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Results of the problem based science analysis

3.2.2) The Mar Menor Lagoon, Spain

Integrated water resources and coastal zone management in European lagoons in the context of climate change

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Author(s): Lloret J, Velasco J, Bello C, Marín A, Department of Ecology and Hydrology. University of Murcia. Spain	
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Contents

1. Introduction

1.1. General description of the Mar Menor lagoon

The Mar Menor is a hypersaline coastal lagoon located in a semi-arid region of southeast Spain (Figure 1). The lagoon occupies a surface of approximately 135 km^2 and a total volume of $610x10^3$ m^3 (Arévalo 1988). Maximum depth in the lagoon reaches 6.5 m with an average depth of 3.6 m. According to the geomorphological classification of Kjerfve (1986), the Mar Menor constitutes a restricted littoral lagoon relatively isolated from the adjacent Mediterranean Sea.

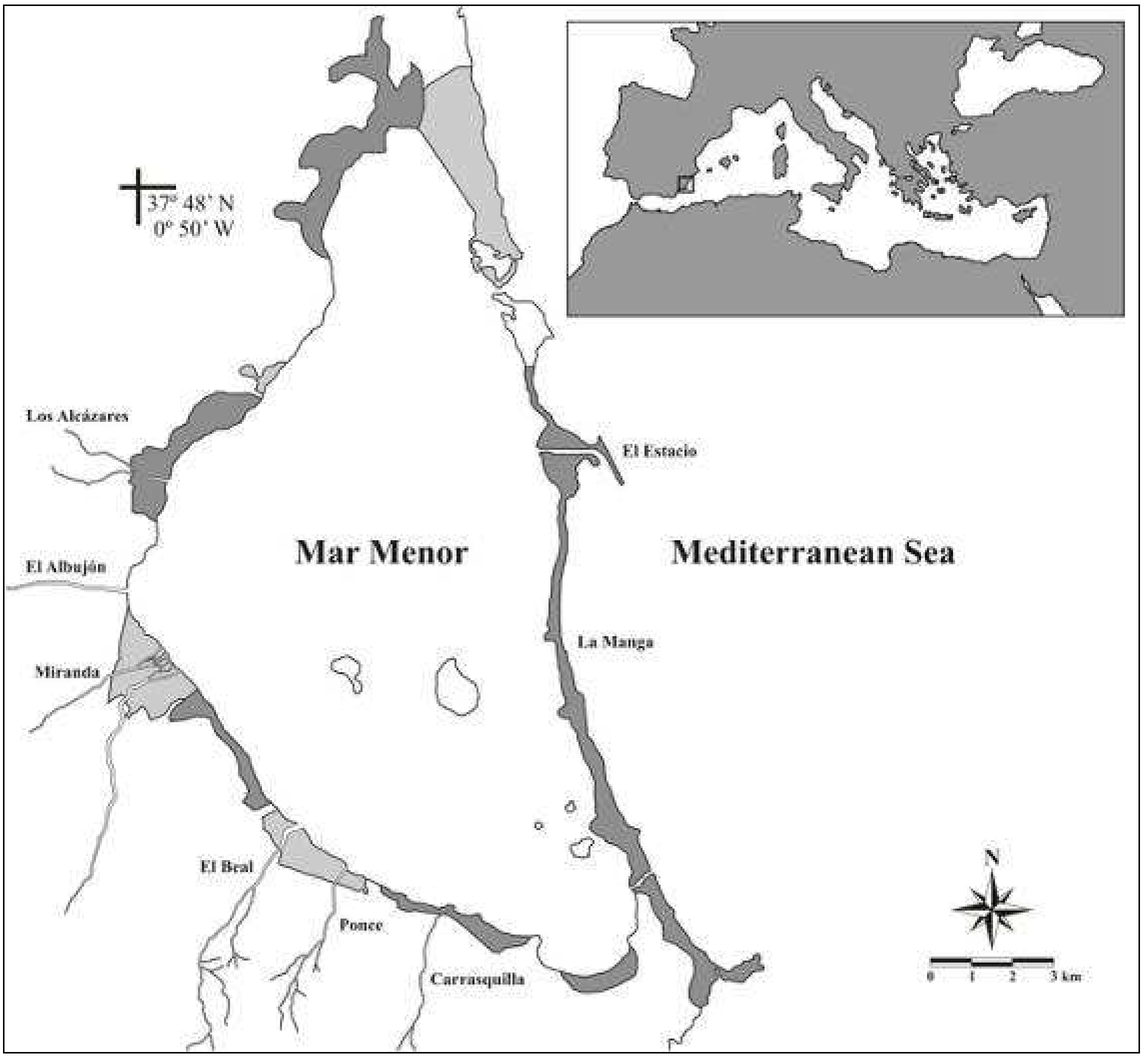

Figure 1. Map of the Mar Menor coastal lagoon showing the location of the main urban areas (dark grey), salt marshes (light grey) and watercourses.

The lagoon is isolated from the Mediterranean Sea by a 22 km long and 100 to 900 m wide sandy bar (La Manga), crossed by three shallow channels (Marchamalo, Encañizadas del Ventorillo y La Torre and El Estacio). In the early 1970s, one of these channels (El Estacio) was dredged and widened to make it navigable. Since then, it has become the lagoon's main connection with the sea. The enlargement of El Estacio channel led to a substantial increase of water renewal rates from the Mediterranean, as well as subsequent changes in water temperatures and salinities. These changes favoured the colonisation of the lagoon by numerous marine species as lagoonal temperatures and salinities reached less extreme values (Pérez-Ruzafa et al. 1991). Nowadays, salinity ranges from 42 to 47 and temperatures are less extreme ranging from 10º C in winter to 30º C during the summer.

The lagoon is situated at the end of a watershed delimitated by a group of mountain ranges (Escalona, Algarrobo, Cartagena) that surround the Campo de Cartagena, an extense plain of about 1,440 km^2. Freshwater inputs into the lagoon are restricted to six ephemeral watercourses called 'wadis' or 'ramblas'. These wide, shallow gullies are generally inactive, but can carry great quantities of water and sediment during flood episodes. The torrential nature of the supplies is aggravated by the impermeable soils and scarce vegetation cover of the watershed areas (Figure 2).

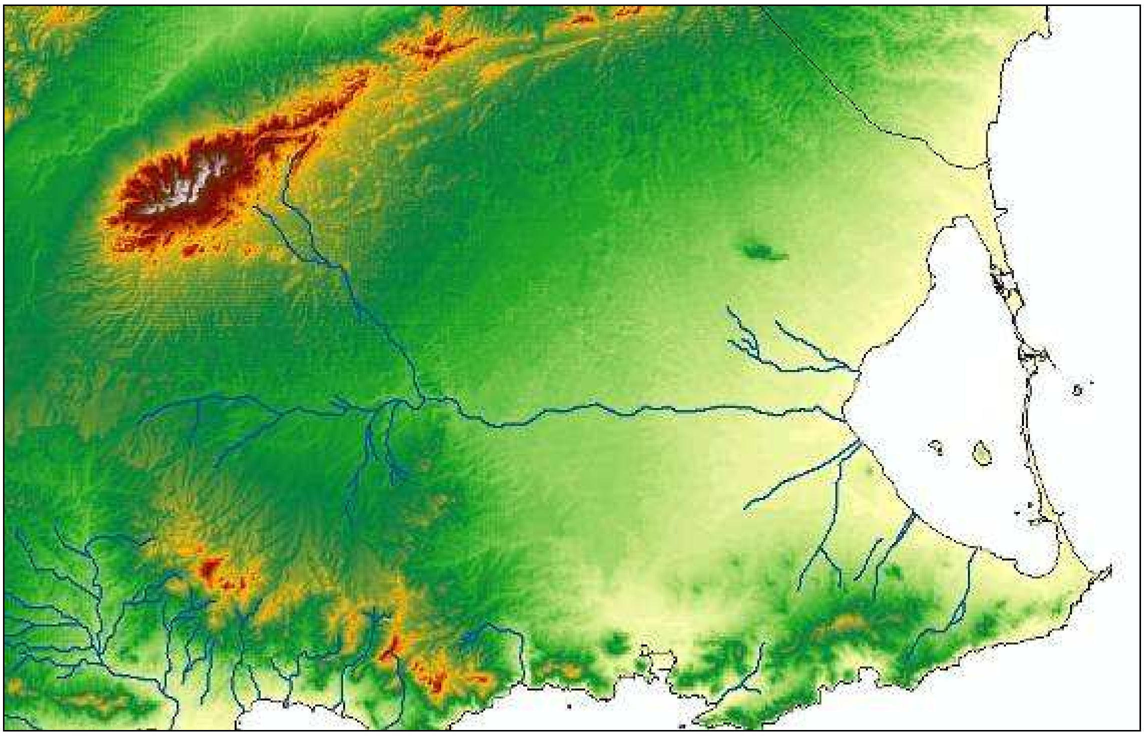

Figure 2. Digital Elevation Model of the study area showing the main mountain ranges and wadis.

El Albujón wadi is the principal watercourse responsible for major inputs of organic and inorganic nutrients that flow into the lagoon (Velasco et al. 2006, García-Pintado et al. 2007). It drains a surface of 441 km^2, about one third of the total surface of the adjacent agricultural area (Campo de Cartagena). The principal source is drainage from irrigated crops, but sometimes waste-water treatment plants located in the watershed area discharge large amounts of untreated or insufficiently treated water into the channel.

1.2. The Mar Menor natural values

The Mar Menor lagoon constitutes one of the most singular and studied environments in the region. Its values in terms of biodiversity have been recognised by numerous protection schemes. At a regional level it is a Regional Park and Protected Landscape. It has been a Ramsar International site since 1994; it is considered a Special Protected Area of Mediterranean Interest (SPAMI) established by the Barcelona Convention in 2001; and a Site of Community Importance (SCI) to be integrated in the Nature 2000 Network (EU Habitats Directive). This zone is also a Specially Protected Area (SPA) for the nest building, migration and wintering of aquatic birds, and is protected by European legislation (Birds Directive 79/409/CEE).

The high protection status of this coastal lagoon is due to the value of its natural environment. A total of 179 water bird and 46 fish species have been sighted in the area. It also comprises 23 habitats of Community Importance, of which nine are considered as Prioritaries.

Many water bird species use the lagoon and its associated salt marshes. Fifty water bird species have been included in Annex I of the Birds Directive 79/409/CEE. Twenty species use the area for nest building. With regard to wintering and migration, approximately 10000 birds have been estimated during January and 5000-6000 during their migration from September to October.

The fish community in the Mar Menor lagoon is also represented by a high number of species. Many of these species are of commercial interest, such as the cyprinodontid fish *Aphanius iberus*, since they constitute an important food resource for other species such as water birds; but they also serve as indicators of the overall ‘health’ of the lagoonal environment. Mugilidae fish species are the most important ones in terms of abundance and biomass but many other species are represented in the lagoon.

1.3. Recent environmental changes in the Mar Menor lagoon

The enlargement of El Estacio channel led to a substantial increase of water renewal rates from the Mediterranean, as well as subsequent changes in water temperatures and salinities. These changes favoured the colonisation of the lagoon by numerous marine species as lagoonal temperatures and salinities reached less extreme values (Pérez-Ruzafa et al., 1991).

One of the main events in relation to this 'Mediterraneanisation' process was probably the colonisation of the lagoon by the invasive alga *Caulerpa prolifera* (Forsskal) Lamouroux. Historically, the principal benthic macrophyte was the phanerogam *Cymodocea nodosa* (Ucria) Ascherson. During the early 1980s, only a few years after the enlargement of El Estacio channel, the bottoms were covered by a mixed meadow of *C. prolifera* and *C. nodosa*. At the present time, a dense monospecific bed of *C. prolifera* covers most of the bottom of the lagoon, and the distribution of *C. nodosa* is restricted to very small patches in the shallowest areas (Lloret et al 2005) (Figures 3 and 4).

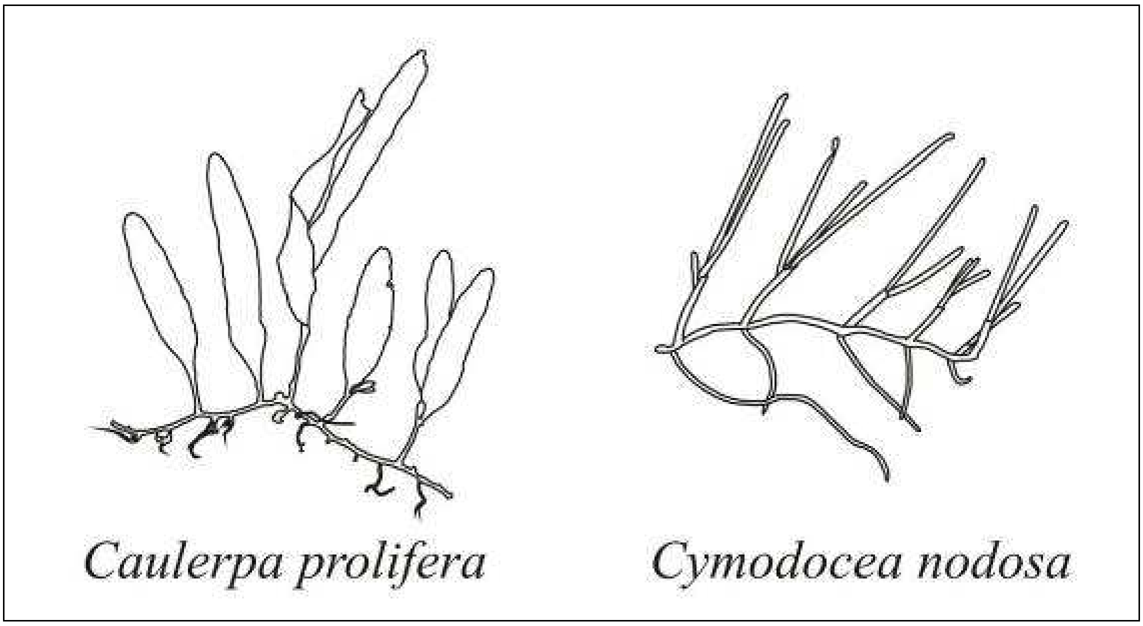

Figure 3. A schematic representation of the talli of the main macrophyte species *Caulerpa prolifera* (Forsskal) Lamouroux and *Cymodocea nodosa* (Ucria) Ascherson inhabiting the bottoms of the Mar Menor lagoon.

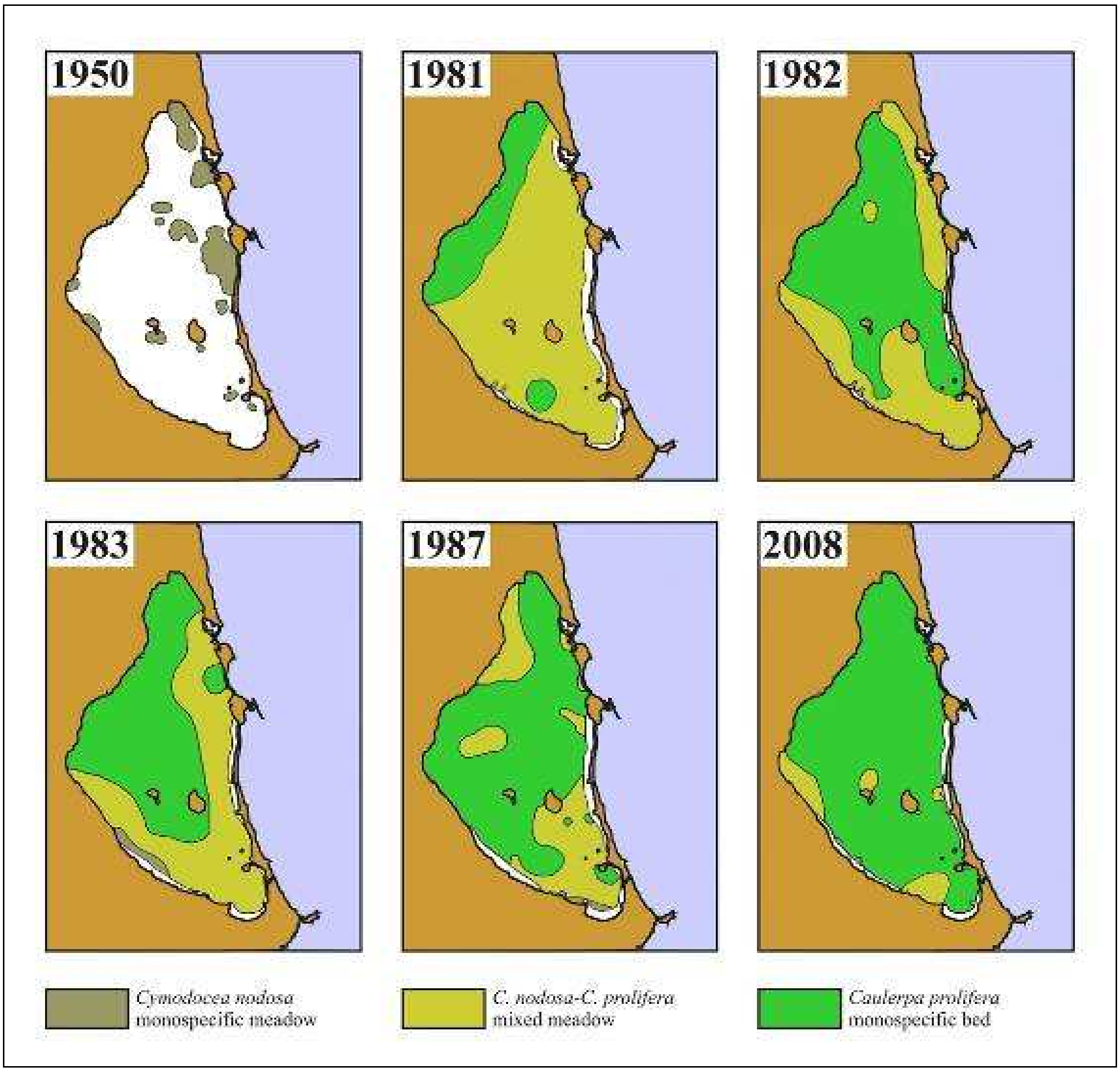

Figure 4. Evolution of the coverage of the bottom by the main macrophytes in the Mar Menor lagoon (Redrawn and adapted from Lozano, 1954 and Pérez-Ruzafa et al., 2009).

Historically, external nutrient inputs to the Mar Menor were mainly via groundwater and atmospheric deposition, in part due to the high ratio of sediment surface area to water volume and lack of major watercourses. However, as in many other Mediterranean coastal zones, the area surrounding the Mar Menor has experienced an intensification of agricultural practises and marked increase in tourist activities that have resulted in increased nutrient inputs to the lagoon.

The distinctive environment of the lagoon has long been attractive for visitors, with the first tourist settlements dating from the first half of the 19th century. However, a surge in touristic activities has taken place in the area since the early 1970s, characterised by intense urban development along the lagoon perimeter to accommodate the growing seasonal population.

The marked seasonality of tourism in the area (July to September) is evident when comparing the numbers of the permanent local population of about 45,000 inhabitants to the tourist population that reaches about 450,000 during summer months.

In mid 1980s, sewage from main urban areas began to be treated with the construction of water treatment facilities. However, overflows of water collectors and discharges of untreated or insufficiently treated effluents can be observed in the area, especially after storms and during the peak summer tourist season. Urban discharges are considered as the main source of phosporus entering the lagoon (Pérez-Ruzafa et al. 2005, Garcia-Pintado et al. 2007).

Around the same time, water derived from the Tajo-Segura river diversion, generated a profound transformation of the agricultural practises in the adjacent agricultural area, Campo de Cartagena, that changed from extensive dry crop farming of cereals, olives, almonds and carob beans to intensively irrigated crops (Figure 5). At the present, Campo de Cartagena is one of the most productive and profitable agricultural areas in Europe, and the use of water, fertilisers and pesticides has increased dramatically.

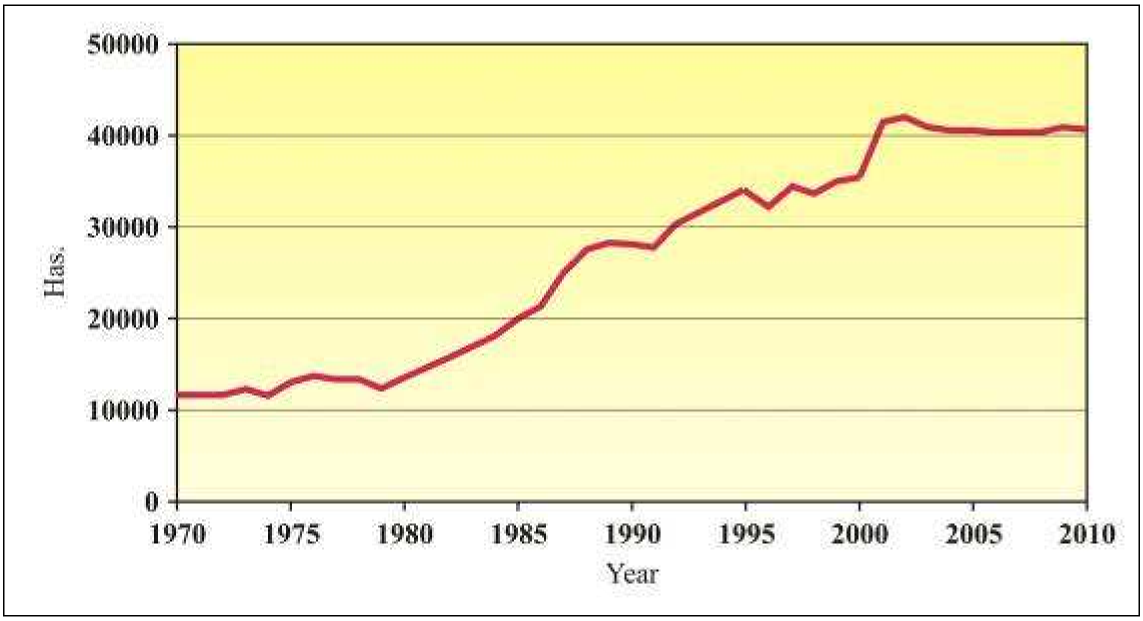

Figure 5. Evolution of the area occupied by intensively irrigated crops (Has.) in the adjacent agricultural area Campo de Cartagena from 1970 to 2010 (Redrawn from Martínez-Fernández and Esteve-Selma, 2005 and completed with data available at www.carm.es).

Due to increased agricultural water usage and decreased groundwater exploitation, phreatic levels have risen, As a result, some watercourses, such as El Albujón wadi, now maintain a regular flux that is fed by ground water with high nitrate levels.

As a consequence of increased inputs, the waters of the Mar Menor have experienced rising nutrient levels that have led to planktonic changes in the lagoon (Gilabert 2001, Pérez-Ruzafa et al. 2005). These changes have also favoured the proliferation of the jellyfish species *Cotylorhiza tuberculata* and *Rhizostoma pulmo*, with severe consequences for touristic activities in the area (Pérez-Ruzafa et al. 2002). Furthermore, modified light conditions of the lagoon waters might have favoured the expansion of *C. prolifera* on the bottoms of the lagoon and the confinement of the traditional phanerogam *C. nodosa* to small patches in shallow areas. These changes have caused a progressive deterioration of the sediments through the accumulation of organic matter and subsequent appearance of anoxic conditions and the production of toxic acid volatile sulphides, all of which have diminished the water quality in several zones of the Mar Menor lagoon (muddy bottoms, bad smell, etc.). In addition, the local fishing industry is negatively affected by decreased populations of commercial fish, as these species, mainly Sparidae and Mugilidae, prefer feeding on patches of the phanerogam or unvegetated bottoms, which are now covered by a dense and continuous bed of the macroalga (Verdiell-Cubedo et al. 2007).

Although these changes have been reported, more severe eutrophication events have not occurred, such as phytoplankton blooms, floating macroalgae proliferations or dystrophic events, despite the fact that the magnitude of inputs is of the same order as that found in other coastal lagoons where eutrophication processes have been reported. This fact highlights the existence of certain biotic feedbacks that may be helping to reduce the level of nutrients in the water column and thus favouring the environmental quality of the lagoon.

2. Main lagoonal habitats and their ecological importance

2.1. The importance of lagoonal benthic habitats

As occurs in many other coastal ecosystems benthic primary producers play an essential role in the functioning of the Mar Menor lagoon. Macrophyte assemblages constitute the habitat for numerous benthic species, and their importance in terms of biodiversity has been widely recognised. Furthermore, dense assemblages of benthic macrophytes are likely to intercept nutrients from the water column or from the sediments, and in some cases this uptake is sufficient to maintain reduced nutrient concentrations in the overlying waters (Grall and Chauvaud 2002), thus increasing the resistance of ecosystems to eutrophication.

The excess of nutrients in the Mar Menor lagoon is rapidly removed by the bed of *Caulerpa prolifera*, which maintains its high biomass even in the winter season. Nutrient fluxes in the Mar Menor lagoon occur mainly from water to sediments through macroalgae mediation. Grall and Chauvaud (2002) stated that in some ecosystems benthic macrophytes may store nutrients in the same order of magnitude as the annual nutrient load coming from freshwater inputs. Other authors demonstrated that the total nutrient amounts stored by macroalgal biomass can be even higher (Sfriso and Marcomini 1994, Sfriso et al. 1994). This is particularly true in the Mar Menor lagoon where annual inputs from the main watercourse flowing into the lagoon from the adjacent agricultural area have been estimated at 2010 tonnes N yr^{-1} and 178 tonnes P yr^{-1} (Velasco et al. 2006); these values are half of the estimation of algal uptake of 3988 tonnes N yr^{-1} and 420 tonnes P yr^{-1} (Lloret et al. 2008).

Furthermore, the Mar Menor lagoon is considered a highly productive system and shows high abundances of benthic macrofauna species. This fauna plays an essential role in the maintenance of coastal ecosystem integrity by mediating exchanges and transformations of energy and materials, including nutrients, between the water column and the sediments (Hansen and Kristensen 1997, Twilley et al. 1999). Furthermore, production by the macrobenthos provides an important vehicle of trophic transfer within the coastal ecosystem (Diaz and Rosenberg 1995).

Benthic communities inhabiting the Mar Menor lagoon constitute a very effective nutrient uptake and retention 'machine' that is responsible for the relatively good condition and ecological quality of the area. Nutrients entering the lagoon are effectively removed from the water column and stored in the sediments. But translocation of these excess nutrients occurs not only in the vertical axis; spatial differences in *C. prolifera* cover and macrofaunal species composition and dominances promote a net transport of nutrients from shallow areas of the lagoon to deeper areas where they are confined. Furthermore, seasonal differences observed in benthic communities favour higher nutrient retention rates before water temperature reaches it maximum, thus avoiding phytoplankton growth during the warm season (Lloret and Marin 2009, Lloret and Marin 2011).

At first sight, benthic communities seem extremely vulnerable to the effects of climate change, since such change would have a strong impact on them as regards their productivity, distribution and function (Nicholls et al. 1999, Short and Neckles 1999, Simas et al. 2001).

Global mean temperatures are expected to rise by 1-3.5 ºC by the end of the century (Watson et al. 1996), although recent studies have predicted increases in the maximum summer temperature and probably an increase in the frequency of heat waves in the same period (Sánchez et al. 2004). The effect of these changes on sea water temperature is difficult to infer and will depend on the particular characteristics of each coastal area, although major changes will probably occur in semi-enclosed water masses, such as coastal lagoons. Increasing water temperature will directly affect benthic metabolism and maintenance of a positive carbon balance established by the relation between photosynthesis and respiration. The direct effects of increased temperature will depend on thermal tolerance and optimum temperatures for photosynthesis, respiration and growth of individual species.

Apart from the rise in temperature, other changes are expected, such as an alteration in rainfall patterns and an increase in the occurrence of extreme climate events, which may lead to a change in the frequency and intensity of storms (Nicholls and Hoozemans 1996 and references within, Watson et al. 1996). The impacts of these changes on benthic primary producers will be due not only by the direct effect of the erosion caused by the storms and associated wave action, but also by the ‘shading’ caused by suspended sediments resulting from the coastal erosion and the increase of storm water runoffs.

Projections of the sea-level rise for the end of the 21st century range from 15 to 95 cm, with a ‘best estimate’ of 50 cm (Watson et al. 1996, IPCC 2001, Rahmstorf 2007). Sea-level rise will have direct consequences on the benthic primary producers of coastal environments, including coastal lagoons, due to the increase in depth, the reduction of light reaching the bottom, the changes of salinity and the alteration of the hydrodynamism of the areas.

Another consequence of future environmental change is the increased nutrient input into coastal areas, which provide natural resources and suitable space for economic activities and human settlements. It is estimated that 50-70% of the world's population lives in coastal zones, a figure that shows an increasing tendency. Furthermore, the use of fertilizers for agriculture in the surrounding watersheds is also expected to rise. This increasing pressure may lead to a rise in the discharge of nutrients into coastal systems, which will be aggravated by the expected changes in hydrological regimes and precipitation patterns (Bethoux et al. 1998, Bethoux and Gentili 1999, Short and Neckles 1999, Bouraoui et al. 2002, Sumner et al. 2003, Dore 2005). The increase of nutrient inputs could promote the appearance and magnitude of eutrophication processes that may affect benthic primary producers of coastal zones through increases in water column light attenuation caused by increased phytoplankton concentrations, the proliferation of floating macroalgae and epiphytes or even more severe phenomena, such as oxygen depletion at the bottom and the subsequent death of benthic consumers.

The main changes that environmental variables of coastal systems will suffer as a consequence of future climate change are those related with a rise in sea water temperature and a reduction in the light reaching the bottom, through the cumulative interaction of the rise in sea-level and increased water column turbidity. Both factors constitute key parameters of coastal benthic species productivity, distribution and survival (Duarte 1995, Livingston et al. 1998, Moore and Wetzel 2000, Plus et al. 2001) and any change will directly affect their role in the maintenance of the trophic status of coastal zones. In addition, changes in the hydrodinamism of water masses and salinities will also have a profound effect on coastal ecosystems.

Recent papers have pointed out not only the sensitiveness of benthic communities of the Mar Menor to the effects of global climate change and an increase in the appearance of eutrophication events in the area, but also highlighted the importance of benthos in regulating the current high ecological status of the lagoon and its response to nutrient enrichment processes (Lloret et al 2008, Lloret and Marin 2009, Lloret and Marin 2011).

2.2. The Mar Menor benthic habitats

As in many other shallow coastal environments the factors determining benthic habitat types can be classified in two major groups: the type of bottoms and the presence of benthic macrophytes. Mapping of these benthic habitats is based on the cartography elaborated by the Geographical and Environmental Information System (SIGA) available at www.carm.es.

a) Classification of major bottom types

In the Mar Menor lagoon two major bottom types can be assigned, mainly based on sediment granulometry. Sandy bottoms are found as a narrow band along the lagoon perimeter. This band becomes wider in La Manga, the sand bar that isolates the lagoon from the adjacent Mediterranean Sea. Muds clearly dominate deeper bottoms of the lagoon occupying most of its surface (Figure 6). Rocky bottoms, although present in the Mar Menor lagoon, are scarce and their presence is limited to small areas mostly close to the islands.

Figure 6. Bottom types in the Mar Menor lagoon according to sediment granulometry.

Both bottom types are clearly differentiated in the lagoon as reflects the analysis of sediment granulometry found in the literature (Table 1):

Table 1. Sediment granulometry of different bottom types in the Mar Menor lagoon.

Bottom type	% Silt-clay	% Sand	# of samples	Source
Muddy bottoms	67.0 – 95.7	4.3 – 21.3	80	Lloret and Marin 2011
Sandy bottoms	0.2 – 10.5	81.6 – 99.0	24	Marin-Guirao et al. 2005a

b) Presence of benthic macrophytes

Two main species of macrophyte are present in the lagoon, the macroalgae *C. prolifera*, which covers most of the bottom of the lagoon as a dense monospecific bed, and the phanerogam *C. nodosa*, restricted to small patches in the shallowest areas.

The phanerogam *C. nodosa*, the traditional macrophyte in the Mar Menor, once covered extense areas of the lagoon but, after the enlargement of El Estacio channel, the colonisation of the bottoms of *C. prolifera*, and the increase of nutrient inputs to the lagoon its distribution is nowadays restricted to shallow areas (Figure 7). Still, in those locations where *C. nodosa* is found, it displays a quite dense coverage of the bottoms with values ranging from 800 to 1500 shoots per square meter and a positive net recruitment (Marin-Guirao et al. 2005b). However, important differences can be found between *C. nodosa* patches located close to the mouth of El Beal and Ponce wadis and those located elsewhere in the lagoon. Historical mining activities in the southernmost area is still responsible for some acid mining drainages and important heavy metal inputs entering the lagoon thus, impacting to an extent benthic communities in the area of influence of these two wadis (Marin-Guirao et al. 2005b).

Figure 7. Presence of the phanerogam *Cymodocea nodosa* in the Mar Menor lagoon.

The macroalga *C. prolifera* covers approximately 90% of the lagoon's bottom as a dense monospecific bed (Figure 8). Its biomass represents approximately 18,000 tonnes in dry weight and its distribution per area is quite homogeneous (around 100-150 g DW m^{-2}) although there are some differences between shallow areas, with lower biomass per area, and deeper areas that display higher biomasses (Lloret et al. 2008). These differences are also responsible for notable differences in the sediment characteristics and invertebrate communities that inhabit these habitats (Lloret and Marin 2011).

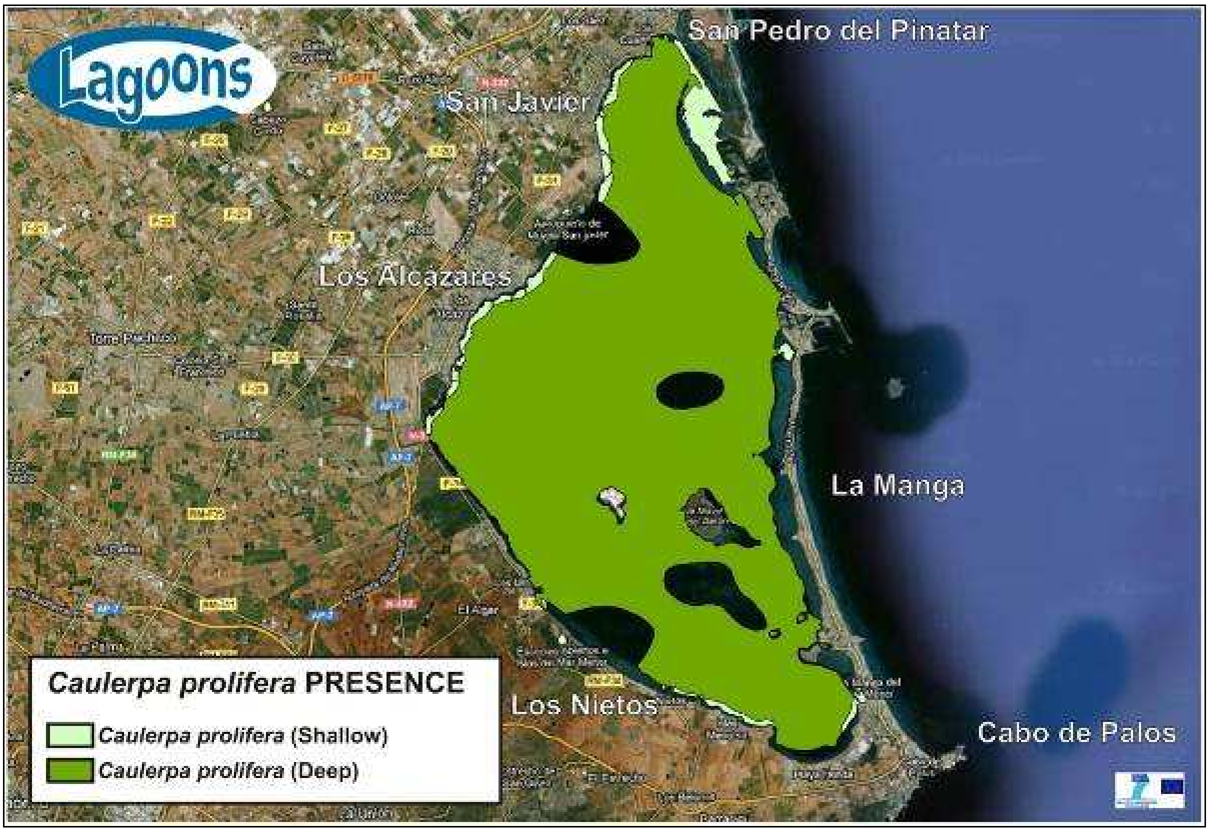

Figure 8. Presence of the macroalga *Caulerpa prolifera* in the Mar Menor lagoon.

c) Main benthic habitats in the Mar Menor lagoon

According to the classification of major bottom types and the presence of the main macrophyte species and their distribution six major habitat types can be defined in the Mar Menor lagoon: muddy unvegetated bottoms (Mub), sandy unvegetated bottoms (Sub), *Cymodocea nodosa* bottoms (Cnu), *Cymodocea nodosa* in polluted areas (Cnp), *Caulerpa prolifera* in shallow areas (Cps) and *Caulerpa prolifera* in deep areas (Cpd) (Figure 9).

Figure 9. Main benthic habitats in the Mar Menor lagoon.

3. Benthic biological diversity and its distribution

3.1. Field sampling and processing

Sampling was carried out in May 2013 in a total of 18 locations within the lagoon (Figure 10). To characterise benthic communities, three replicates were collected at each habitat type using a hand grab (0.040 m^2). Samples were sieved (0.5 mm mesh) and preserved using a buffered solution of 4% formaldehyde. Macrobenthic fauna samples were sorted in the laboratory using a stereo microscope, then classified at species level and counted.

Figure 10. Location of sampling stations for the characterization of benthic macrofauna (Mub: muddy unvegetated bottoms, Sub: sandy unvegetated bottoms, Cnu: *Cymodocea nodosa* bottoms, Cnp: *Cymodocea nodosa* in polluted areas, Cps: *Caulerpa prolifera* in shallow areas and Cpd: *Caulerpa prolifera* in deep areas).

3.2. Benthic diversity indices

A total of 37 species were found in the samples. A complete list of the species found is listed in table 2:

Table 2. List of benthic macrofauna species found in the samples.

Phyllum	Class	Family	Species
Annelida	Polychaeta	Capitellidae	*Heteromastus filiformis*
		Cirratulidae	*Chaetozone setosa*
		Eunicidae	*Nematonereis unicornis*
		Glyceridae	*Glycera capitata*
		Lumbrineridae	*Lumbrineris coccinea*
		Nereididae	*Platynereis dumerilii*
		Orbiniidae	*Scoloplos armiger*
		Paraonidae	*Cirrophorus sp.*
		Phyllodocidae	*Hypereteone foliosa*
		Sabellidae	*Fabricia sabella*
		Spionidae	*Aonides oxycephala*
		Syllidae	*Syllides edentatus*
		Terebellidae	*Polycirrus pallidus*
Arthropoda	Malacostraca	Aoridae	*Microdeutopus gryllotalpa*
		Bodotriidae	*Bodotria scorpioides*
		Corophiidae	*Siphonoecetes sabatieri*
		Gammaridae	*Gammarus aequicauda*
		Grapsidae	*Pachygrapsus marmoratus*
		Paratanaidae	*Leptochelia savignyi*
		Sphaeromatidae	*Cymodoce truncata*
	Ostracoda	Cypridinidae	*Cypridina sp.*
Cnidaria	Anthozoa	Boloceroididae	*Bunodeopsis strumosa*
Mollusca	Bivalvia	Cardiidae	*Cerastoderma glaucum*
		Limidae	*Limea loscombii*
		Lucinidae	*Loripes lacteus*
		Mytilidae	*Mytilaster minimus*
		Paphiidae	*Venerupis aurea*
		Tellinidae	*Tellina planata*
		Veneridae	*Dosinia lupinus*
	Gastropoda	Bullidae	*Bulla striata*
		Cerithiidae	*Bittium reticulatum*
		Nassaridae	*Cyclope neritea*
			Hinia sp.
		Oxynoidae	*Oxinoe olivacea*
		Rissoidae	*Rissoa membranacea*
		Volvatellidae	*Cylindrobulla fragilis*
	Polyplacophora	Chitonidae	*Chiton sp.*

Various benthic diversity indices were applied on the species abundante matrix with the help of the PRIMER-E package (Clarke and Gorley 2006). The results are listed in the following Table 3:

Table 3. Results of benthic diversity indices in the samples.

Station	Species	Individuals	d Margalef Richness	J' Pielou Equitativity	H'(log_2) Shannon-Wienner Diversity	Lambda Simpson Dominance
Mub1	6	9	2.28	0.97	2.50	0.19
Mub2	7	47	1.56	0.61	1.72	0.43
Mub3	5	15	1.48	0.85	1.96	0.31
Sub1	7	11	2.50	0.91	2.55	0.21
Sub2	4	9	1.37	0.72	1.45	0.48
Sub3	7	35	1.69	0.65	1.82	0.38
Cnu1	11	29	2.97	0.82	2.83	0.20
Cnu2	13	73	2.80	0.76	2.82	0.23
Cnu3	10	41	2.42	0.86	2.84	0.18
Cnp1	6	11	2.09	0.86	2.22	0.27
Cnp2	8	46	1.83	0.84	2.53	0.20
Cnp3	5	11	1.67	0.96	2.23	0.22
Cps1	9	83	1.81	0.81	2.58	0.21
Cps2	13	69	2.83	0.55	2.05	0.44
Cps3	11	94	2.20	0.78	2.69	0.20
Cpd1	13	99	2.61	0.72	2.67	0.20
Cpd2	8	73	1.63	0.68	2.04	0.32
Cpd3	9	62	1.94	0.90	2.86	0.16

3.3. Benthic diversity distribution

According to the classification of major benthic habitats in the Mar Menor these results provide an insight on the distribution of benthic diversity within the lagoon. Areas populated by macrophytes, both *C. nodosa* and *C. prolifera* are the most diverse and richest in species and individuals, while unvegetated bottoms are poorer (Table 4 and Figures 11 to 13). The highest number of species present was found in *C. nodosa* bottoms while the highest abuindances were found in shallow *C. prolifera* bottoms. Benthic diversity was generally high in all cases although unvegetated bottoms displayed the lowest values of this index.

Table 4. Averaged values (±S.D) of the benthic diversity analyses on each habitat type.

Habitat type	Number of species	Abundance	Benthic diversity
Muddy unvegetated bottoms	6.0 (± 1.0)	23.7 (± 20.4)	2.06 (± 0.40)
Sandy unvegetated bottoms	6.0 (± 1.7)	18.3 (± 14.5)	1.94 (± 0.56)
Cymodocea nodosa bottoms	11.3 (± 1.5)	47.7 (± 22.7)	2.83 (± 0.01)
Cymodocea nodosa polluted	6.3 (± 1.5)	22.7 (± 20.2)	2.33 (± 0.18)
Caulerpa prolifera shallow	11.0 (± 2.0)	82.0 (± 12.5)	2.44 (± 0.34)
Caulerpa prolifera deep	10.0 (± 2.6)	78.0 (± 19.0)	2.52 (± 0.43)

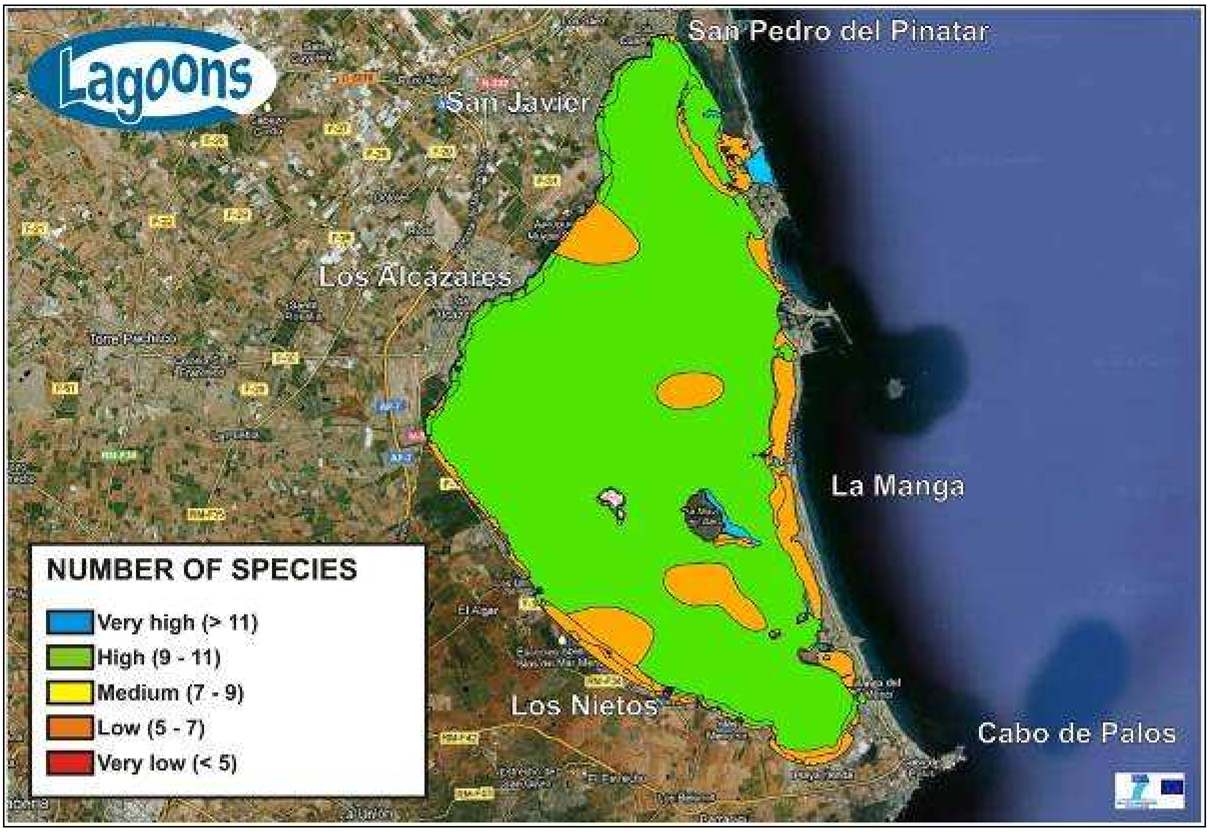

Figure 11. Averaged number of species of benthic macrofauna in the samples of the different habitats in the Mar Menor lagoon.

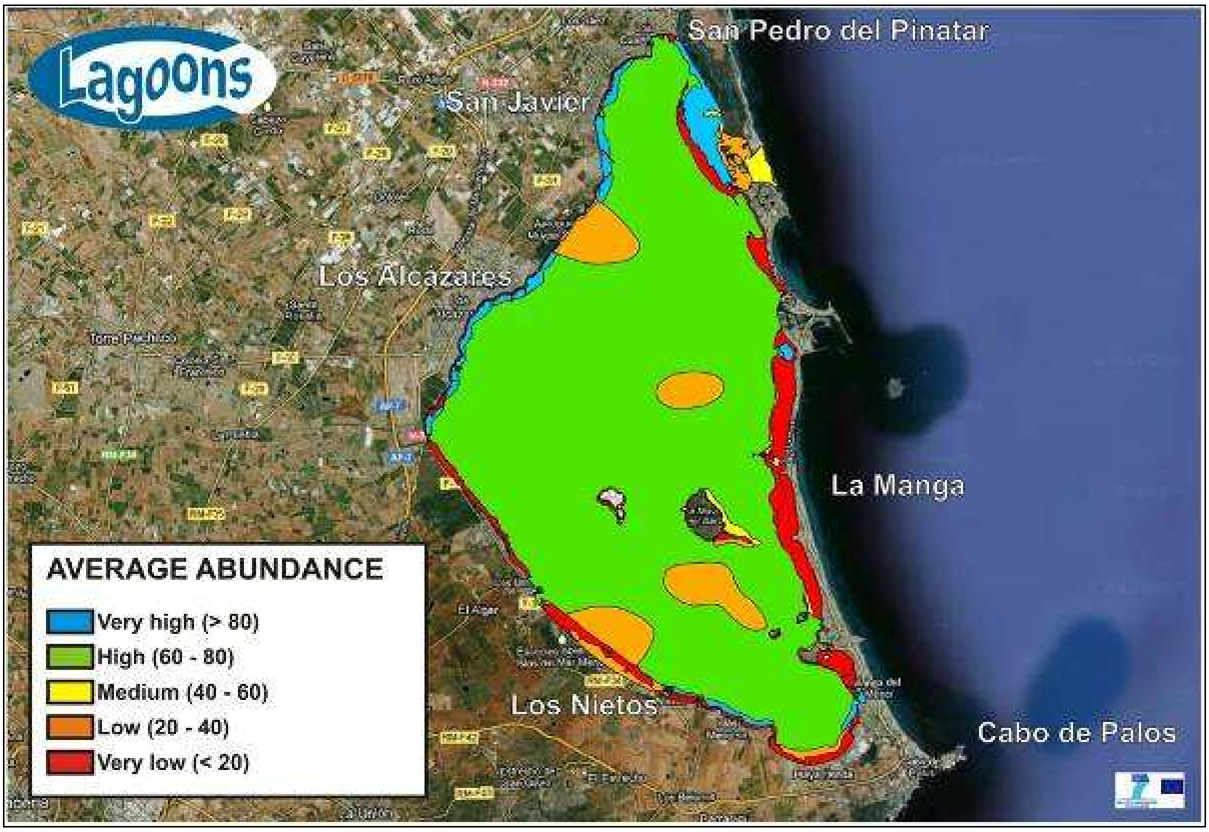

Figure 12. Averaged abundances of benthic macrofauna in the samples of the different habitats in the Mar Menor lagoon.

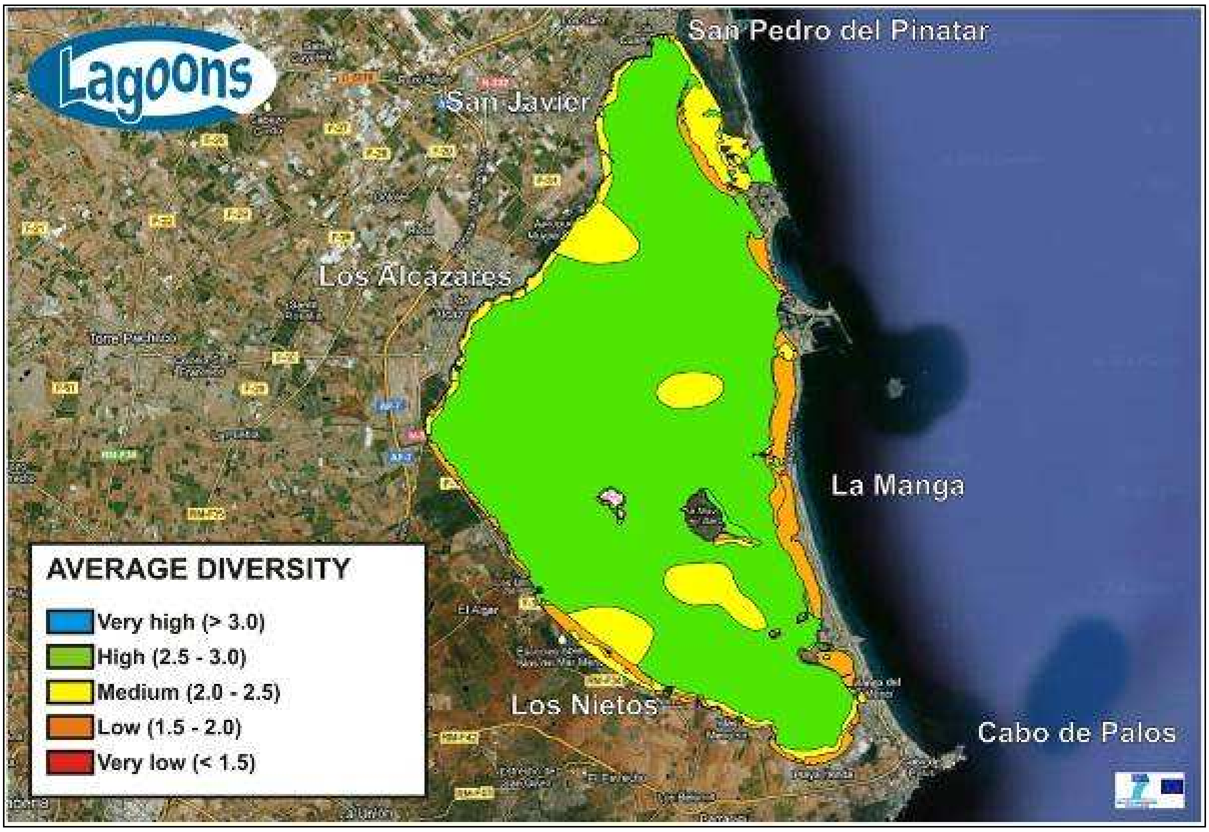

Figure 13. Averaged diversity of benthic macrofauna in the samples of the different habitats in the Mar Menor lagoon.

Results showed that the habitat complexity associated to the presence of macrophytes in the Mar Menor lagoon, together with the overall productivity of macrophyte assemblages and increased food sources, clearly favours the settlement of complex and diverse benthic macrofaunal assemblages in these areas of the lagoon. MDS ordination of samples also showed those differences between vegetated and unvegetated bottoms, although in some cases, such as *C. nodosa* bottoms impacted by heavy metal inputs, it was difficult to differentiate benthic communities from those found in sandy unvegetated bottoms, probably due to the impact of pollutants in these areas (Figure 14).

The analysis of benthic diversity in the Mar Menor showed that, in general, the lagoon is characterised by an abundant, rich and diverse macrofaunal community, mainly due to the presence of macrophytes in the bottoms. *C. nodosa* and *C. prolifera* loss or regression would have a clear deleterious impact on the overall ecosystem benthic diversity with profound consequences for the functioning of the lagoon, the maintenance of valuable ecosystem services and the support of higher trophic levels, including fisheries and water bird species of high ecological interest in the area.

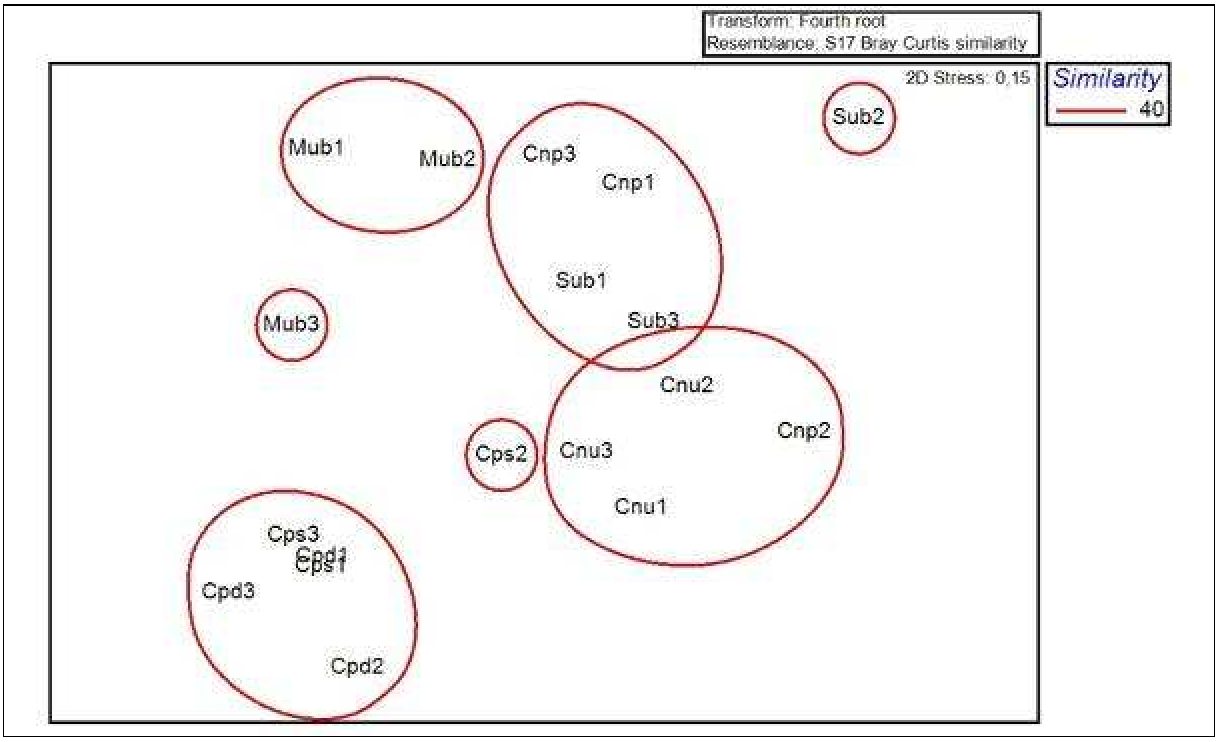

Figure 14. 2D graph showing the results of the MDS ordination of samples.

4. Benthic ecological quality and its distribution

4.1. The AMBI index

Results of the application of the AMBI index on the abundance matrix is shown in the following Table 5:

Table 5. Results of the calculation of AMBI index on the species abundance matrix for each habitat.

Habitat type	I(%)	II(%)	III(%)	IV(%)	V(%)	Mean AMBI	Disturbance Clasification	EcoQ (sensu WFD)
Muddy unvegetated bottoms	50.7	11.3	5.6	32.4	0.0	2.461	Slightly disturbed	Good
Sandy unvegetated bottoms	76.4	12.7	7.3	3.6	0.0	0.786	Undisturbed	High
Cymodocea nodosa bottoms	78.0	9.2	10.6	2.1	0.0	0.545	Undisturbed	High
Cymodocea nodosa polluted	52.9	22.1	19.1	5.9	0.0	1.164	Undisturbed	High
Caulerpa prolifera shallow	42.2	3.0	34.1	20.7	0.0	1.954	Slightly disturbed	Good
Caulerpa prolifera deep	41.5	5.0	21.5	32.0	0.0	1.964	Slightly disturbed	Good

Results showed that in all cases the most abundant group was Group I or ‘sensitive’ species. Groups II and III were also abundant in the samples and Group IV species were also abundant in those habitats characterised by fine sediments (Mub, Cps and Cpd). The lowest AMBI-highest quality habitats were *Cymodocea nodosa* bottoms while the highest AMBI-lowest quality habitats corresponded to Muddy unvegetated bottoms. According to the Ecological Quality clkassification (EcoQ) stablished by the Water Framework Directive sandy unvegetated and *C. nodosa* bottoms displayed a ‘High EcoQ’ and muddy unvegetated and *C. prolifera* bottoms a ‘Good EcoQ’.

4.2. Benthic quality distribution in the Mar Menor lagoon

According to the disturbance classification of AMBI index most of the bottoms of the lagoon can be classified as ‘Slightly disturbed-Good EcoQ’. Muddy unvegetated and *C. prolifera* bottoms are both characterised by sediments with very high silt-clay content (up to 90% in some cases). These sediments also display very high organic matter contents what favours the appearance of anoxic conditions below the sediment-water interface and the release of toxic methane and acid volatile sulphide compounds which, in turn, may affect the survival of some sensitive macrofaunal species. Sandy unvegetated and *C. nodosa* bottoms, restricted to shallow areas of the lagoon, were classified as 'Undisturbed-High EcoQ' according to this classification (Fiugre 15).

The colonisation of the lagoon's bottom by the macroalga *C. prolifera* and the subsequent organic matter enrichment of the sediments has promoted a certain degree of disturbance of the benthos. However, the existence of the monospecific bed of the macroalga might be also supporting a complex macroinvertebrate community above the sediment-water interface therefore favouring a higher benthic ecological status in the lagoon as previously stated by Lloret and Marin (2011).

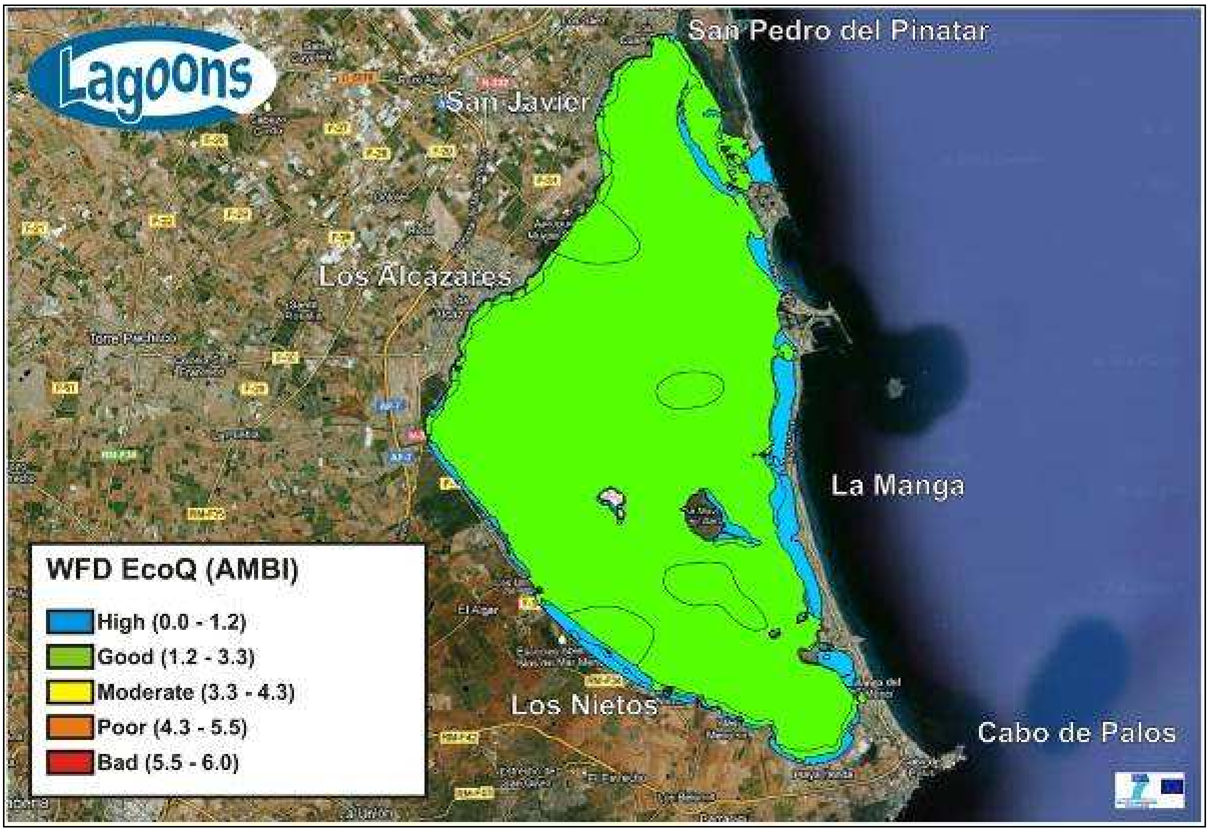

Figure 15. Water Framework Directive classification of benthic ecological quality status (EcoQ) based on the AMBI index calculated in the samples of the different habitats in the Mar Menor lagoon.

5. Fisheries

The Servicio de Pesca y Acuicultura (Fishing and Aquaculture Service) is the government service responsible for the management of fishing activities in the Mar Menor lagoon. The fishing policy in the Mar Menor follows the fisheries Regulations of 1984. The Mar Menor lagoon is characterized by its mainly artisanal fishing fleet regulated with a tight administrative control.

The Servicio de Pesca y Acuicultura gave (2007) the Fishermen's Cooperatives of San Pedro del Pinatar a system of floats with a signal transmitter which identify each fishing gear. The transmitter floats were distributed to each vessel to control the fishing activity, to improve the navigation system and to detect illegal fishing (María Dolores et al., 2009). However, the illegal fishing has been underlined as agrowing problem because it jeopardise the entire activity of professional fishermen. Ecologist Associations have pointed out that at least a quarter of all nets deployed at the Mar Menor lagoon are illegal, and the total length of the nets was as much as 30 km, which is beyond ecosystem's capacity (ANSE, 2013 http://www.asociacionanse.org/anse-denuncia-la-excesiva-presion-de-la-pesca-en-el-mar-menor/20120208).

The main commercial catches are the finfish gilthead breams, eels, annular seabreams, sand steenbras and shellfish prawns (Table 6).

Table 6. Main catches in the Mar Menor lagoon			
Species	Common name	Biomass (kg)	Euros
Engraulis encrasicolus	Boquerón	4179	9.468
Anguilla anguilla	Anguilas	32671	184.951
Diplodus anularis	Chapas	32078	83.196
Atherina boyerii	Chirrete	26876	122.972
Aphia minuta	Chanquete	2751	20.166
Sparus aurata	Dorada	18486	158.566
Solea vulgaris	Lenguado	3335	75.875
Mugil spp.	Mujol	9202	27.421
Dicentrarchus labrax	Lubina, lobarro	3106	49.854
Lithognatus mormyrus	Mabre, magre	29414	124.276
Mullus barbatus	Salmonete	12979	136.116
Crangon sp.	Quisquilla	3275	21.768
Carcinus mediterraneus	Cangrejo	913	7.042
Penaeus kerathurus	Langostino	3023	199.838

The fishing gears permitted by the fishing regulation are “pantasanas”, “pantasanetas”, “boqueroneras”, “morunas”, “paranza del seco”, “paranza del hondo”, “ langostineras”, “chirreteras”, “palangres” and “las encañizadas”. Fishing weirs or “encañizada” (fences) are a typical fishing gear on the Manga of Mar Menor. The "encañizadas", barricades from Moorish times, were for many years the most peculiar feature of the fishing traditions in this area. In each gut or communication canal between the Mediterranean Sea and the lagoon, there was one of these inventions that was made with reeds, stakes and nets to trap fish in hides and tricks. There were “pockets” where fish were kept and then pulled out alive (a procedure known as "defishing") aided by flat boats called "planks" used by the fishermen as their access to land.

The local government also monitors the jellyfish populations. The administrative proceedings for the control of jellyfish were carried out from 1997 due to the excessive jellyfish proliferations that affected tourism and fishing activities in the lagoon. These administrative proceedings mean an annual expenditure of $1x10^6$ euros per year. Three different measures to control the jellyfish population were adopted (María Dolores et al., 2009):

- To surround main bathing areas with fishing nets that block the entrance of jellyfish to these areas. These nets were very successful because without swell almost all jellyfish did not across the nets. In addition, the nets are also regulate traffic of small vessels, preventing their entrance in the bathing areas.
- To promote jellyfish captures by fishermen. The jellyfish capture system has had an important effect in jellyfish populations due to the lagoon closed system. The total catches have decreased during the last years due to fishing efforts.
- To perform a biological monitoring network of jellyfish populations in the Mar Menor lagoon.

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