearly, the progressive rise of sea level will oppose this gravity flow; to remain quantitatively significant, it will necessitate higher and higher waters in the lakes. Normally, a rise of the level of the lakes should accompany that of the sea, but the upper parts of the Vaccares system, since they are conditioned by commercial activities, other than fishing, they hamper the gravity drainage of the delta towards the cultivated basins and threaten the generalized flooding of the lowlands.

It is foreseen by P. Heurteaux that without intervention, the Vaccares and the lower lakes of the Camargue will be transformed into an hypersaline system (50-70 g/l^{-1}). They will then loose all their biological interest and all their macroflora. The salinity will be too high to allow fish colonization. The permanent salt marshes located around the system Vaccares of the lower lakes will not be affected, due to their very artificial conditions (i.e. salinity and hydraulic regime) by massive inflows of freshwater. The salinity of the temporary, uncontrolled salt marshes will probably increase especially in the winter, due to a brackish water rise in the main water table.

Their dry period could be shortened by the losses of drainage capacity caused by a rise of sea level. Changes will be the more notable, as the salt marshes are of feeble elevation, close to the water table. Change in the macroflora of the marshes should be minimal, nevertheless the species that are more sensitive to salt (they are also the most rare in the Camargue,

e.g. Damasonium stellatum), could be seriously affected.

It is rather unlikely that man will remain passive in the face of a drastic modification of salinity and drainage conditions in the Camargue. The intervention will be directed to counteract the increases in the Vaccares and the lower lakes, which could become brackish or poly-brackish as well as to ensure the flushing of rain and waste waters. According to the entity of the measures taken, the salinity of the Vaccarés could be considerably reduced, down to its present values, or lower. The lake would then be a favourable environment for the development of an important macroflora, though one cannot foresee of what kind. A fish colonization like the present one would follow, provided there will be access to the sea between October and March (otherwise no fish could migrate). The other lakes, which communicate with the sea, should bear the same fish populations as today.

The managed salt marshes that stretch around the Vaccares and the lower lakes would not be modified. Human intervention could, however, improve the drainage of the Camargue, and by that slightly shorten the duration of the submergence of the temporary natural marshes.

In some parts, the increase of temperature could favour phytoplanctonic development and the growth of benthos. But it will also systematically favour in situ bacterial activity, as well as the turn-over of bacterial populations. This increased bacterial activity would take place at the expense of the organic matter in each basin. With the decrease of primary productivity, however, it could be that, in time, the reserve of organic matter will be exhausted, thus limiting bacterial blooms and the recycling of nutrients.

In general, one can expect a first phase of de-oxygenation in the coastal basins with localized distrophic tendencies (the development of sulphate-reducing bacteria and of methanogenesis being favoured by the anoxic environment and by temperatures above 21°C). This first phase will be quite significant, especially in the basins dedicated to intensive shell and fish culture.

The second phase would be a re-equilibration of the systems, on the one hand by the bacterial activity itself, and on the other with a decrease of primary production which will be damaged by the reduced flushing of the inland areas.

6. Changes in the bird fauna (Chapter 5, p. 46)

(5.3 Forecast of changes in the bird fauna)

As the birds are at the end of the food chain, the impacts of climatic changes on them are difficult to foresee. As regards wintering species, the expected deterioration of the ichtyofauna in the central part of the Camargue will certainly affect the species that are fish-eating, especially the cormorans, grebe and herons.

As regards the nesting birds, the well being of the Ardeids (e.g. the grey heron) could depend on the persistence of the permanent fresh water, or slightly brackish marshes, and of their fish and anphibian fauna.

The flamingo, more than any other species, will benefit from an increase of salt waters.

The Laro-Limicoles will not be affected, as they are not fish-eating. The survival of the sterns will depend on the persistence of freshwater marshes.

Migrating birds will be positively or negatively affected, according to their habitats. Species like the chevalier cocorli would benefit from more saline waters, while visitors that instead live in fresh water marshes (e.g. the chevalier sylvain) would suffer from their shrinkage.

7. Socio-economic impacts

(a) The future of the Camargue

It is not quite certain whether today the approach of harmony between Man and Nature has prevailed over the former approach of subjugation or outright domination. However, there is a general consensus about the kind of response which coastal societies could make to the threat of sea level rise.

In 1965 André Malraux, Minister for Culture, in effect indicated that in the Camargue it would be better to control human activities and to oppose all those that tend to modify the natural environment.

The approach that the present coastal activities are immutable is quite questionable. There is nothing to indicate that farmers will be prepared to increase water pumping in order to save activities that are already threatened and maintained by subventions, like rice growing.

Returned again to a surface of 10,000 ha, thanks to the

financial assistance of the Ministry of Agriculture, would rice culture survive new EEC restrictions and the freezing on acreage expansion?

After the failure of an attempt in 1975 to grow reeds for paper-making (Picon, 1978), and the more recent (1980) failure of a reconversion to aquaculture (Picon, 1985), the future of new agricultural investments, in natural conditions even more uncertain than before, is rather doubtful.

There is nothing to suggest that the Henin Bank will be ready to invest a considerable amount of capital in the elevation of salt marshes. It is possible instead that out of regard for nature, its vagaries included the lower Camargue of farming and salt-pans will move towards natural recreation activities. After all, a survey conducted among visitors to the Camargue indicates a strong demand for natural spaces (Picon, 1987). An enquiry made in 1984 indicated that 82.5% of visitors were attracted by nature. Furthermore, the persistence of a very low population density (since Roman time, Table I), a sign of demographic adaptation to the limitations of the environment could be an advantage in the context of renewed shoreline instability.

It could be suggested that the latter, rather than impose the need for new projects of coastal management and defense, could instead afford the opportunity of a further development of green tourism. This type of recreation is in increasing demand by the urbanized middle classes of western Europe, and do not necessitate infrastructures like marinas and yachting harbours.

After 1981, when camping was forbidden on the beach and dunes of Sainte-Maries-de-la-Mer, summer campers (65% of whom were workers, clerks and craftsmen from the region) have been replaced by hikers of upper-middle class origin from European cities (Pico, 1987).

If social demand, natural conditions and economic profit are thus combined, it is possible to envisage that the physical evolution of the coast will produce rather than a new constriction situation one of flexibility which will stop development projects for the sake of avoiding the risk of national disasters. Recent investigations (B. Pico et al, 1987) have shown that in the lower Camargue the offer of natural spaces can be as profitable for the landowner as agricultural or industrial production.

This awareness on the part of landowners appears to derive from a progressive modification of the concept they used to hold of their own environment, dominated for a long time by the logics of an agricultural economy. Hostile in principle to the

creation of nature reserves and to tourism, they appear to have considerably modified their position. Those who conceived the saline and lacustrine environments of the lower Camargue only as a hindrance to agricultural development have gradually begun to realise that in the context of a post-industrial society it can now be looked at even as a resource..

(b) The future of the Languedoc-Roussillon coast

(i) Climatic changes. An increase in temperature could be considered a positive element in regard to tourism and to activities associated with it. An extension of the warm season would improve the regional potential versus the Spanish, Italian, or North African coasts, allowing quicker returns for investments, thanks to a more intensive utilization of facilities over a longer period. It could also increase the duration of seasonal activities that depend on the flow of mass tourism.

On the other hand, longer or more frequent periods of drought would jeopardize the availability of water supplies that are needed for a large concentration of population.

(ii) Sea level rise, longer or more storm surges could cause, from year to year, a detioration of beaches and infrastructures resulting in escalating costs of protection and repairs, and of raising technical and financial problems of coastal defense, not experienced so far.

Such new physical parameters will require the intervention of public authorities with complex problems to be solved regarding financing as well as the designation of the responsibilities of individual and of executive bodies such as local communities, departments or regional authorities or the State. Beyond the expected physical effects, climatic changes could induce modifications in the behaviour of society and of the business community in a more general way.

The logic of business involves both elements of time and risk. Increased risks will be reflected in new investments on the maintenance of existing installations and of tourist uses. In the longer term, the question might be raised of man's use of the coast for tourism, as the shore becomes more and more unstable and therefore less hospitable.

Responses to climatic changes could include a relocation of tourist activities, for instance their greater concentration on rocky coasts, though this prospect ought to be considered as an extreme scenario. The Languedoc coast would then return to its former conditions - those that prevailed at the end of the XIX and beginning of the XX century.

CONCLUSIONS

It is fortunate that the insalubrity of the coast in the past centuries caused most of the large urban centers of the Gulf of Lion (Perpignan, Narbonne, Bèziers, Montpellier, Nîmes, Arles) to be built sufficiently back from the beach, so that they are protected from the serious impact of a foreseeable rise of the sea level (fig. 1).

On the other hand, the coast with its tourist and harbour installations is particularly vulnerable due to: narrowness of the strip of sand for most of its length, the low altitude of the dunes and coastal ridges, their levelling for construction purposes and their decayed condition due to abandonment of the period which separated the farming phase from the tourist development phase.

At the present time, the major risk would from the increase in the frequency and the seriousness of the storms which is linked to the activation of cyclonic circulations. The great storm of 1982 fortunately acted as an alarm signal for public authorities. A number of actions and control measures was launched, either experimental or definitive in order to reinforce a defense policy which already existed, to respond to the most critical situations. The aim of these actions and measures is threefold: to control tangential transits (rockfill), to help to bring back and to hold the sand on the beach and on the dune (network of semi-permeable barriers, nets, planting schemes, etc.) and to create an obstacle to storms while at the same time maintaining a wide enough strip of usable beach (artificial dunes, dykes for the bottom of the beach, etc.).