

Impact of Coastal Development on the Infralittoral Zone Along the Southeastern Mediterranean Shore of Continental France

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Numerous waterfront developments built on the sea along the southeastern French Mediterranean coast have resulted in large-scale destruction to the infralittoral zone. A total of 185 development projects, extending over 106 km have been built along the 656 km of rocky shores of the Provence-Alpes-Côte d'Azur region. 30.57 km² have been covered by ports, dikes, land fills and artificial beaches. Because the coast of this region has a very narrow continental shelf (only 314.72 km² between 0 and -20m), every construction on the sea significantly reduces the area where the benthic life is richest. Today a total of 9.7% of the shallow water zone between 0 and -20m and 14.5% between 0 and -10 m have been irreversibly destroyed, covered by waterfront development.

In the past twenty five years, development of the coastal zone in the south east of the French Mediterranean coast (Provence-Alpes-Côte d'Azur region) has increased. In this region (more than 2 million inhabitants on the littoral with more than one million tourists in summer, principal cities Marseille, Toulon and Nice, Fig.1) where tourism is one of the major industries, these constructions are mostly associated with recreational use of coastal waters. So, pleasure boat harbours, semi-enclosed artificial beaches and land fills have been built on the sea. Along the coast of the region, these installations are interspersed with other constructions reclaimed from the sea, such as large commercial and military complexes, some built during the past century. The most important are : the ports of Toulon and Marseille, and the more recently constructed airport of Nice. All these constructions on the sea represent total and irretrievable destruction of the marine life formerly present.

Moreover, the redevelopment of the coast and of the littoral zone causes considerable perturbation of the hydrodynamic equilibrium around the construction site. Furthermore, the ports enclose water bodies extremely polluted due to port activities.

Because the coast of the Provence-Alpes-Côte d'Azur region from the Italian boundary (Menton) to the Rhône delta (Martigues) has a very narrow continental shelf, every construction reclaimed from the sea reduces the habitat just where the benthic life is richest. In this area, the seagrasses *Posidonia oceanica* (L.) Delile and *Cymodocea nodosa* (Ucria) Ascherson are the species most affected by this destruction.

The purpose of this study is to present a complete inventory of the area of development reclaimed from the sea. The total area developed is compared with that of shallow water (0 to -10m and 0 to -20m), for evaluation of its impact on the marine environment.

Methods

In order to calculate the area of the infralittoral zone between 0 and -20 m, and that of installations built in the sea we used a high precision digital planimeter with frequent verifications with an other method. In some sections (where the -20 m isobath was very close to a winding coast line), the charts used were enlarged x 2. The final result was rounded to the nearest 0.01 ha. The area of the zone located between 0 and -20 m was calculated from 28 charts edited by the Service Hydrographique et Océanographique de la Marine (S.H.O.M.). For the calculation of the surface area of the shallow-water zone, only its surface projected on a horizontal plan was measured. In the areas where the shore line was modified, the original configuration of the coast was used. In some cases, very old charts were used to trace the the shape of the original shore line. Thus, the surface area calculated for the shallow-water zone represents its original area before development. The infralittoral shelf between 0 and -10 m, where most of the photosynthesis organisms are present, was differentiated from the 0 to -20m zone (both isobaths were represented in the charts).

For the calculation of the surface area of the constructions, a complete inventory of the works larger than 0.01ha on the coast was compiled. To carry out this inventory, several trips along coast were made as well as several aerial surveys. Furthermore, 140 charts of the developed areas, made by the Services Techniques of coastal communities the Service Maritime des Direction Departementales de l'Equiperment and the Port Autonome de Marseille were consulted. The scale of these charts, ranging

from 1:250 to 1:1000 for the small projects and 1:1000 to 1:5000 for the larger ones, proved to be very practical for the calculations. The aerial photographs allowed for the correction of several charts that were out dated due to redevelopment. Finally, in some cases where the charts were unavailable and the areas of constructions were inferior to 2 ha. the area was measured on sight. For the development in the sea, only the emerged area reclaimed on the sea was considered. The area of the bottom covered by immersed foundations was not measured. In harbours and artificial beaches, the emerged surfaces, sea walls, land fills, dikes etc., were differentiated from enclosed bodies of water. The boundaries of an enclosed body of water were taken to include the shortest distance between the furthest extremities of its sea walls or between the sea wall and the coast.

For the calculation of the length of the natural shore line and that of complexes and installations a high precision digital curvimeter was used. The average of several measurements of the same area was used. These calculations were made using maps of the Institut Geographique National (I.G.N.) and charts of the SHOM with a 1:25000 scale. For the calculation of the linear extension of a developed coast line, the length of the natural shore modified by the construction was measured.

This study began in 1976 with the department of Alpes Maritimes (Meinesz and Lefèvre 1978) followed by the department of Var (Meinesz, Astier *et al.*, 1981), and then the department of Bouches du Rhône (Meinesz *et al.*, 1982). The area occupied by new development was adjusted in 1985 and checked in 1990.

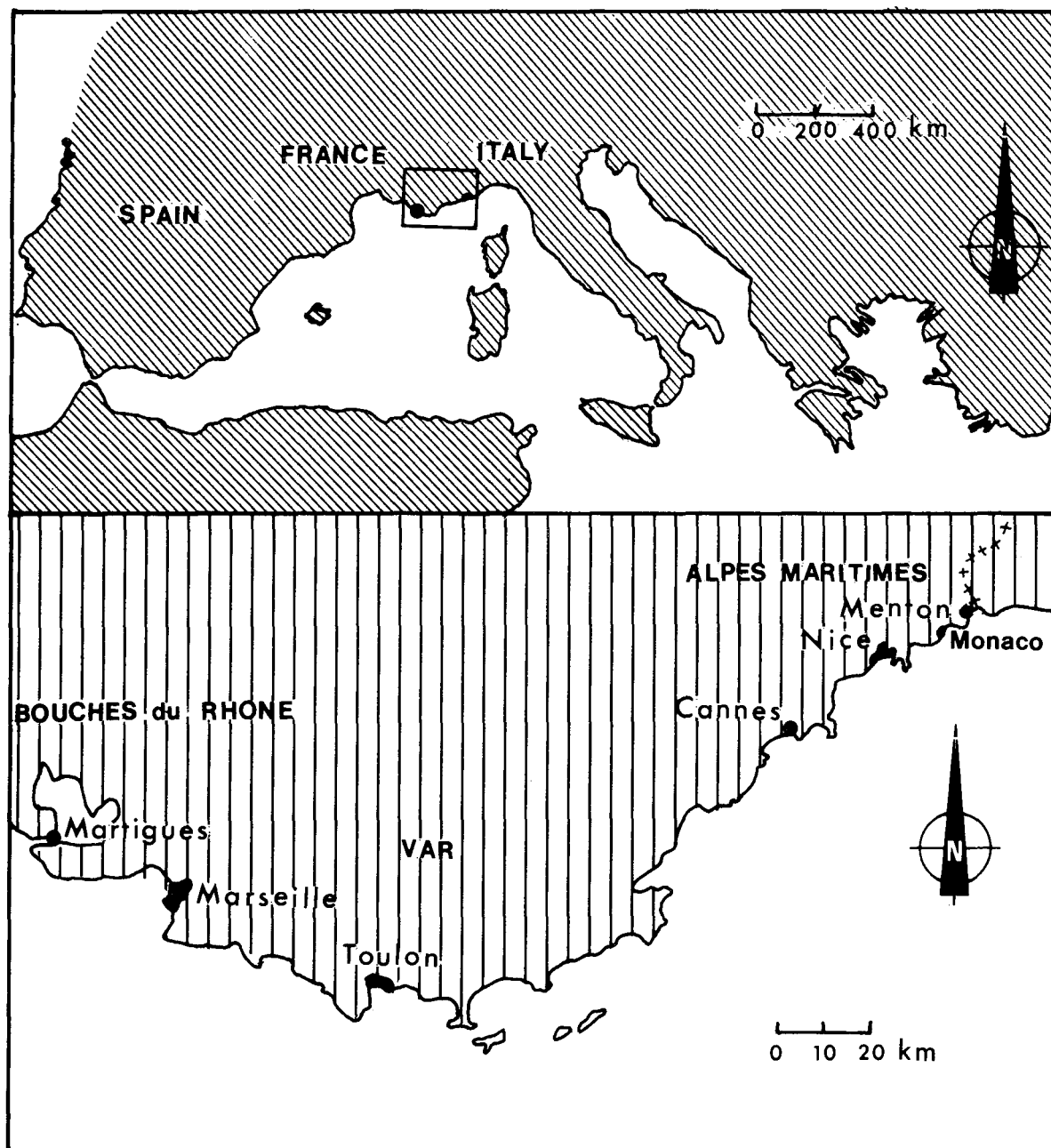


Fig. 1. Localisation of the littoral of the region Provence-Alpes-Côte d'Azur.

Results

Most of the construction in shallow water has taken place in depths between 0 and -10 m, while the zone enclosed between the isobaths 0 and -20 m includes most of infralittoral biocenoses, and includes a major part of the populations of the seagrass *Posidonia oceanica*, the most abundant benthic plant in terms of biomass. On most of the coast of Provence-Alpes-Côte d'Azur, the lower limits of *P. oceanica* beds have not been charted precisely. In places, however, studies on this coast made by diving, side scan sonar and using a submarine have indicated lower limits between -25 and -30 m (Meinesz, Cuvelier *et al.*, 1981). The mostly rocky coast of these region (between Menton at the eastern boundary of France at Martigues at the west of Marseille Fig. 1) shelves steeply. This is reflected in our measurements, giving only 152 Km² between 0 and -10m, 163 Km² between -10 and -20 m (total 315 Km² between 0 and -20m) for the whole 656 Km coast (Table 1). The area occupied by *P. oceanica* has been estimated at 200 Km².

Table 1: Characteristic of the original coast line and infralittoral zone between Menton and Martigues

	Alpes Maritimes and Monaco	Var	Eastern Bouches du Rhône	Total
Original coast line (Km)	119	362	175	656
Original area (km²)				
between 0 and -10m	32. 12	94. 15	25. 51	151. 78
between -10 and -20m	21. 15	110. 15	31. 64	162. 94
Total (0 to -20m)	53. 27	204. 30	57. 15	314. 72

The 185 reclamations on the sea occupy 106 km (16.2%) of the coast line. The impact of this development on the shallow-water environment is twofold. Firstly there is direct, irreversible replacement of the natural environment, and secondly permanent alteration of biocenoses in enclosed waters polluted by human activity. The extent of these two types of damage is given in Table 2.

Reclamations, covering a total of 30,6 Km², have destroyed or seriously altered : 14.5% of the zone between 0 and -10 m; 5.2% between -10 and -20 m and 9.7% between 0 and -20 m.

Most of the destruction of the shallow-water zone is due to the following port and airport development :

- 1 *Nice Airport*. 2.3 Km² of reclaimed land and 0,028 Km² of enclosed water. The entire sandy salt-rich plain formerly to the east of the Var delta has been completely destroyed.
- 2 *Port complex of Toulon-La-Seyne*. 7.3 km² of water surface and 2.2 km² of reclaimed land. The numerous port projects build during the past two centuries in the Bay of Toulon have destroyed or severely altered the seagrass meadows of *Posidonia*, *Cymodocea* and *Zostera*. A chart published by ECOMAIR (1973) shows that seagrass meadows are now absent in the enclosed waters while the meadows described by Bonnet (1927) in the southern part of the port have retreated considerably.
- 3 *Ports of Marseille*. 4.1 km² of reclaimed land and 4,1 km² of enclosed water. This port, built over a century ago, destroyed a very extensive *Posidonia* bed which supported a very productive fishery (Marion, 1883).
- 4 *Yacht harbours*. The recent boom in construction of harbours for pleasure boats (now 65 harbours of a area >2 ha), represents a total area destroyed of 8.2 km².

This development is distributed irregularly, and in certain zones development is very dense. For instance, of the shallow water of the Principality of Monaco, with 5 Km of coast line, more than 75% has been irreversibly destroyed by replacement.

As well as the primary impact of development due to replacement or enclosure of shallow-water areas, secondary impact extends to neighbouring waters. For instance, modification of water movement and sedimentation caused by nearby development can bring about either suffocation of seagrass beds due to increased sedimentation, or else their erosion.

Marked perturbation around a site is frequently noticeable as soon as construction work begins, and certain construction techniques are particularly damaging. When on-site construction materials are insufficiently protected, they are often partially dispersed during winter gales. The fine material often settles on nearby seagrass beds, and may seriously damage them.

Additionally, some types of construction are responsible for particular types of environmental damage. The water enclosed by ports receives large amounts of human waste from ships, detergent, hydrocarbons and leachate from antifouling paint. A more indirect type of destruction is caused by the increase in numbers of both harbours and slipways, leading to greater presence of boats in anchorages near the beaches concerned. These areas receive more and more pleasure boats which

stay in the area several days. In these zones, the physical action of anchoring causes destruction and regression of *Posidonia* seagrass beds.

All these secondary impacts felt in the neighbourhood of projects remain difficult to evaluate, especially with the absence of precise charts indicating the location of different biocenoses before site development.

Table 2 : Inventory of all development reclaimed from the sea : number and total areas.

a : Nice airport; b: Toulon military - industrial complex ; c : Marseille commerce harbour.

Development characteristics	Alpes Maritimes and Monaco	Var	Eastern of Bouches du Rhône	Total
Small harbours (<2 ha)	16 (13.66 ha)	33 (18.16 ha)	20 (12.56 ha)	69 (44.38 ha)
Large harbours (>2 ha)	22 (294.09 ha)	29 (307.35 ha)	14 (167.63 ha)	65 (769.07 ha)
Isolated land fills	7 (18.23 ha)	7 (22.75 ha)	7 (2.01 ha)	21 (42.99 ha)
Artificial beaches	12 (63.26 ha)	7 (52.98 ha)	6 (70.77 ha)	25 (187.01 ha)
Industrial constructions	-- --	-- --	2 (4.39 ha)	2 (4.39 ha)
Very large constructions	1 (a) (231.75 ha)	1 (b) (953.34 ha)	1 (c) (826.41 ha)	3 (2011.50 ha)
TOTAL	58 (620.99 ha)	77 (1354.58 ha)	50 (1083.77 ha)	185 (3059.34 ha)
of which enclosed waters	227.83 ha	924.41 ha	558.28 ha	1710.52 ha
Artificial coast line	28.0 km	42.0 km	36.4 km	106.4 km

Conclusion

1. The total area covered by seafront development, 30.57 km², suggests that this type of physical impact on the marine environment is far the principal cause of destruction or alteration of the littoral underwater flora and fauna in the Provence-Alpes-Côte d'Azur region.

2. The principal characteristic of this impact is its irreversibility. It would be utopian to imagine that one day development achieved will be removed to reconstitute the pre-existing benthic communities. The narrow littoral zone, in which are concentrated a large proportion of the local species, has been seriously reduced in area, and also secondarily impacted by construction on the sea.

3. In the Mediterranean, a component essential for littoral, underwater life comprises *Posidonia oceanica* meadows, which cover the greater part of depths from 0 to -30m in the studied region. These meadows are : (i) destroyed by development involving reclamation, which replaces them; (ii) altered or destroyed around development projects involving reclamation either because of modification in the nature of water movement or because they are smothered by sediment, originating from building materials, which is washed into the sea; (iii) lastly urban wastewater results in local destruction around outfalls, and more large destructions in the deeper parts of the seagrass depth range due solely to an increase in turbidity.

The biological characteristics of *P. oceanica* are not conducive to rapid recolonization of their environment: sexual reproduction (seed-germling) has only been observed in the Mediterranean very exceptionally; natural transplantation is not common, with only an estimated 3 successful transplants per hectare per year. Finally horizontal growth of rhizomes from the edge of an existing bed is very slow, only 3 cm per year. It would thus take 3000 years for the plant to recolonize a 100m wide band of shallow water, where it might have lived only several decades previously, before being decimated by a short period of pollution.

These findings led to a law being recently (1988) passed to halt destruction due to replacement of plant communities essential to the littoral biota. This law protects *Posidonia oceanica* and *Cymodocea nodosa* from all destruction. All construction projects on seagrass meadows have been prohibited. Lastly, research has been initiated to develop transplantation techniques for *P. oceanica* in order to speed up the natural, but slow, process of recolonization in environments formerly damaged but where conditions have been improved.

4. In order to reduce irreversible destruction, a maximum occupation threshold should be fixed for shallow (0 to -10m) waters. Alternatives, however, will have to be found so as not to damage expansion due to tourism and industry. Yacht harbours should have their "dry" storage parts built ashore, and ports built offshore in waters deeper than -50m would be less damaging to the littoral environment.

5. Nothing has been envisaged for the immediate future to reduce pollution in harbour waters, such as that due to waste water, hydrocarbons and leachate from antifouling paints, and the eutrophication of enclosed water bodies. At present harbour water remain untreated, while all waterfront municipalities now spend considerable sums town treating the greater part of their waste waters. Yacht harbours thus represent, in the short term, one of the principal sources of pollution in the littoral of Provence-Alpes-Côte d'Azur.

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