

The sand dunes and their vegetation along the Mediterranean coast of France. Their likely response to climatic change

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Abstract

The Golfe du Lion is mainly bordered by low and narrow sand dunes. Since about four decades, 1/3 of its shoreline has been receding, while 1/3 has been prograding and another 1/3 is stable.

Several types of dunes may be described mainly depending on storms, high wind frequencies and sand grain size. Vegetation on dune system is distributed along a primary gradient according to sand stability and soil development, and a secondary gradient along slope of dune according to a seasonal cycle of fresh and salt phreatic water level.

Global changes in climate may influence these geomorphological and biological structures mainly through:

- Winter minimum temperatures changing the distribution of several plant species, especially in the middle part of the Golfe du Lion.

- Frequent high storms which cause damages to the front of the dune systems and disrupt the shore.

Changes in dune ecosystems will be cyclic so these tendencies will be obvious only upon a long term period.

Physiography of the Golfe du Lion

The Golfe du Lion (Fig. 1) forms an arc of about 270 km long. Situated between lat. 42'30' and 43'30' N and long. 3° and 5° east, the Golfe is open towards the southeast. It extends from the crystalline massif of the Albhes in the SW, which creates a deeply indented rocky coast, to the Estaque calcareous chain in the NE. Most of the coast is lagoonal with a few rocky capes (Cap Leucate, La Clape Mts, Cap d'Agde, near the mouth of Hérault river, Mont Saint-Clair at Sète). The Rhône delta is situated on the east of the Golfe. As much as 40% of the shoreline has been formed by the alluvial deposits of the Rhône river.

Present climate

The climate of the Golfe du Lion belongs to the Mediterranean subhumid type with cool to mild winters (Emberger 1945). It has also been called 'transitional,' because it can occasionally display oceanic climate characteristics and more rarely continental ones (Baudière and Emberger 1959). Annual rainfall ranges between 400 and 750 mm with 50 to 95 rainy days a year. Average temperatures range between 14° and 15°C throughout the year.

From the SW to the NE the annual average of the minimum temperatures of the coldest month decreases by +4°C on the Albères coast (Cap Béar) to +0.9°C in Montpellier and it increases to +1.7°C in the Camargue and beyond the Golfe, to

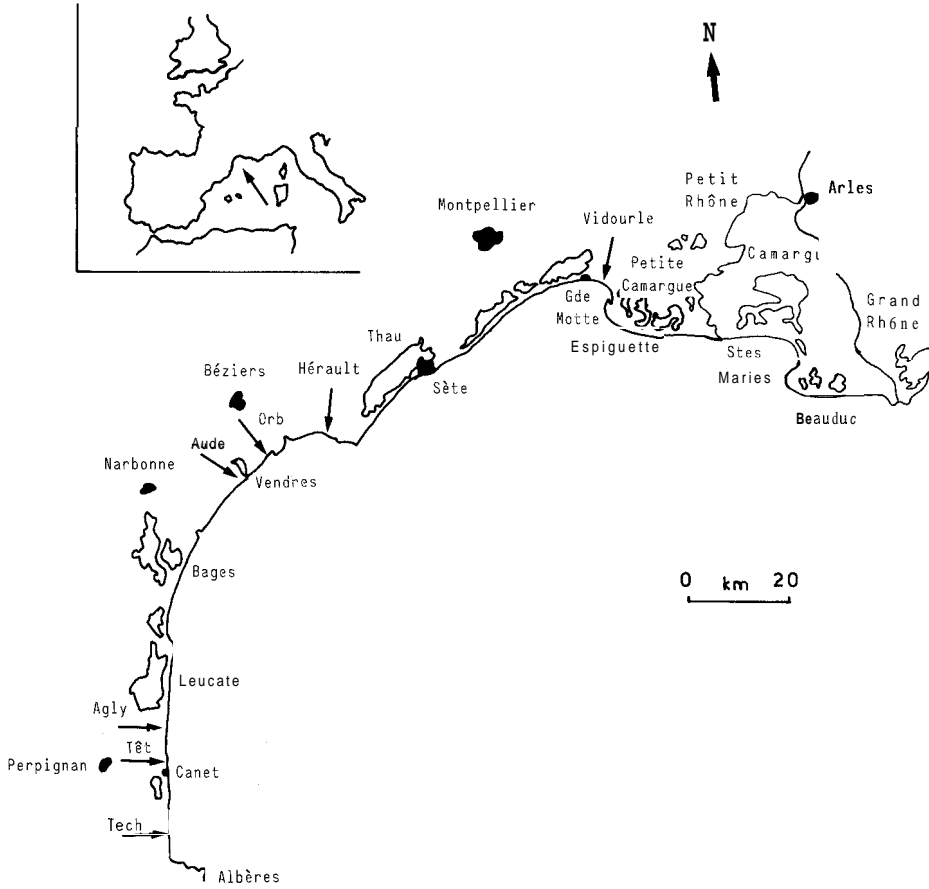


Fig. 1. Golfe du Lion. Arrows shows the place of rivers mouths.

+8°C in Monaco, near the Italian border. The central part of the Golfe coast is thus relatively cold in the winter and this constitutes a barrier from a biogeographic point of view.

Climatic changes have been studied in detail by Daget in Corre *et al.* (1988) on the basis of continuous observations from 1945 to 1987, issued from Camargue (Fig. 1). It seems that rainfall shows periodic fluctuations without any general tendency to increase or decrease. As far as temperatures are concerned, the annual average of the minimum of the coldest month is stable; whereas the annual average of the maximum of the warmest month has been slowly increasing over the two last decades. This general tendency, though, is not obvious owing to variability from one year to another.

In the region of the Golfe du Lion the prevailing winds have a NW-SE orientation with a strong

preponderance in the NW sector. This is of importance for the eolian activities in dune area (Jungerius *et al.* 1989).

Physical structure of the Golfe

The present structure of the coast is the result of the Flandrian transgression and the deposition of fluvial sediments (Monaco 1971). From the north of the Albères to Canet the Flandrian transgression was considerable in the area and caused the formation of a coastal strip with sedimentation in deltas and lagoons.

The frequency of NW winds is 59% at Cap Béar with wind speeds in excess of 8 m s⁻¹ occurring during 39% of the time (Ascensio *et al.* 1987). The frequency of SE winds is 16% with wind speeds in

excess of 8 m s⁻¹ occurring during 7% of the time. Sand is coarse (d₅₀ = 300 to 1500 μ , Clique *et al.* 1984, Greslou 1984). Due to the wind and the size of sand grains, dunes are not fully formed and are only about 1 or 2 m high. They are shaped by waves and flooded by storms.

Further north, to the borders of the Hérault département (pond of Vendres), the coast seems to be more indented with gulfs like those of Leucate, of Narbonne (occupied by the Bages and Vendres lakes). This part of the coast developed rapidly because of alluvial deposits. Through the successive closing of the bays, the coastline became smoother and the lagoons took on their present form. The dune system has a width of a few hundred meters.

Winds are also frequent and high. At Port la Nouvelle (Clique *et al.* 1984), the frequency of NW winds is 50% with wind speeds in excess of 8 m s⁻¹ occurring during 57% of the time. The frequency of SE winds is 10% with wind speeds in excess of 8 m s⁻¹ occurring during 30% of the time. Near Port la Nouvelle, the sand is finer (d₅₀ = 180 μ). Due to the wind velocity and the fine size of sand grains, dunes are low and scattered. The beach is very flat because sand deflated to the level moistened by phreatic water. Around the mouth of the Orb river sand is coarser (d₅₀ = 270 μ), so there we have a linear system of narrow dunes (about 200 m wide) and 5 to 7 m high which are dissected by wind and storms.

Further north, the lake of Thau (43.20° lat., 3.3° long.) is an old gulf now closed by 1 km wide sand bar and lagoon sediments.

At Sète (Ascensio *et al.* 1987), the frequency of dominant land winds is 41% from the NW and 18% from the NE with wind speeds in excess of 8 m s⁻¹ occurring during 15 and 4% of the time, respectively. The frequency of sea winds from the SE is 8% with wind speeds in excess of 8 m s⁻¹ occurring during 6% of the time. Sand is relatively coarse (d₅₀ = 230 μ). The dune massif includes foredunes and behind 'impeded dunes' (in part stabilised by vegetation, Paskoff 1985).

From Sète to the Grande Motte, the coast does not seem to have altered greatly since the Flandrian period (Bazille 1974).

From the Grande Motte onwards, the dune

system has an easterly direction and divides into several sandy ridges spreading out like a fan: lagoons alternate with ridges. This system extends throughout the Petite Camargue and is several kilometres wide. It is abruptly cut off near the Petit Rhône, at right angle to the Saintes Maries by a fault lying perpendicular to the coast. Each one of the sand ridges indicates several stages of a strongly prograding coastline. These structures have been formed since the Flandrian transgression (Bazille 1974). Even now the coastline is prograding as can be seen by the formation of the Espiguette Cape.

Near La Grande Motte (Greslou 1984), the frequency of dominant land winds is 24% from the NW and 23% from the NE with wind speeds in excess of 8 m s⁻¹ occurring during 9 and 4% of the time, respectively. The frequency of sea winds from the SE is 14% with wind speeds in excess of 8 m s⁻¹ occurring during 14% of the time. Sand is fine (d₅₀ = 100 to 200 μ). The dunes (< 10 m) are 0.2 - 0.5 km wide and they are strongly altered by the land winds. The dunes are very diverse. Their height (even though being the highest along the entire coast), does not exceed 12 m. Under the influence of land and sea winds, they are evolving to a string of ellipse dunes (Figs. 2 and 3) or 'hairpin parabola' (Olson and Maarel 1989).

Beyond Saintes-Maries, towards the east, the landscape consists of a mosaic of ponds, earth banks, remnants of dune strips. This landscape is the result of the combined action of fluvio-swamp deposits, predominant in the north and of laguno-marine deposits in the southern areas.

In Camargue (Heurteaux 1969), the frequency of dominant land winds is 40% from the NW with an average velocity of 6.5 m s⁻¹. The frequency of sea winds from the SE is 20% with an average velocity of 5.8 m s⁻¹. Sand is fine (d₅₀ = 100 to 200 μ). Fore-dunes are sparsely distributed.

Main factors of the present dynamic

To summarize, the main factors influencing the morphology of the dunes are the velocity of land and sea winds and the size of sand grains. These two parameters are very diverse along the Golfe du

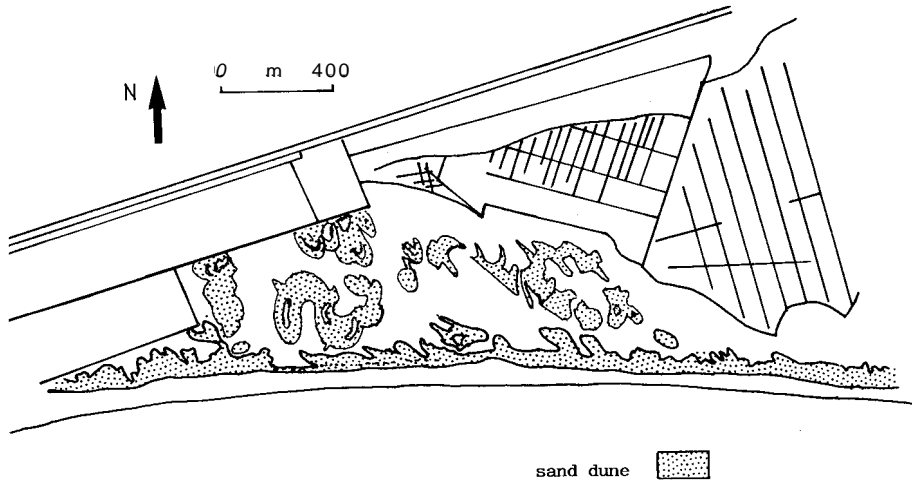


Fig. 2. Strings of ellipse dunes near Grande Motte from an air photograph of 1946. The sea is on the south. Dominant winds are from NW and SE.

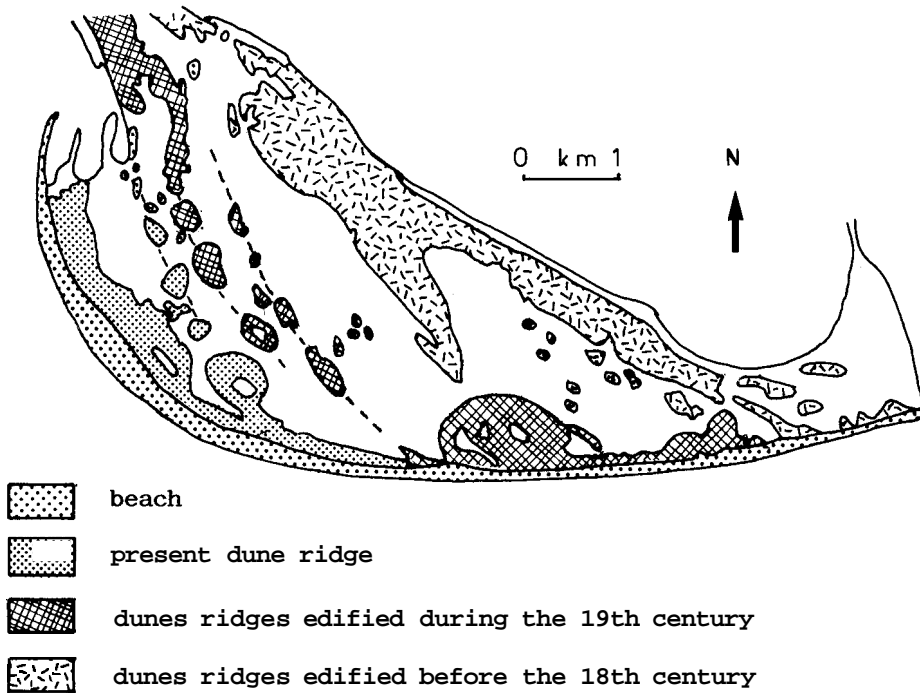


Fig. 3. Dune system at Espiguette, from an air photograph of 1963. This system has developed during the past three centuries. The shore-line progrades to the SW and retreats to the East. The dotted line shows the direction of successive dune ridges.

Lion. Uncommon storms have also an important impact on the dune landscape. Rueda (1985) predicts the probability of a high storm with waves 6.4 m high as being once per century. In 1982 during a storm, waves were 7 to 8 m high and the average level of the sea was more than 1 m higher.

This resulted in major sand formation disturbances (opening channels between sea and lagoons, receding of dunes, filling the wet low grounds between dunes) all along the seashore of Golfe du Lion. In the past, similar high storms were observed (Mouret 1981). One such storm on 4 december 1742

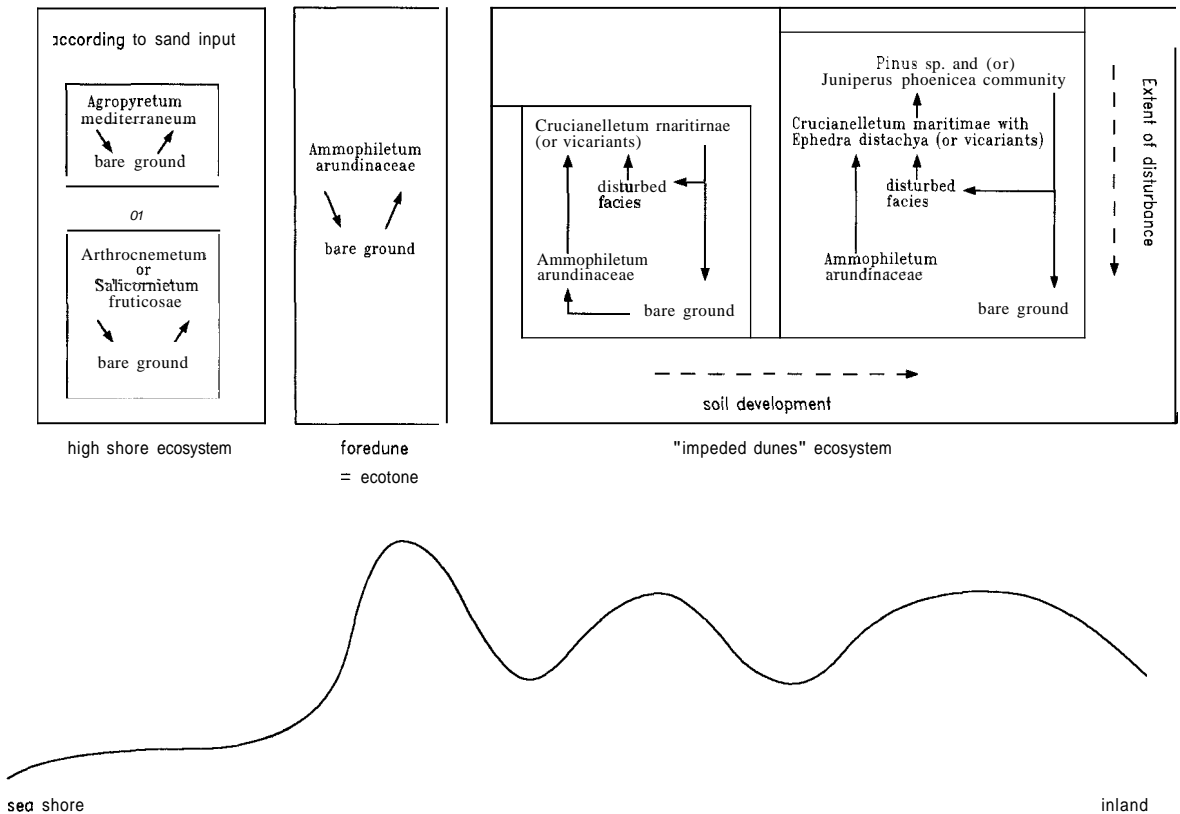


Fig. 4. General scheme of the plant communities structure on dune systems along the Golfe du Lion. Relation with dune structure. Beach and sea are on the left.

broke through the dune barrier near Sète at several locations.

Storms have consequently made construction works (groynes, embankment, etc.) necessary to stabilize the coastline.

A study with aerial photographs made between 1946 and 1977 shows changes of the shoreline of the Golfe du Lion (Corre 1990). The coast accretion (about 30% of the shore) has been mainly found in the SW and its retreat (about 40%) in the NE. Near many river mouths (Tech, Têt, Orb, Hérault, Petit Rhône) the coast has receded. This confirms what Bird (1986) has observed all around the Mediterranean sea; it can be explained by a decrease in sediment deposits like that of the Rhône River (Blanc 1977).

Dune vegetation

It is well known that plant communities contribute to the stability of dunes, so to predict the change of a dune system under future climate change, it is necessary to bear in mind the different patterns of plant distribution from seashore to inland and the factors which influence it.

A general scheme of this pattern for the Golfe du Lion is given in Fig. 4. The high shore ecosystem including the beach and dune foot is influenced mainly by the sea and salt ground water. According to the topography of the beach, different plant communities establish themselves. Often there are only some annuals like *Salsola kali* L. or *Cakile maritima* Scop. subsp. *aegyptiaca* (Willd) Nyman. Between two high storms *Agropyretum mediterraneum* (Kuhn.) Br.-Bl. may settle. Near Port la Nouvelle or in Camargue where the settlement of dunes

geomorphological and soil development gradient

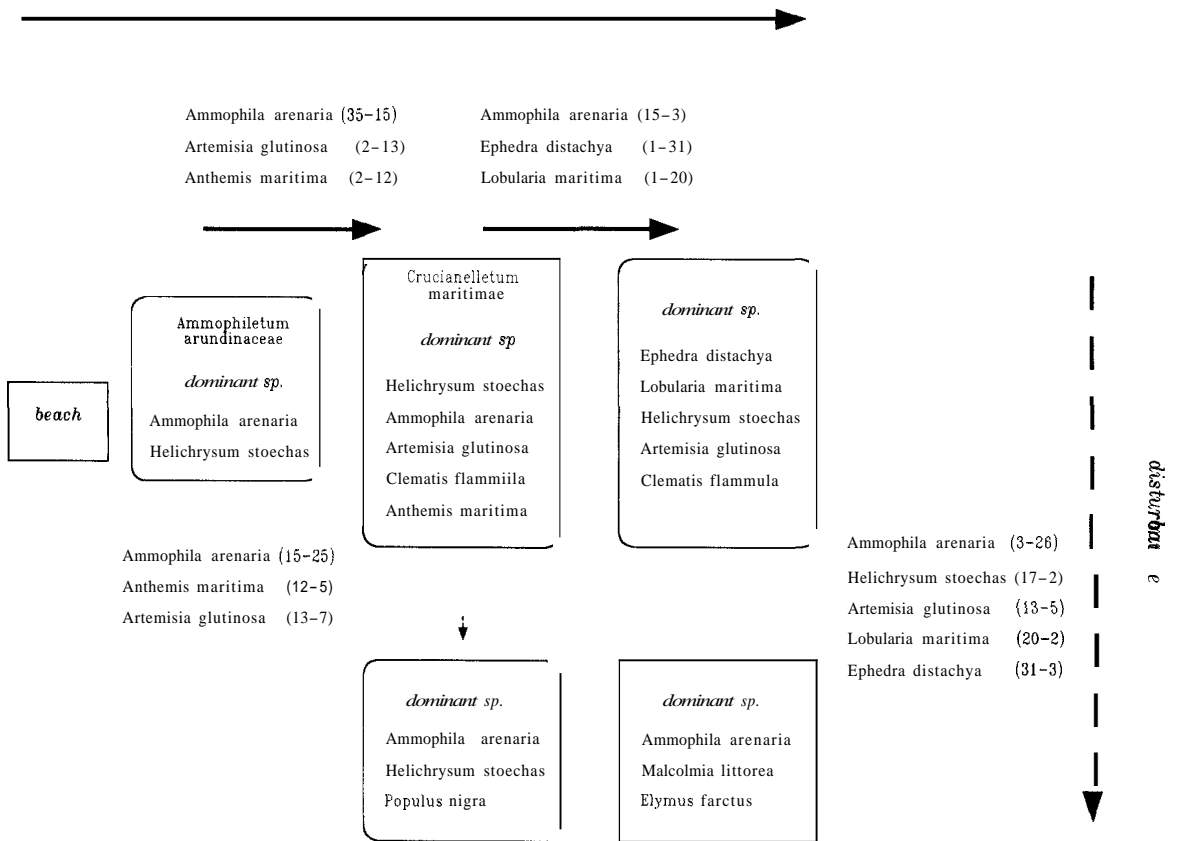


Fig. 5. Scheme of the structure of plant communities on the dune system near Grande Motte (from seashore to hinterland). Numbers in brackets indicate the changes of frequency for some characteristic species. Continuous lines point out the gradient of maturity for communities, dotted lines point out their gradient of disturbance. *Artemisia gallica* = *A. campestris* L. subsp. *glutinosa* (Gay ex Besser) Bott.

is difficult because of high winds and fine sand textures, *Arthrocnemum* Br.-Bl. or *Salicornietum fruticosae* Br.-Bl. are to be found.

The foredune front can be seen as an ecotone between the beach and the 'impeded dunes' ecosystem. Winds bring new sands and high storms erode it. Vegetation belongs to *Ammophiletum arundinaceae* Br.-Bl. Along the shore of Golfe du Lion it is exceptionally a pioneer stage but generally cicatricial and its floristic cover cannot evolve to mature stage on account of wind and storm disturbance.

The diversity of the 'impeded dunes' ecosystem is mainly influenced by winds and soil development. Soil development is less conspicuous than on other

coasts of Europe like the Atlantic coast or the North Sea coasts (Olson 1974). For the dunes near Grande Motte, Pignatti (1959) cannot give any significant value of the mold content. Nevertheless, following Leclerc (1985), there are differences between available inorganic nitrogen in the foredune and in different stages of the 'impeded dunes.' One can distinguish zonations perpendicular to the coastline of plant communities (Fig. 5) which seem to be related to a gradient of soil development (Corre unpublished data). Along this gradient the geomorphological structure (Corre 1990) also changes (Fig. 6). *Crucianelletum maritimae* Br.-Bl. is on dunes in rack form, vegetation with *Ephedra distachya* L. and *Lobularia maritima* (L.) Desv. indi-

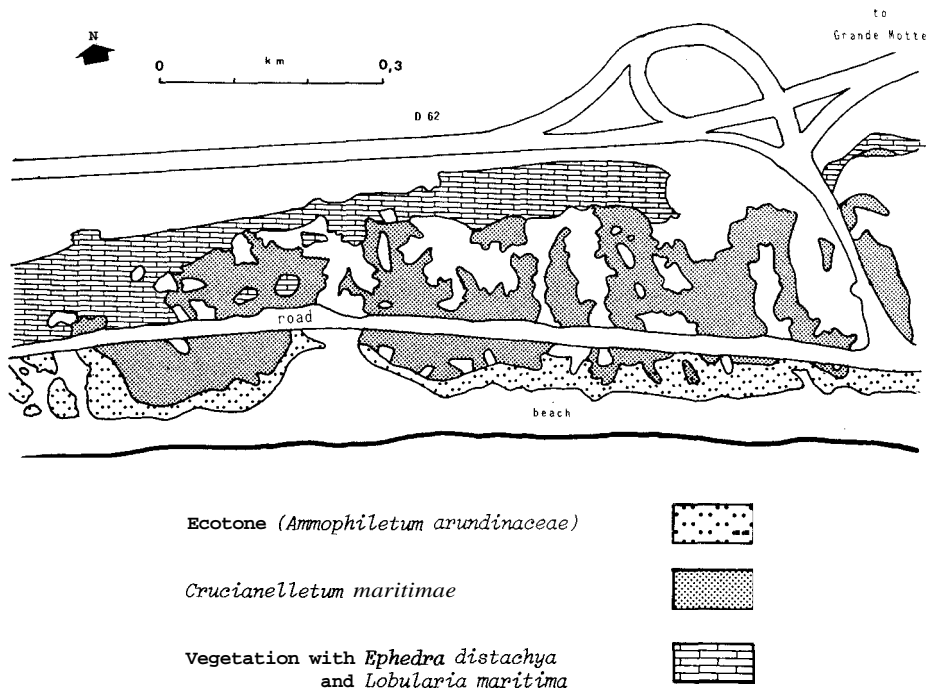


Fig. 6. Distribution of plant communities according to dune geomorphology near Grande Motte. *Ammophiletum arundinaceae* is on the foredune (ecotone); *Crucianelletum maritimae* is on the rake dunes modelled by dominant winds; vegetation with *Ephedra distachya* and *Lobularia maritima* shows evidence of a linear dune which offers resistance to wind.

cates a linear system of dunes. For each of these stages it is possible to describe a facies of disturbance (Fig. 5).

There is a seasonal gradient of fresh and brackish water along lower dune slopes and valley bottoms resulting from seasonal rains and the level of salt phreatic level. Plant communities settle along this gradient if the 'impeded dunes' are sufficiently stabilized. Figure 7 is an example of this phenomenon which shows the seasonal variations of balance between fresh and salt phreatic water (Corre 1976).

Biogeographic structure of Golfe du Lion

According to Gehu *et al.* (1987), for the French coastal environment (including dunes, cliffs and salt marshes), about 422 species or subspecies have been listed. This is about 10% of the French flora. About 16% of this part is formed by species preferably associated with Mediterranean dune systems. These estimates may also be too low.

Several species are near the limit of their climatic distribution like *Anthyllis barba-jovis* L., *Mesembryanthemum crystallinum* L., *Limoniastrum monopetalum* (L.) Boiss., *Cynanchum acutum* L. which does not fructify and have only a vegetative reproduction, *Thymelaea hirsuta* (L.) Endl., *Carpobrotus edulis* (L.) N.E. Br., etc. Some of them, like *T. hirsuta* or *C. edulis* have disjunct distribution areas between Camargue in the north-east and Narbonne in the south-west. It seems that this can be associated with the relatively cold winter in this part of the Golfe (Corre *et al.* 1988). This idea is supported by the fact that species like *Thymelaea hirsuta* (Dommée *et al.* 1984) or *Carpobrotus edulis* are present in the intermediate sector during warmer years. Sbte is a significant climate station because in this cool part of the Golfe some thermophile species like *M. crystallinum*, *A. barba-jovis*, *T. hirsuta*, etc., take refuge.

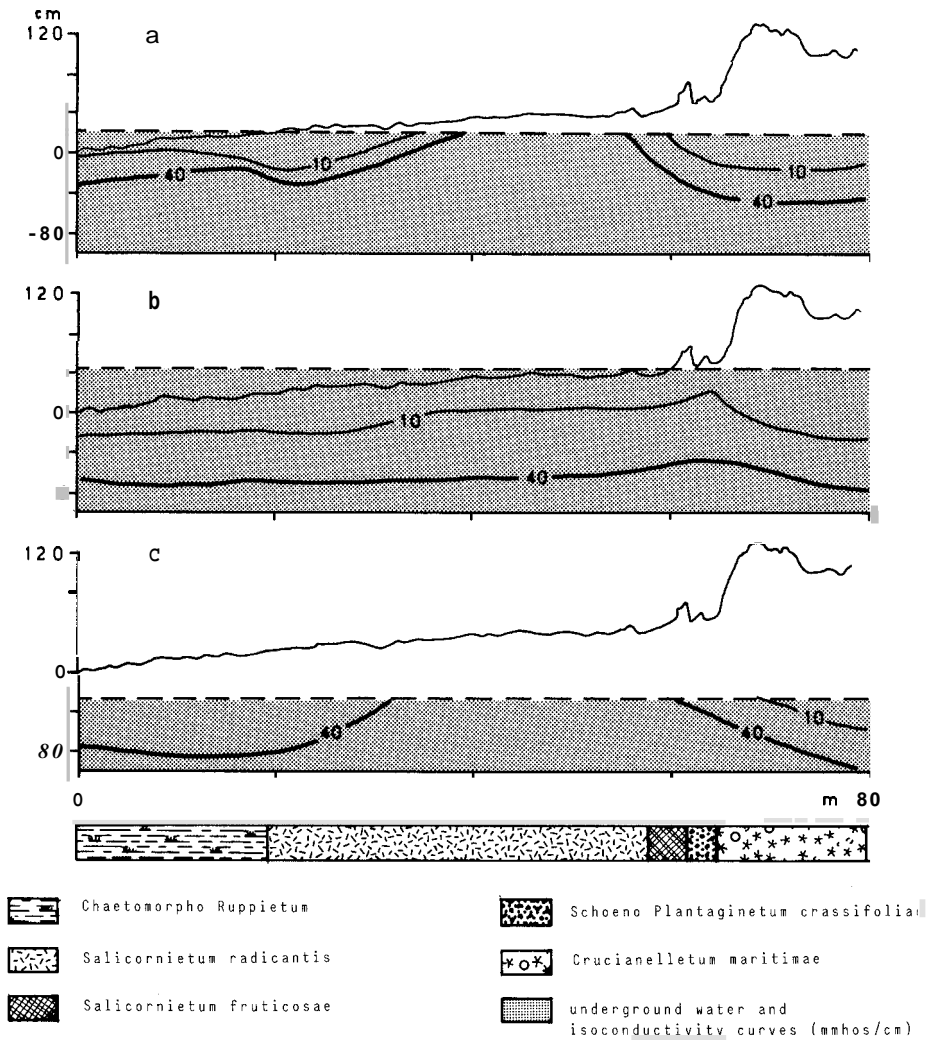


Fig. 7. Section along the slope of a dune near a lagune in the hinterland of Espiguette. a: 21 October 1971; b: 12 May 1972; c: 23 August 1972.

Expected influence of climate change

According to climate models (Bach, 1987), winter temperature would be colder (below 0.5°C than now) with more variability from year to year. Spring and summer temperature would be the same but autumn would be warmer. Winter rainfall would be more abundant than now, but scarcer in summer. Consequently, seasonal differences would increase.

If the global earth climate is warmer, cyclonic activity would be more important. It is what Rognon (1981) described for the warming of climate during

the first part of our century. In the same way, Rueda (1985) notes from 1880 to 1960 a general tendency for waves to be higher. According to local data from 1944 to 1987 (*cf.* Daget, in Corre *et al.* 1988) it appears that systematic changes in temperature cannot be identified since there is considerably year to year variability.

If these climatic changes occur then the following predictions may be made:

a. Changes in plant species distribution

The most important parameter seems to be winter temperature since this affects species mortality. The

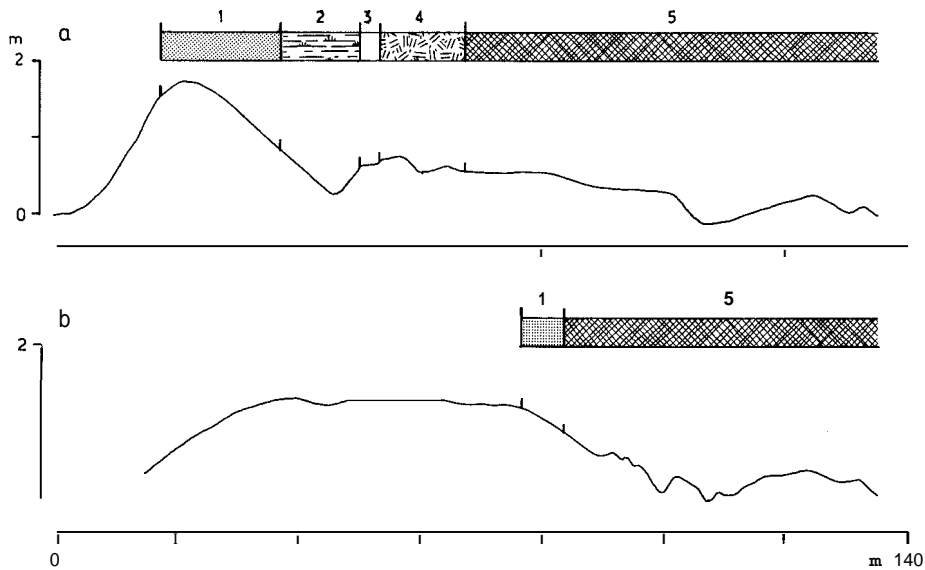


Fig. 8. Survey of a ridge of sand and gravel near Sète before and after a high storm. a: 26 October 1982, before storm; b: 3 May 1982, six months after storm. 1: Plant community with *Anthemis maritima* L. and *Elymus farctus* (Viv.) Runemark (facies of *Agropyretum mediterraneum*); 2: Plant community with *Arthrocnemum fruticosum* and *Carex extensa* Good. (facies of *Salicornietum fruticosae*); 3: Footpath; 4: Plant community with *Halimione portulacoides* and *Juncus acutus* L. (facies of *Agropyreto-Inuletum crithmoidis*); 5: Plant community with *Arthrocnemum fruticosum* and *Juncus maritimus* Lam. (facies of *Salicornietum fruticosae*). In May 1983 facies of *Agropyretum mediterraneum* is a pioneer community which now covers all the bare ridge.

best examples are the fluctuations of *Thymelaea hirsuta* and *Carpobrotus edulis* above mentioned. In the same way, *Crypsis aculeata* (L.) Ait. which is a paleo-subtropical species, is frequently mentioned all along the Golfe du Lion (herbarium of Montpellier and National Museum of Paris). There were several records of occurrences between Sète and Grande Motte up to the beginning of this century, but the last reference was in 1940 (herbarium Braun-Blanquet). Now it seems that the nearest occurrences would be in Camargue in the east (Molinier and Tallon 1974), and Etang de Capestang in the SW of the Golfe, that is to say in parts of Golfe du Lion where winter temperatures are warmer. Perhaps cold years in the past is the reason for changes in its distribution, but we have no direct proof. Care must be taken in regarding this plant as an indicator species since it is also affected by grazing and treading.

b. Geomorphological and plant communities changes

The main risk comes from extreme meteorological events and, particularly, high storms. We have a re-

cent experience of this in November 1982. On low shores, ridges are levelled and plant communities are destroyed. Figure 8 shows the result of such changes. By chance we made a topographic and plant community study with students just before the 1982 storm, and Gignoux (1983) made another one at the same place seven months after.

It was a ridge (about 2 m high) with gravels and sand. After the storm, it was partly flattened and materials were pushed landwards, so the vegetation had been destroyed in front of the beach or buried. For example *Otanthus maritimus* (L.) Hoffmann & Link, which is relatively rare along Golfe du Lion, disappeared from this station after the 1982 hurricane. Seven years later only few individuals have come back. Some communities in the zonation parallel to the shore have disappeared (Fig. 8), like: (1) facies of *Agropyretum mediterraneum*, (2) facies of *Salicornietum fruticosae*, (4) facies of *Agropyreto-Inuletum crithmoidis* Br.-Bl. The second facies (5) of *Salicornietum fruticosae* is in part buried. In May 1983 the community (1) began to settle down again.

In some parts of these low lying beaches, storms

break through the ridges and open up new inlets between the sea and the lagoons.

Even if there is a more substantial dune barrier, these high storms have great consequences: in three days the 1982 storm caused the coast to recede several meters locally. The dune ridge was opened up at several locations. In principle these corridors favour further erosion because sands are transported inland into marshes and thus the material is lost for dune building. On the other hand inland winds blow through the corridor and level the beach, so waves easily reach the foot of the foredunes and erosion is favoured.

In 1959 Pignatti described the result of such an opening through the foredunes near Grande Motte. A salt community develops in the dune hollows. On the 1946 aerial photographs it was not visible, on the 1968 photographs the breach was closed, probably as a consequence of the 1952 storm. At the same place, Hekking (1960) described salt communities with *Halimione portulacoides* (L.) Aellen, *Arthrocnemum fruticosum* (L.) Moq. Now these stations are closed by a road and new foredunes. Salt water does not enter and these species have disappeared.

A geomorphological cycle is possible. For example, at the above location described by Pignatti and by Hekking, the foredune retreated 35 m between 1946 and 1954, advanced 27 m between 1954 and 1968, and retreated again 25 m between 1968 and 1987. This has been observed by using aerial photographs. With such cycles, trends of vegetational and related changes would be difficult to observe except over a long period.

Conclusions

The dunes of the Golfe du Lion are vulnerable because they are low and narrow. They are the more vulnerable because the winds are high and frequent with a direction at a right angle or oblique to the shoreline. Wind erosion favours the development of corridors between the dunes, through which storms can enter. The diminishing sediment deposits will increase the destabilization of the dunes and promote shoreline retreat.

The diversity of sand grain size and wind parameters prohibits the development of a single model of development of the Golfe, so each homogeneous system must be identified by its geomorphological characteristics, and its expected dynamic change be defined accordingly.

If there are changes, they will be obvious through a long term period, perhaps more than half a century. Periodic oscillations which are very likely to happen will obscure changes during shorter periods (of the order of the decade).

There are insufficient results about these ecological and geomorphological oscillations in the dune systems. A close comparison between climatic records, and biological and geomorphological records (unfortunately scattered) must be intensified.

It is obvious that particular conditions in Golfe du Lion will urge wise management, especially with respect to real-estate development which will lead to long-term problems and difficulties.

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