Environmental and Biological Changes Related to Recent Human Activities in the Mar Menor (SE of Spain)

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The Mar Menor is a mediterranean hypersaline coastal lagoon that supports important fisheries and is the object of an intense tourist development. The effects of recent human activities in the Mar Menor, including enlargement of a channel of communication with the open sea and dredging and deposition of sand to make beaches, are studied. Some of these effects are colonization by new marine species, the spreading of stands of *Caulerpa prolifera* and increase of silt-clay fraction and organic carbon in the sediments. Some of these processes result in fall in the fisheries stocks of some species and in a decreasing attractiveness for tourists in the area.

In coastal lagoons, human activities and developments include fisheries, aquaculture, tourist and recreational, scientific and educational. In spite of this, lagoonal ecosystems are also used as receptacles for wastes, which cause accelerated degradation of these systems (Barnes, 1980; Paskoff, 1985).

The Mar Menor is a hypersaline coastal lagoon of 135 Km^2 surface area, located on the SE coast of Spain, and connected with the adjacent Mediterranean Sea through five shallow channels. Traditionally, it has supported important fisheries (grey mullets, sea breams, prawns, etc.). Recently, the broad outlines of the evolution of the Mar Menor, have been reconstructed (Perez-Ruzafa *et al.*, 1987) and some of the cause-effect relationships have been established.

Human activities have exerted an increasing influence on the lagoon evolution. Ploughing of the surrounding catchment, and deforestation in the 13th to 18th centuries lead to an increase in sedimentation rates from 30 to 40 mm/century and recently to 30 cm/century, with a resulting reduction in lagoon size (Simonneau, 1973; Perez-Ruzafa *et al.*, 1987). Mining activities which go back to 2000 B.C. and continued dumping of wastes from mineral washing until the mid 1950s, with the resulting increase of heavy metals levels in sediments (Simonneau, 1973), also contributed to this process.

In recent years, tourist activities have increased their influence on the lagoon environment through the proliferation of coastal settlements, sports harbours and reclamations. Most important include the deepening of a shallow channel (El Estacio) connecting the lagoon with the Mediterranean in the early 1970s for the construction of a harbour and a navigable channel, and more recently (since 1987) a policy of creation of artificial beaches from dredging for sediment extraction and deposition of sand along the coast.

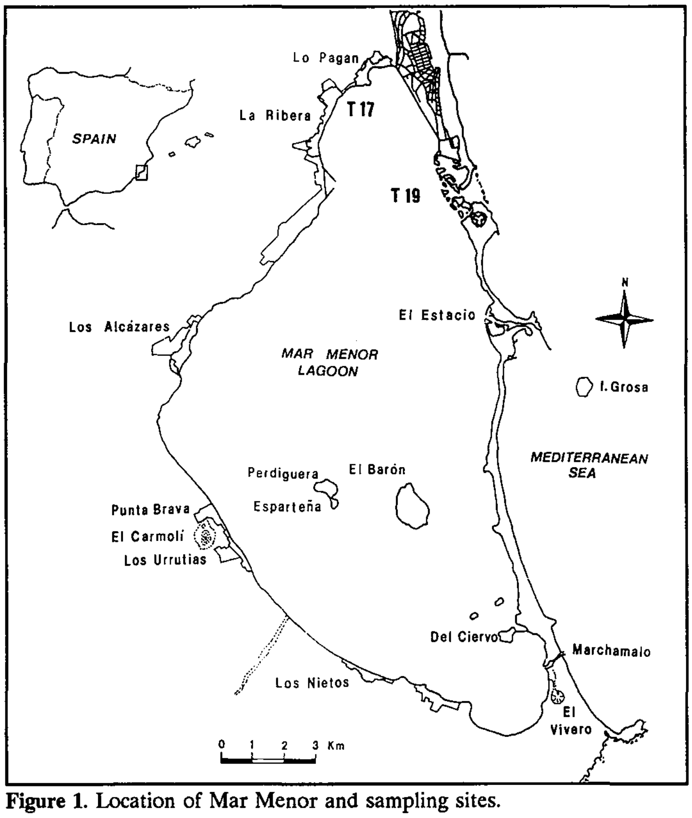

Figure 1. Location of Mar Menor and sampling sites.

Material and Methods

The status and evolution of benthic assemblages in the Mar Menor after the enlargement of El Estacio channel have been reported in several works (Ramos & Pérez-Ruzafa, 1985; Pérez-Ruzafa & Marcos, 1987; Pérez-Ruzafa *et al.*, 1988, Pérez-Ruzafa, 1989 and Pérez-Ruzafa, *et al.*, 1990). Information about previous conditions is scarce but it can be reconstructed from data in Butigieg (1927), Navarro (1927), Lozano (1954, 1969) and Simonneau (1973). Salinities and temperature have been measured in different stations in the lagoon and during the year (Pérez-Ruzafa, 1989). The water interchange rates with the open sea have been estimated by the application of the conservation principles of the volume and salt (Pickard & Emery, 1982).

For the study of the effects of dredging and deposition of sand, the dredged areas on the

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NE zone of the lagoon and the site of creation of the beach in Lo Pagán (Fig. 1), were monitored before and during two years after the actions.

Sediment samples were collected by diving and subsequently they were air-dried. Organic matter was estimated by the Walkley & Black method (Buchanan, 1984). Particle size analysis was made by the Boyoucos densimeter method (Day, 1965) after than salts and organic matter were removed.

The productivity of microphytobentos was estimated *in situ* by mean of plexiglass incubation vessels by the ^{14}C method (Varela, 1985). Measures have been made in the upper centimeter. During incubation the vessels (two transparent and one opaque) remained buried so the upper surface of the enclosed sediment was at the same level of that of the surroundings.

Results

The enlargement of El Estacio channel has involved an increase in the interchange rates between the lagoon and sea. Although the volume interchanged is related to the balance between evaporation and precipitation, in years with a similar balance, as in 1970 and 1980, the volumes interchanged are approximately 1.8 times bigger in 1980 than in 1970. This has resulted in a smoothing of the extreme temperatures, mainly the lower ones, and an important decrease in salinity (table I), which has permitted the colonization of new, marine species.

Table I. Evolution of some environmental and biological features in the Mar Menor before and after enlargement of El Estacio channel (1973).

	1970	1980	1988
outflow of water to the Mediterranean (m^3)	$3.6x10^8$	$6.1x10^8$	$6.4x10^8$
inflow of water from the Mediterranean (m^3)	$4.5x10^8$	$7.2x10^8$	$7.3x10^8$
residence time (years)	1.28	0.81	0.79
salinity (%.)	48.5 - 53.4	43 - 46	42 - 45
Temperature (°C) (1971/1981)	7.5 - 29	12 - 27.5	12 - 30.5
organic carbon in muddy bottoms (%)	0.69 - 2.9	2.19 - 5.7	2.19 - 5.7
main benthic macrophytic meadows	Zostera-Cymodocea	Caulerpa-Cymodocea	Caul.-Cymod.
number of phytoplanktonic species	32	307	-
number of mollusc species	30	72	106
number of fish species	38	63	67

In the last 15 years, the number of species of molluscs and fishes have had a twofold increase. The meadows of *Zostera* sp, *Cymodocea nodosa* and scarce patches of *Posidonia oceanica* have been replaced by mixed beds of *Cymodocea nodosa-Caulerpa prolifera* or monospecific stands of *C. prolifera* on muddy bottoms and scarce stands of *C. nodosa* on sandy bottoms (Pérez-Ruzafa *et al.*, 1989). The spreading of *C. prolifera* is still in progress and it is colonizing also rocky substrates. Changes in vegetation cover have involved changes in the sediment nature, with an increase in the organic matter content of muddy bottoms. At the same time, dissolved oxygen in the water at the bottom level decreases nearly to zero in muddy areas with dense plant cover (Pérez-Ruzafa, 1989).

Related to these changes has been an important fall in the fisheries stocks of some of the more relevant species (mainly Mugilidae and *Sparus aurata*) (Fig. 2).

A similar effect took place at the end of 19th century when a serie of storms broke the sandy bar between the lagoon and the Mediterranean Sea, and at the same time an artificial channel (Marchamalo) was opened. As results of this, the stocks of Mugilidae became reduced while new colonizing species (Sparidae) became common.

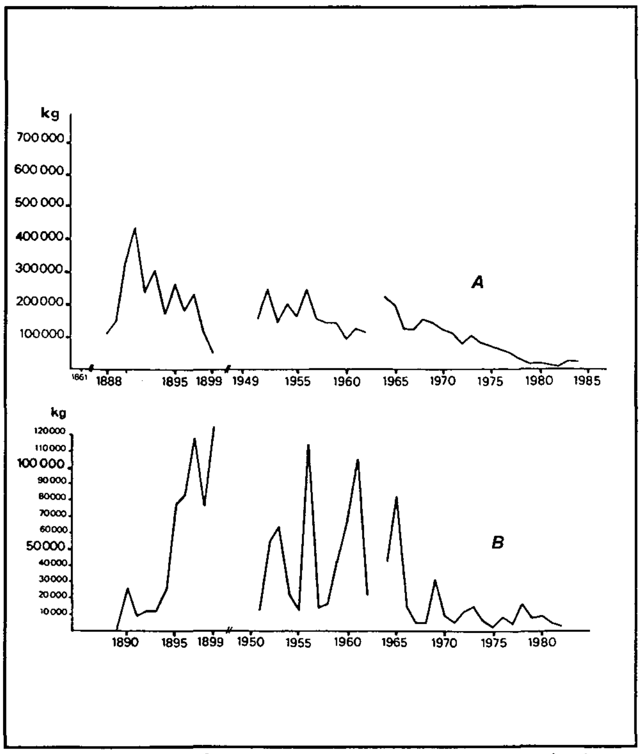


Figure 2. Evolution of the catches of the main fishing species in the Mar Menor lagoon. A: Mugilidae; B: *Sparus aurata*.

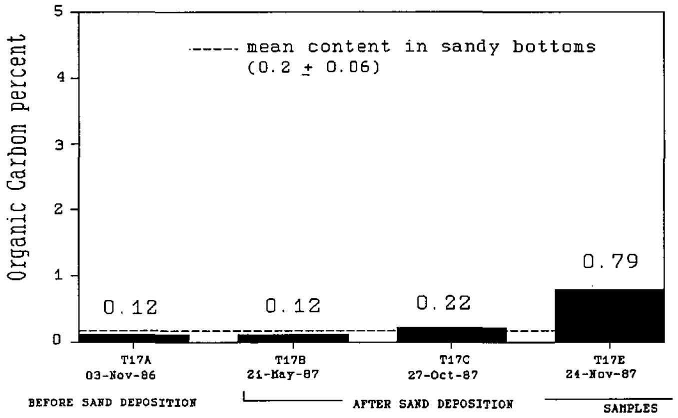


Figure 3. Time change in the organic carbon content in the sediments at Lo Pagan beach (T17).

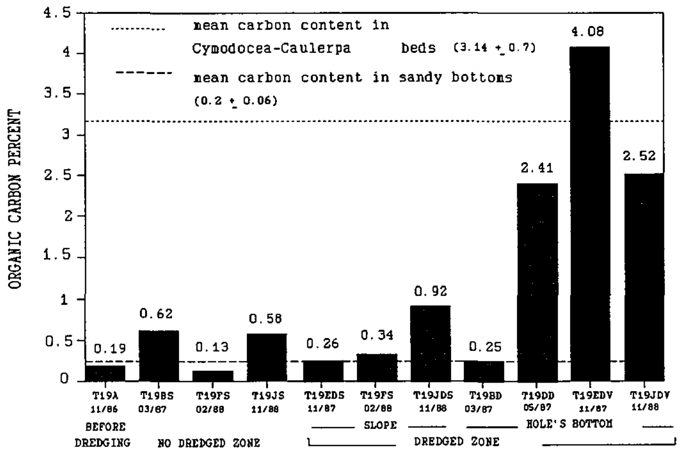


Figure 4. Time change in organic carbon content in sediments at the dredging zone: non-dredged areas (T19-S) and dredged holes (bottom T19-DD/V and slope T19-DS).

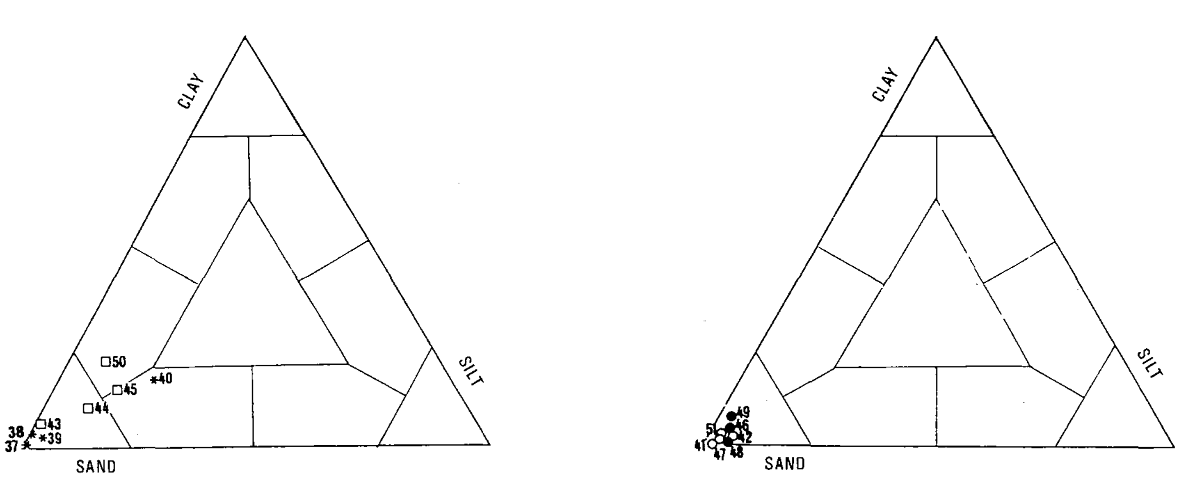
On the other hand, dredging and filling-in of beaches, shows some aspects in common with processes described above. Before this human activity both dredged areas and beach were sandy, with low silt and clay and in organic matter contents. After the beach nourishment at Lo Pagan beach the organic carbon content of the sediments showed a gradual increase related to a progressive rise of the silt-clay fraction (Figs. 3-5).

In contrast, sediments adjacent to the dredged area (T19-s) remained nearly constant, both in particle size and in organic carbon content.

Inside the dredged holes, in less than 2 months after dredging, the organic carbon content at the bottom rose from 0.25 %, characteristic values of the sandy sediments, to 2.41 %, corresponding to muddy bottoms with *Cymodocea-Caulerpa* meadows. This values increased twofold in one year to drop again to 2.52 % one year later.

At the slope the increase of organic matter is slower. As above, the gain in organic matter is related to an increase in silt-clay fractions.

The stress and the nutrient release caused by remotion and deposition of sediments favours the development and implantation of stands of *C. prolifera* and masses of *Chaetomorpha linum*. The status of dredged area (T-19) at the end of the study is showed in figure 6. Progression of *C. prolifera* and colonization by mean of rhizomes, starts from the nearest meadows that occupy the central basin of the lagoon. The cover percentage of this algae decrease towards the shallow waters. On the other hand, floating masses of *Ch. linum* are holded and develops inside the holes, mainly in those that are in shallowest areas.



* 37 T17A (11/86)	□ 43 T19BD (03/87)	o 41 T19A (11/86)	• 46 T19EDS (11/87)
* 38 T17B (05/87)	□ 44 T19DD (05/87)	o 42 T19BS (03/87)	• 48 T19FDS (02/88)
* 39 T17C (10/87)	□ 45 T19EDV (11/87)	o 47 T19FS (02/88)	• 49 T19JDS (11/88)
* 40 T17E (11/87)	□ 50 T19JDV (11/88)	o 51 T19JS (11/88)	

Figure 5. Samples in the textural triangle. Note evolution in silt-clay fraction content at Lo Pagan beach (*) and dredging zone (non-dredged area (o) and holes: bottom ([]/T19-D), bottom after colonization by vegetation ([]/T19-DV) and slope (o/T19-DS).