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Diagnosis of complex coastal ecological systems: Environmental GIS analysis of a highly stressed Mediterranean lagoon through spatiotemporal indicators

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ABSTRACT

This article explores the need for implementing spatiotemporal criteria in environmental planning of special protected areas, applying the analysis of reaction patterns in the case study of the Mar Menor, a Mediterranean coastal lagoon in South-Eastern Spain. To perform this, the Mar Menor environmental patterns suffering traditionally from intense coastal urbanization, and in recent years from important eutrophication problems, will be analyzed from an integrated approach and retrospectively assessed through territorial indicators. The evaluation will provide a clear example of a protected area regulated by multiple European Natura 2000 figures of protection that nevertheless is suffering from a strong and varied anthropic process over time. The results will show that paradoxically this process sometimes has little territorial linkage origin with the area concerned. This aspect will be addressed by using GIS indicators, to present the real correlation between coastal urbanization and agricultural land transformation with Mar Menor evolution over time (in which it is pointed out that the weight of the latter is much greater than the former) and how far it is necessary to establish an area of influence of the environmental impacts by proposing a new scope of application for the resolution of the current situation of eutrophication in its waters.

1. Introduction: the Mar Menor lagoon, an example of stressed highly protected territory

The planning and management of highly protected areas is a discipline that has traditionally been widely studied for different places from the scientific perspectives of biology and ecology (Crouzeilles et al., 2013; Hockings, 1998; Oldfield et al., 2004; Salerno et al., 2013; Schmidt-Soltau and Brockington, 2007; Wiens et al., 2011). In particular, the derivatives of the protected Natura 2000 Network in Europe are especially interesting from the environmental planning point of view, because of the great impact they have had on spatial planning in European countries in recent years (Bryan, 2012; Macedo-Sousa et al., 2009; Opermanis et al., 2012; Tsianou et al., 2013). These figures raise environmental regulation in principle and provide definitive solutions for the protection of areas of high environmental value affected by human activity. Nevertheless, we sometimes witness singular environments subjected to important anthropizing impacts in which the simple regulation of the protected area may not prove sufficient, since it is necessary to take into account the spatial-temporal behavior patterns of the territory on a larger scale. In south-eastern Spain, a particularly interesting case of territory protected by the Natura 2000 network is the Mar Menor lagoon, an area with considerable difficulties in its management due to multiple territorial conditioners, which since 2015 has leaped onto the international stage for being in a critical environmental situation.

The Mar Menor is a salt water lagoon (between 135 and 170 km^2, mean depth 3.6 m, maximum 6 m) located in the East of the Region of Murcia, a semi-arid Mediterranean region of Spain. This area is characterized by scarce precipitation ($<$ 300 mm per year) which mainly occurs during storm events in autumn and winter (Martínez-López et al., 2014). The lagoon is isolated from the Mediterranean Sea by a 20 km long and 100–900 m wide ancient sandy bar, now highly urbanized (called La Manga), and crossed by five very shallow channels (Fig. 1).

The balance between the internal waters of the Mar Menor and the waters of the Mediterranean Sea is maintained by regulation actions of three of these communication channels which allow the water flow between them. Due to its location between land and sea, the Mar Menor lagoon is subject to an elevated rate of dynamic changes in the natural environment that result in high biological productivity and diversity. In 1994, the Mar Menor was considered part of the important RAMSAR list (Convention on Wetlands, with 15,000 Ha designated as wetlands of international interest all over the world). This is due to the high natural value of the area and its many species of birds. It has been proposed

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Fig. 1. Mar Menor area (shallow channels crossing La Manga from Mediterranean Sea indicated in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

that it should be a Specially Protected Area of Mediterranean Importance (SPAMI) under the Convention for the Protection of the Marine Environment in the Coastal Region of the Mediterranean.

The lagoon and its environment support a wide variety of human uses including large tourist resorts, intensively irrigated agriculture, salt and mining industry, military uses, or marinas, among others (Fig. 2). In the field of tourism, the problem of seasonality concentrating uses and urbanization in the area (July to September) is evident when the number of the permanent local population (around 30,000 inhabitants) is compared to the tourist population reached (up to 350,000 during the summer months, see García-Ayllon, 2016).

As noted, the Mar Menor environment is fundamentally conditioned by different anthropic human activities. Some of them have produced a deep and extensive transformation of the perimeter and the territory surrounding the Mar Menor, altering many of its most important natural elements, with coastal urbanization traditionally being the main impact associated to global anthropization of the lagoon. Activities such as fishing or mining extractions go back to the time of the Romans, but most of these anthropic actions have been developed fundamentally in the last decades. Their situation also differs geographically, while at the same time their impacts on the salt lagoon are very different. On the one hand, the east side adjacent to the Mediterranean Sea has several impacts of hypertrophied urbanization generated by mass tourism. The indicated seasonal tourism, in addition to sewage generated on the salt lagoon, has a significant effect on coastal dynamics. This impact is further accentuated by the so called "Mediterranisation process" which is occurring in one of its five ruffs or by the "barrier effect" that make the buildings in La Manga preventing the traditional contribution of sands from the beaches of the Mediterranean Sea to those of the Mar Menor (Miralles and García-Ayllón, 2013a). On the other hand, several watercourses discharge runoffs from different basins on the west side of the lagoon. This territory contains the wide agricultural area annexed known as the Campo de Cartagena, linked to the lagoon by the watercourses.

Despite being included in most existing figures of environmental protection, the Mar Menor has suffered an important process of intense anthropization over the last five decades. One of the main indicators of the transformation impacts occurring in the Mar Menor in the last decades was the exponential growth in the population of a new species of jellyfish called *Cotylorhiza Tuberculata*, reaching more than 100 million specimens each summer (Robledano et al., 2011). This phenomenon, which was causing controversy around tourism, has been approached from the biological perspective in several scientific studies (Lloret et al., 2012; Martinez et al., 2007; Pérez-Ruzafa et al., 1991, 2000, 2005; Velasco et al., 2006). However, the approach taken demonstrated the lack of in-depth analysis from a comprehensive perspective, since the disappearance of these jellyfish in the year 2015 coincided with an exponential increase in the turbidity of the waters of the lagoon because of an important process of eutrophication. This phenomenon has since motivated a strong social alarm as a result of the

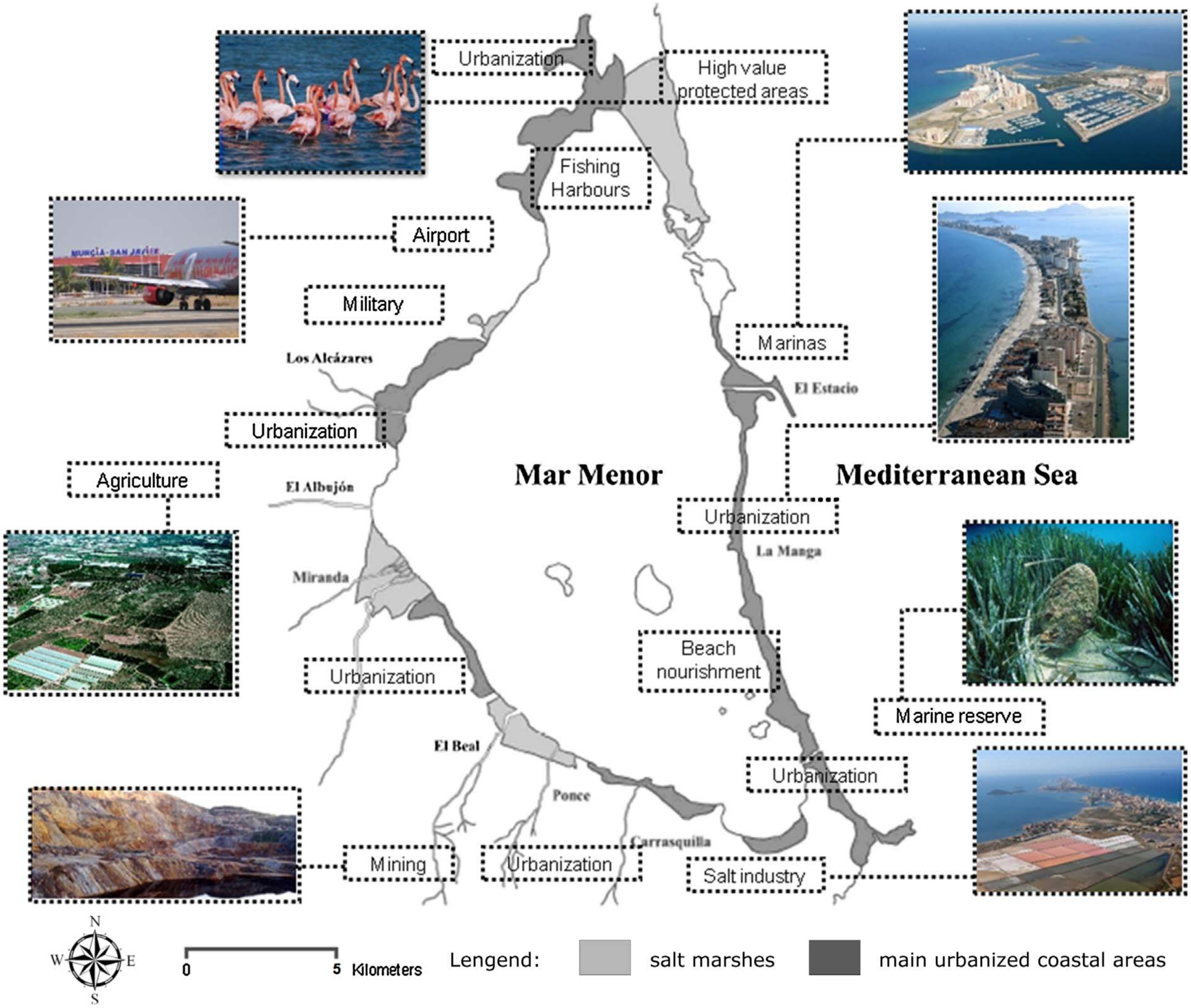


Fig. 2. Schematic description of Mar Menor land uses and activities showing the location of the main urban areas, salt marshes and watercourses.

change from the usual and touristic blue color of the sea to a dense greenish color (Fig. 3).

2. Methodology: GIS analysis of land transformation

Within the described set of activities territorially interacting with the environment of the Mar Menor, it should be noted that not all have the same level of intensity, or the same future trend. Firstly, there are activities such as mining, extinguished for the last twenty years, and whose impact could be assumed as purely landscaping. However, the contributions of sterile from old mines through runoff during heavy rains may still exist (Velasco et al., 2006). Other activities such as the salt industry, military activity or fishing remain today, although their presence is somewhat residual and is focused enough. Activities with greater effects on the land and ecosystems of the Mar Menor – the presence of agricultural industries, plantations, buildings, airports or marine developments – fall mainly in the fields of agriculture and tourism.

All these impacts are correlated and require first a comprehensive vision to focus a correct diagnosis of the current issues of the Mar Menor. It must be taken into account that problems in the lagoon (although correlated) are many and varied, but not all of them have the same level of importance or urgency. In this sense, to carry out an integrated diagnosis of the current situation a workshop with all the stakeholders involved in the Mar Menor (public administrations, universities, business associations, citizen platforms, ecologists groups, etc. see Appendix A for details) was held. In this way we can introduce an integrated vision of the current impacts (Fig. 4) beyond the simple biological analysis assessing whether they are positive or negative with the widest possible approach (for example the existing overpopulation of jellyfish that was initially interpreted as a negative element to damage tourism was finally a “natural purifier” of the contributions from agriculture that currently generate alarming turbidity, although the nature of this impact should be reassessed without forgetting, however, that it was basically the consequence of a global unbalanced socio-ecological system).

This integrated vision of the problems of the Mar Menor confronting the different points of view and needs has also allowed to hierarchize the reality of its current impacts. Despite the fact that most of them are correlated, two of the problems detected are, in the opinion of stakeholders, clearly the main causes of the current situation: urban development on the coast and contributions from agriculture (Table 1).

These two fields have a significant impact from the territorial point of view, which may be behind the most important impacts that the Mar Menor faces in the environmental field today. Nevertheless, they are not a recent phenomenon, but a long-term process whose temporal patterns of alteration need to be identified. As can be observed in Fig. 4, one interesting proposal in order to tackle the strategic analysis to assess impacts in stressed complex environments such as the Mar Menor is the use of GIS techniques through indicators (good examples of this approach can be found Martinez-Graña et al., 2014). Therefore, the transformation of soil which has occurred in the surroundings of the

Fig. 3. Up: *Cotylorhiza Tuberculata* jellyfish overpopulation (left) and collection thereof by fishing vessels in the Mar Menor to not disturb tourism. (right) Down: Usual aspect of the waters of the Mar Menor (left) and situation in 2016 after the disappearance of the jellyfish (right).

Mar Menor in the last 50 years as a result of tourism and agriculture will consequently be analyzed through spatiotemporal GIS indicators of land transformation to contrast the impacts.

2.1. Index of coast occupation I_{CO}

In the case of tourism, the urbanization of the coastline in the Mar Menor began mostly in the 1960s with the accelerated construction on the 20 km of La Manga (Fig. 5). In addition to this situation, one must add the expansion on the continental west front of the Mar Menor from some coastal towns such as San Javier, Los Alcazares and San Pedro del Pinatar through tourism (Table 2). The construction of marinas, the widening of the natural ruffs to allow the passage of pleasure craft, the landfills for land reclamation and other projects (such as roads to communicate the ancient dunes with the outlying islands), have altered the coastal dynamics and La Manga sedimentary flow. The changes in the ecosystem during years have generated visible results with consequences that are appreciable nowadays (Miralles and García-Ayllón, 2013b).

This situation can be transferred to the territorial area by an index that values land transformation for a given area within the perimeter of the Mar Menor. This index, called the Index of Coast Occupation, represents the load factor of the first 500 m of the coastline for each reference area (in this case the municipality, corresponding to LAU2 EU divisions). The calculation of occupancy expense is as follows:

Formula: $I_{CO} = U_A/S_A$ (1)

I_{CO}: Index of coast occupation showing the percentage of land occupied by artificial surfaces within the first 500 m of coast for each reference area (%).

U_A: Urbanized area (Km^2 occupied by artificial areas)

S_A: Reference Area 500 m coast (Km^2 of LAU2 [Local Administrative Unit level 2] or NUTS3 [Nomenclature of Territorial Units for Statistics level 3] EU divisions within a 500-m buffer).

The evolution in recent decades of the I_{CO} index as a result of population growth and mass tourism development can be summarized in Table 3

A clear contrast can be seen when looking at the coastal urban development of the Region of Murcia at a certain scale, in the degree of urbanization of the north-eastern coastline bordering the province of Alicante and the coast reaching the south to Andalusia. This distribution generates a strong territorial asymmetry that has concentrated its urban impact on the north-eastern coast around the Mar Menor perimeter. This makes the Region of Murcia paradoxically one of the globally less average anthropized regions of the Mediterranean coast in Spain in its first coastline kilometer (currently 13.6% vs. Catalonia, Andalusia or Region of Valencia with average rates over 30%).

This configuration is not due to a special protection degree on coastal environmental protection or to a particular territorial policy, but is the result of the so-called historical “urban sink effect” of La Manga (see García-Ayllon, 2015). This phenomenon concentrated the whole urban development activity around La Manga and the Mar Menor causing high inertial anthropization on its coast and ecosystems, but liberating the rest of the regional coastal territory from the strong tourist development of the 1960s, 1970s and 1980s. This situation can be seen in that the percentage values of land occupied in coastal municipalities from the Mar Menor (representing only 20% of the coastal perimeter of the Region of Murcia), are much higher than the mean value of the whole region. This clearly indicates that the coastline of the rest of the region is much less urbanized, thus a great anthropic pressure is concentrated in the Mar Menor, as a result of tourism.

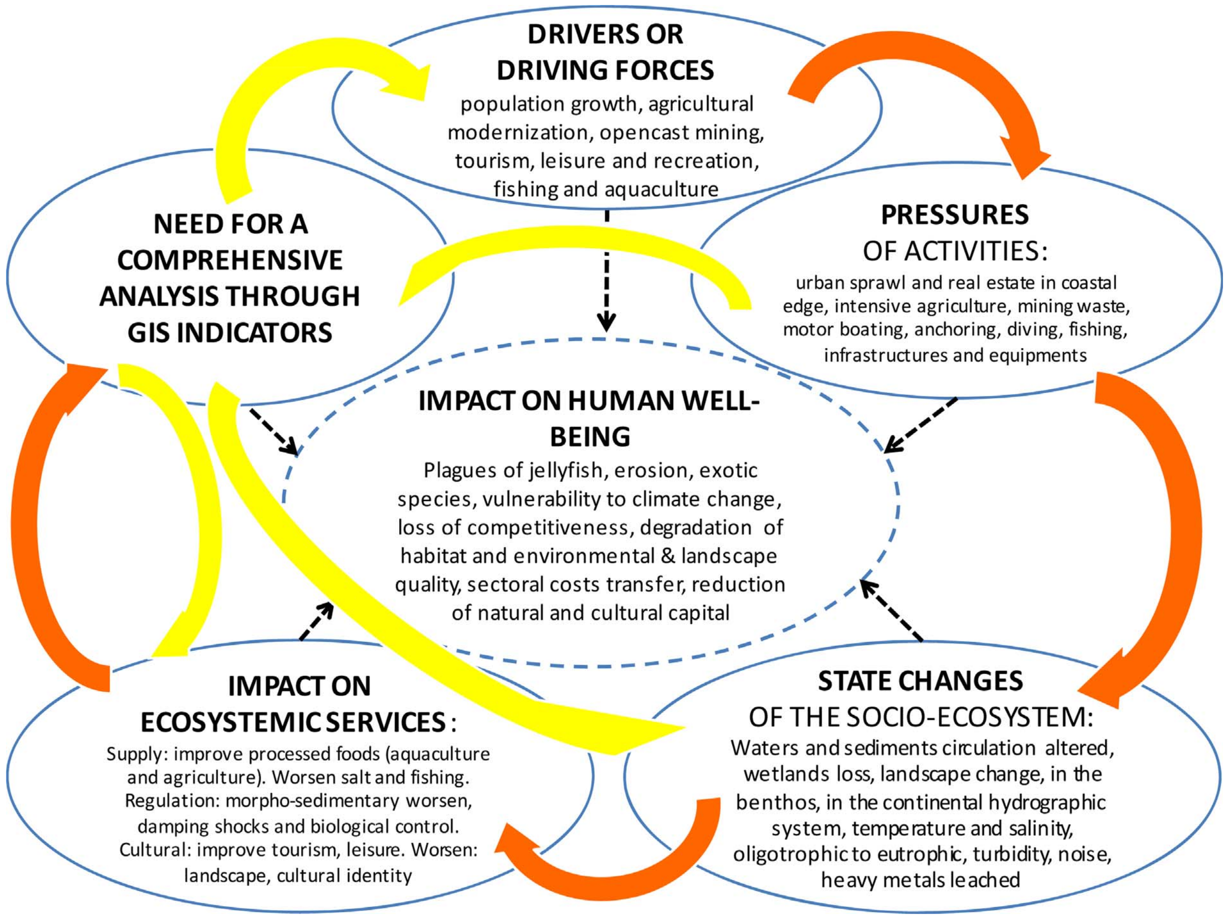


Fig. 4. Schematic representation of an integrated diagnosis of the problems of the Mar Menor taking into account the nature of the impacts from a multidisciplinary approach.

Table 1
Impacts by origin included by stakeholders as one of the three main causes of issues in the Mar Menor current situation.

Impacts (by origin)	%
Urban coastal development	82.1
Contributions from agriculture in the surroundings of the lagoon	66.2
Contributions from extinct mining industry	38.6
Marinas and infrastructures that modify coastal dynamics	36.2
Motor navigation and irregular moorings	35.9
Fishing and aquaculture industry	29.6
Salt industry	22.8
Others	16.4

2.2. Index of fertile soil transformation C_{FL}

Independently of the phenomenon of mass tourism, the other activity that results in a major transformation of soil is agriculture. In the mid-1980s, water derived from the Tagus-Segura river transfer in Spain started to generate a profound transformation of the agricultural practices and activities in the adjacent agricultural area of the Mar Menor, called the Campo de Cartagena, which changed from extensive dry crop farming of cereals, olives, almonds and carob beans to intensively irrigated crops. At present, the Campo de Cartagena is a vast cultivated area of 144,000 Ha (Fig. 6) and one of the most productive and profitable agricultural industries in Europe, but the use of water, fertilizers and pesticides has increased dramatically (Martinez et al., 2007; Velasco et al., 2006).

In the case of tourism, land transformation was concentrated in La Manga (eastern coast of Mar Menor) in the 1960s and 1970s (period of developmentalism until oil crisis) and later dispersedly from 1995 until 2007 (Spanish real estate bubble until subprime crisis) on the coastal front of the mainland. Agriculture has had exponential growth, but only in the municipalities of the continental territory, thanks to water provided by the Tagus-Segura river transfer. A larger plot development and the agricultural transformation were located in the vicinity of the wadis that flow into the Mar Menor. These are located mainly in the municipalities of Cartagena and Torre Pacheco. In the latter, the growth of the agricultural land has led to ground transformation, creating an increment of agricultural soil of 2700% in the last 40 years. By carrying out a GIS evaluation of the territory affecting the Mar Menor, the evolution of land transformation can be accurately observed for each municipality belonging to the Campo de Cartagena area.

This situation will be transferred to the territorial analysis by using an index that implements land transformation trends for agricultural use. This index, called "Index of fertile soil transformation" analyzes natural soil subject to agricultural transformation over a given period of time in relation to total existing fertile soil area at regional and/or local levels.

Calculation method:

Formula: $C_{FL} = FL_{sf}/S$ (2)

C_{FL} = Index of fertile soil transformation (natural land subject to land transformation, final data are expressed as a percentage).

FL_{sf} = fertile land transformed into agriculture (according to Corine Land Cover criteria)

S = total natural soil area (according to Corine Land Cover EU divisions).

The Land cover classification used is based in Corine Land Cover project criteria for level I and II in order to implement an index and results that are homogeneous and comparable in European territories

Fig. 5. Images of La Manga in the 1950s and now. Source: IDERM (2015).

(it must be taken into account that environmental protection instruments are common for European Member States). In order to accurately calculate the total area of agricultural land, all polygons of Corine Land Cover in Class 2 (see Corine Land Cover, 2006) Agricultural Areas have been taken. The reference areas correspond in this case to LAU2 EU divisions, corresponding to municipalities. The definition taken of agricultural areas is detailed in Appendix B.1.

This indicator makes it possible to take into consideration and homogenize all of the different definitions of fertile soil as per the national legislations. It is necessary to compare the available data relating to areas subject to land consumption (natural soil occupied for agriculture or rainfed crops transformed into intensive agriculture) with those concerning fertile soil consumption in order to identify the total extent of fertile soil subject to land consumption. The intersection between both sets of data typically represents the extent of natural soil subject to land consumption. If the behavior of this indicator is analyzed in the vicinity of the study area, it can be seen that land transformation levels in some municipalities near the Mar Menor are quite different to those of other municipalities and neighboring regions in the last two decades, and a trend of increasing transformation can be appreciated during the years of implementation of the Natura 2000 regulations in the whole Region (Table 4).

3. Analysis of spatiotemporal patterns: correlation between agricultural transformation, urban coastal development and lagoon evolution

As mentioned above, the study of the existing impacts on the Mar Menor is currently the realm of several researchers focusing on it from the perspectives of ecology and biology. Empirical studies show the existence of various chemical compounds present in the waters of the Mar Menor, probably from products of agriculture or sewage sanitation from urbanizations. Such studies indicate that the products present from these two activities are the main nutrients of the jellyfish species *Cotylorhiza Tuberculata*, thus causing its proliferation (see for example Velasco et al., 2006). Despite this, the interaction between land transformation patterns and the behavior of the existing ecosystem remains today as a great void within the scope of scientific analysis. An interesting aspect of the necessary study is to establish to what spatial extent land conversion from these two activities over time in recent decades is related to the evolution of the environmental impacts of the Mar Menor, and to determine the degree of responsibility each one has.

For this, the possible existence of statistical correlations between the evolution over time of various significant environmental indicators of the Mar Menor status has been raised, with data regarding land transformation by agriculture and tourism. This distinction is quite interesting since, as seen in the previous section, the times of increased development activity for tourism were between 1960 and the late 1970s, and then from 1995 to 2007, while the most active agricultural transformation occurred from 1979 to the mid-1990s (Miralles et al., 2012), which easily allows the uncoupling of data. To accomplish this, for the case of environmental indicators of Mar Menor status, we will use data obtained from the various biological studies cited (Coastal Oceanographic Observatory of Murcia, 2012; Conesa, 1992; Lloret et al., 2012; Lozano-Cabo, 1954; Mas, 1994; Muñoz-Vera et al., 2016; Martinez et al., 2007; Perez-Ruzafa, 1991; Pérez-Ruzafa et al., 2000, 2002, 2005, 2009; Velasco et al., 2006) and statistics obtained from

Table 3
Ico index (%) in the Mar Menor municipalities between 1960 and 2006.

Municipalities	1960	1969	1977	1985	1990	1999	2006
Alcázares (Los)	8.3	12.7	22.1	23.5	27.7	42.7	67.6
San Javier (mainland area)	15.1	20.6	27.4	38.8	44.5	68.3	87.2
San Pedro del Pinatar	3.1	6.3	12.4	13.3	14.2	18.2	22.6
La Manga	0.1	6.7	33.4	53	66.7	78.2	86.7
Cartagena (mainland area)	3.4	5.6	9.1	9.3	11.4	16.3	24.4
Region of Murcia	2.1	3.3	6.4	7.9	8.3	10.4	13.6

Table 2
Population growth since 1970 in the Mar Menor area (population estimated according to urban plot increase).

Municipalities	1970	1980	1990	1995	2000	2005	% (70 – 05)
Alcázares (Los)	562	1992	3,683		7,513	12,264	2,082
San Javier	14,696	17,282	14,696	17,282	18,925	26,337	79
San Pedro del Pinatar	6520	8917	12,057	13,916	15,583	19,666	202
La Manga area	5,332	66,924	103,874	146,737	189,362	203,663	3,719
Mar Menor area	44,671	130,132	196,130	241,876	269,425	319,153	614
Region of Murcia	822,342	942,109	1,009,743	1,086,464	1,149,328	1,335,792	62

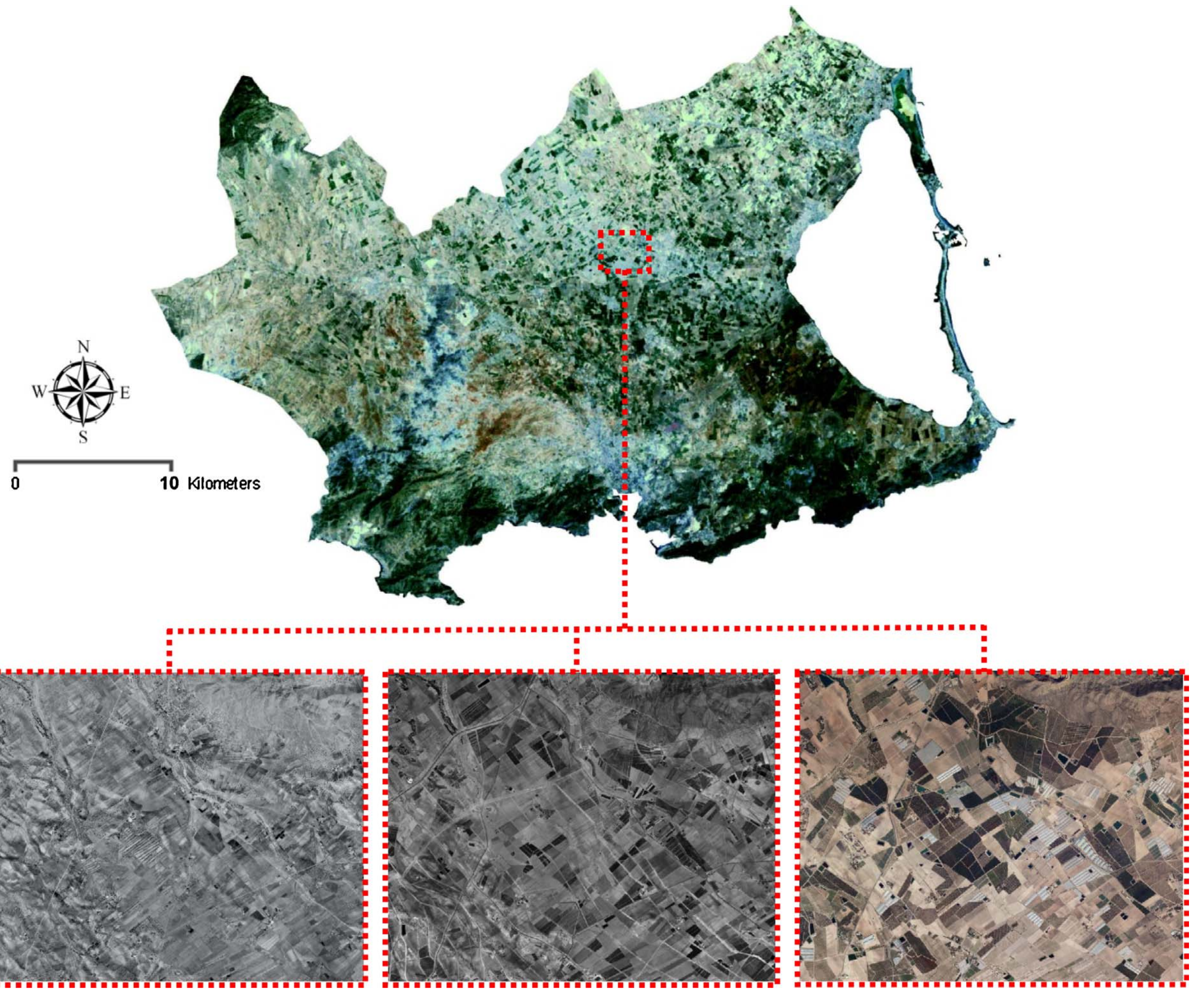


Fig. 6. Campo de Cartagena cultivated area and example of 1956–1981-2007. Source: IDERM (2015).

Table 4
GIS evolution of CFL index (%) between 1961 and 2004.

Municipalities	1961	1979	1999	2004	Increase 1961–2004 (Ha)	Difference 1961–2004 Ha (%)
Cartagena	7.1	12.6	42.2	39.3	11,432	513
Fuente Álamo	2.2	4	8.3	8.1	1,889	248
San Javier	13.8	13.6	51.2	43.5	2,484	185
San Pedro de Pinatar	5.7	61.9	52.7	49.6	1,248	765
Torre Pacheco	4.5	35.2	90.7	87.6	14,794	2,646
La Unión	1.3	5.6	10.1	10.1	362	978
Campo de Cartagena area	5.1	14.5	39.6	37.2	32,209	633
Whole Region of Murcia	3.1	6.3	14.6	13.8	123,205	174

different public administrations, such as the number of jellyfish collected annually, while land transformation data will be based on the GIS analysis carried out in the previous section.

Facing the choice of the territorial area of involvement for tourism and agriculture, it is clear that in the case of tourism, the reasonable scope area is the perimeter of the Mar Menor. Therefore, data from the strip of 500 m of the coast analyzed in the previous section has been used as it is a size usually used for determining coastal direct environmental impacts that covers the main urban construction of the Mar Menor (the Spanish coastal policies refer to it as "influence area"). In the case of the affected agricultural territory to analyze, the choice is more complex. For example, the Albujon watershed area has been selected as the study area because, despite the importance of agricultural activities in different parts of the coastal perimeter of the Mar Menor, the biggest environmental impact on the lagoon may be paradoxically far from its coastline. As seen in section 1, the Mar Menor is situated at the end of a large watershed delimited by a group of mountain ranges that surround the area of the Campo de Cartagena, an extensive plain of about 1440 km^2. Freshwater inputs into the lagoon are restricted to the six ephemeral watercourses called 'wadis'. These wide and shallow gullies are generally inactive, but can carry great quantities of water and sediment during the traditional Mediterranean flood episodes of autumn. The torrential nature of the supplies is aggravated by the impermeable soils and scarce vegetation cover of the watershed areas, going directly to the Mar Menor.

El Albujón wadi constitutes the most important watercourse and drains the adjacent agricultural area of the Campo de Cartagena. The Miranda wadi presents two main channels that converge diffusely in the Carmoli salt marsh. The other three wadis are less important, and do not usually carry inputs related with agriculture (Pérez-Ruzafa et al., 2000, 2005; Velasco et al., 2006). The Albujon watershed, draining a surface of 441 km^2, covers about one third of the total surface of the whole Campo de Cartagena, with its territorial relationship with the Mar Menor being a very illustrative example (see Appendix B.1). Since 1980 it has flowed permanently into the lagoon due to a surplus of irrigation water. This wadi, 42 km in length, presents a fan form with the low section constrained to < 2 km width. According to Serra (2002), the drainage network is dendritic, with a low drainage density.

The tributaries are concentrated in the upper section of the watershed, while the last 20.5 km of the principal channel is without tributaries. The mean watershed slope is 3.02%, ranging from 25 to 30% at the head to < 1% in the lowland section and the mouth (see Appendix B.2).

According to Perez-Ruzafa et al. (2000), in normal local climatic conditions, the Albujon wadi is fed by land-based points and diffuse sources. The principal source is the drainage of irrigated crops, but sometimes the Alcazares town waste-water treatment plant, located in the watershed area, discharges large amounts of untreated or insufficiently treated water originated from tourism into the channel. This severe episodic pollution occurs especially after storms, and in summer months when the population of the inland coast of the Mar Menor increases from 30,000 to 300,000 inhabitants. During heavy rains, the Albujon wadi is fed principally by surface runoff. The drainage waters collected by channels converge at a pumping plant next to the Albujon mouth (at 100 m distance).

Regarding the study variables implemented in the statistical analysis, in the case of environmental indicators there will be three: the concentration levels of chemicals or organic compounds present in the water of the Mar Menor (qualitatively, the literature-cited nitrate levels, organic matter and suspended sediments have been taken as valid, according to the criteria specified in Table 5) and the jellyfish population of *Cotylorhiza Tuberculata* species (estimated qualitatively, or using data of jellyfish-collecting boats). It should be remembered that all these values will come from different studies, constituting a heterogeneous sampling to be taken at different points of the Mar Menor and in different seasons. However, as the analysis was carried out with a large sample (more than 60 correlated values) over a very lengthy period of time (1960–2016), it can be assumed to be a significant enough sample and devoid of statistical bias. From the territorial point of view, population will be implemented estimated from the urbanized area in coastal municipalities, land transformed by agriculture throughout the Albujon watershed and the built-in 500-m strip of Mar Menor coastline perimeter surface.

To enhance the robustness of the results and minimize the existence of biases from heterogeneous sources for environmental indicators, if for the same year there are different measurement values for an indicator, this value has been repeated as many times as measurements exist. It must be borne in mind that there are no environmental measurements of all parameters for every year, and the data density is not uniformly distributed throughout the whole time period (although this is not the case for regional index measurements, where GIS tools provide ample homogeneous data). Furthermore, it must be remembered that annual data for inputs to the Mar Menor can be influenced by climatic variables, such as the existence of more or less precipitation in a year. However, the sample covers a wide enough time frame (> 50 years) to be independent of the different hydrological series. Both have also been correlated with the GIS index with population trends in the area to be used as a comparison.

4. Results

The obtained results are as follows (Fig. 7):

From the graphs observed in the previous section it can be stated that:

– As could be expected, a strong statistical correlation (0.98357) between population growth in the set of municipalities of the Mar Menor and the urbanization of its first 500 m of coastline is observed, as tourism is the main cause of population growth and coastal development. The relationship is nearly linear, even so, one can see some concave curvature for low urbanization rates (traditional urban plot with high-rise buildings in the 1970s and 1980s) against certain convex curvature when higher rates are achieved (appearance of the resort phenomenon, more invasive in land occupation and less dense in population for the period 1995–2007). In contrast, the relationship between urbanization data processing of artificial soil on the coast and the evolution of the parameters of environmental status of the Mar Menor, although there is a certain correlation, is sometimes rather moderated. Therefore, one cannot conclude definitively in general terms that there is a direct link between the urban transformation of the coast and the global environmental impact of the Mar Menor, although it is indeed clear that there is a certain statistical correlation.

– On the other hand, a significant statistical correlation between the data of agricultural land transformation in the Albujon watershed area and the evolution of environmental parameters analyzed in the Mar Menor is observed (correlations of 0.87-0.88 vs. 0.63-0.64 for urbanization process). Based on this data, it can therefore be raised that the transformation of agricultural land of the Campo de Cartagena (as a result of the water supply for irrigation from the Tagus-Segura river transfer), has had a clear environmental impact on the Mar Menor as a clear derivative consequence, and is surely the main impact that exists today.

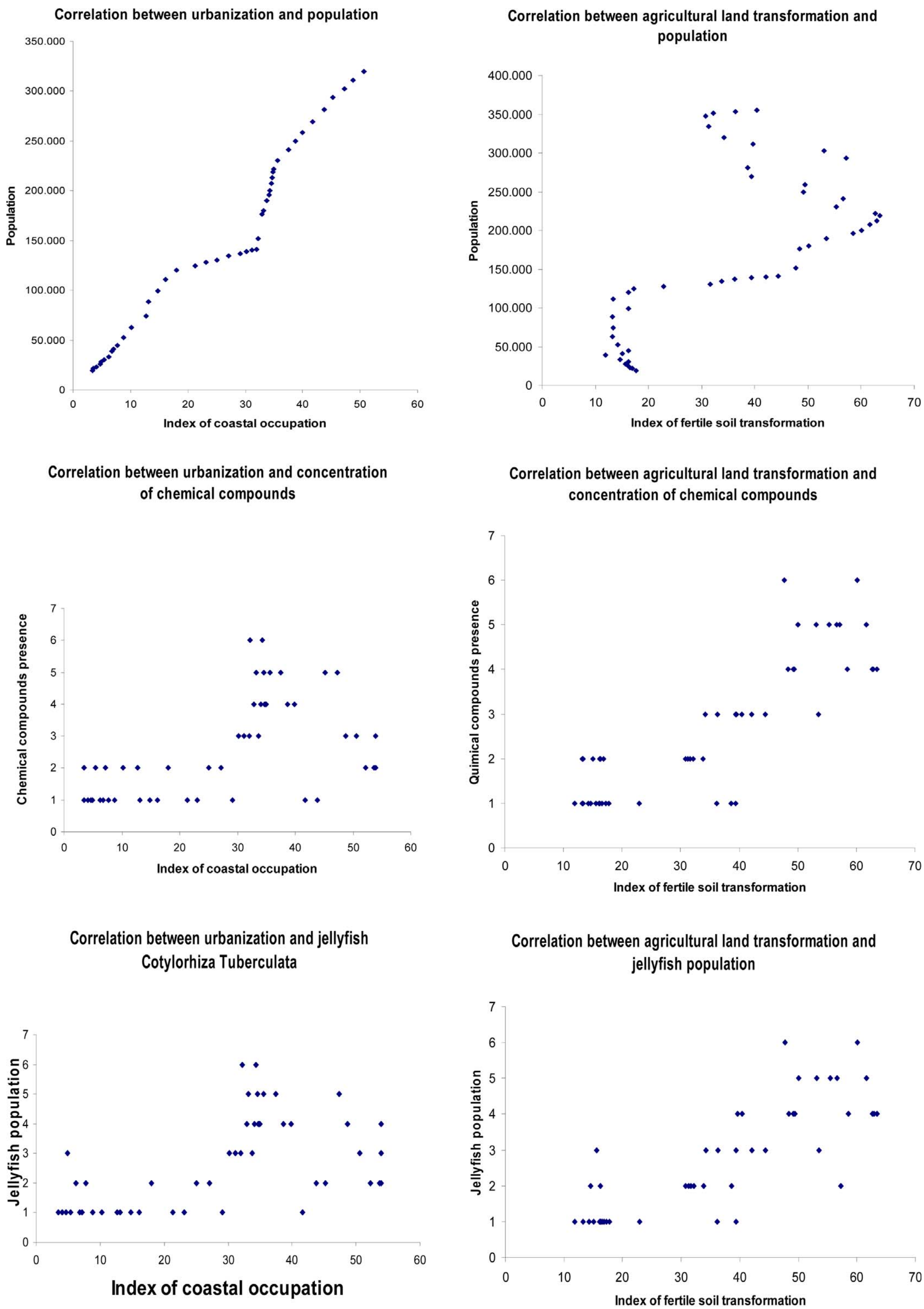
5. Discussion: the role of spatial planning and land use management in environmental planning of stressed ecological systems

The analyzed territory constitutes, as has been seen, a space of relatively complex management. Its influence area overlaps large tracts of agricultural development such as the Campo de Cartagena, major transport infrastructures such as highways or airports, large nuclei of summer tourist populations on the coast and a growing phenomenon of resorts (isolated developments permanently occupied throughout the year developed under models of urban sprawl growth), plus a varied catalogue of secondary uses such as mining, the salt industry or marinas. In this heterogeneous context, protected areas of the Mar Menor are framed, whose clearest territorial expression is the environmental planning policy developed by the Natura 2000 network and other European directives.

These directives set out in their environmental planning process different instruments designed to protect ecosystems and wildlife. Those instruments are transferred directly to the territory after the approval of protected areas' plans, sometimes based purely on analysis and parameters from the fields of ecology and biology only within the geographical area of the territory to be protected. This situation can sometimes lead to the diagnosis of the management needs of a protected area being incomplete when this area is subjected to complex anthropic configurations. In this sense, the Region of Murcia has for example an area of 11,313 km^2, about 25% of which has been protected by the Natura 2000 instruments (SCI and SPA) network. If to the

Table 5
Ranking criteria taken according to the orders of magnitude found in the literature reviewed.

Concentration of chemical compounds			Estimated presence of jellyfish *Cotylorhiza Tuberculata*		
1	Low	Inappreciable values	1	Low	No data of jellyfish
2	Low- Medium	Suspended sediments < 1,000 $t{\cdot}year^{-1}$,	2	Medium	documented but negligible
3	Medium	particulate organic matter < 100 $t{\cdot}yr^{-1}$,	3	Appreciable	documented and not negligible
4	Medium-High	particulate organic matter < 300 $t{\cdot}yr^{-1}$,	4	High (overpopulation)	< 100 t. collected per year
5	High	Suspended sediments < 10,000 $t{\cdot}year^{-1}$, nitrates > 100 $t{\cdot}year^{-1}$	5	Very high (overpopulation)	> 1000 t. collected per year
6	Very High	Nitrates or equivalent > 150 $t{\cdot}year^{-1}$			



	Population in Mar Menor	Concentration of chemical compounds	Estimated presence of jellyfish *Cotylorhiza Tuberculata*
Index I_{CO}	0.98357	0.63117	0.64979
Index C_{FL}	0.61654	0.87964	0.88518

Fig. 7. Graphics of correlation and Pearson linear coefficients between the different parameters analyzed.

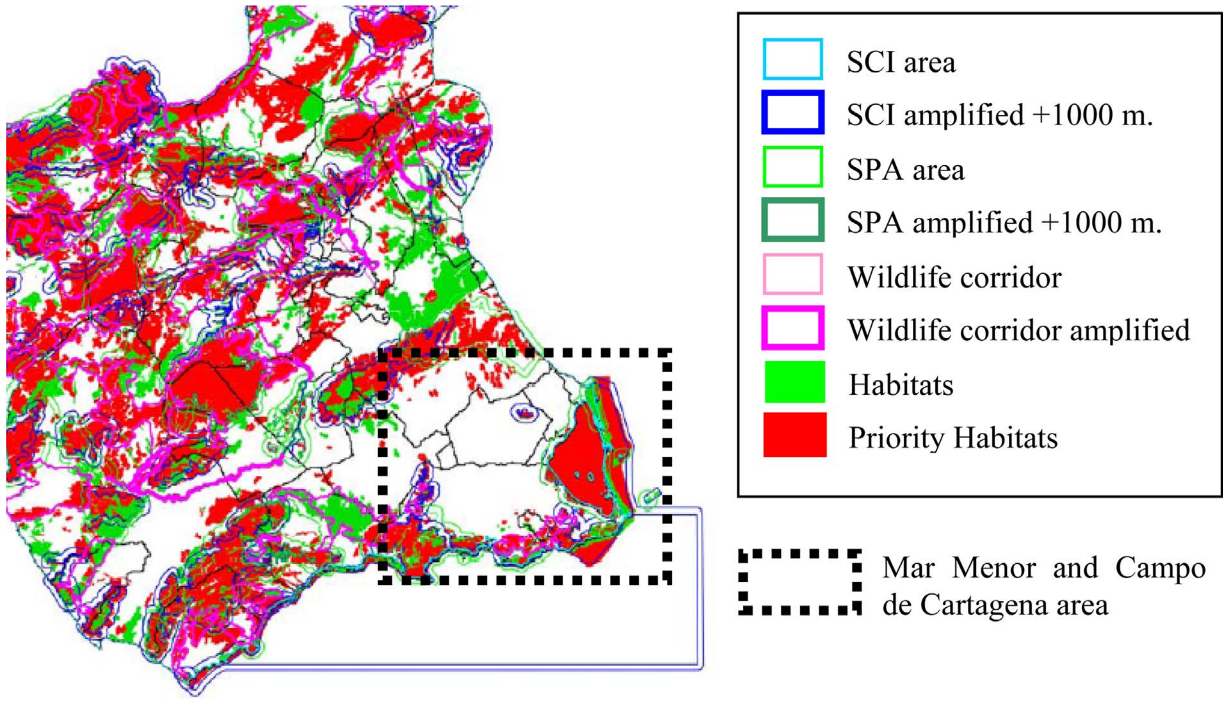


Fig. 8. Overlapping of figures combined into one from Natura 2000 network in the Region of Murcia. Source: authors, information about SCI and SPA areas come from European Environmental Agency (2015) data and maps.

existing figures of the Natura 2000 network the planned surface for potential ecological corridors and protected areas by 92/43/EEC directive on the conservation of natural habitats and of wild fauna and flora spaces is added, then the protected area could reach a total of 790,323 ha. This accounts for more than 58% of the whole region, and is one of the highest values in Europe at regional level. Despite this, the Mar Menor, which is the main environmental asset in the region, is unable (as noted in the previous sections), to deal with the main anthropic activities in its area. The 170 km^2 of the Mar Menor, despite enjoying the protection of all possible instruments of the Natura 2000 network on its surface, suffers directly, as has been demonstrated through GIS indicators, the environmental impact of land transformation associated with neighboring agricultural activities of the Campo de Cartagena, which lacks restriction figures in its area, because of the lack of environmental values in its territory (Fig. 8).

The environmental planning process developed in the Region of Murcia during the implementation of the Natura 2000 network is therefore inefficient and suffers from the lack of the necessary comprehensive approach in complex areas like the Mar Menor that methodologies like the one presented could have provided. The lagoon is currently managed within a complex legislative and policy environmental context (see Appendix A.2), with a wide variety of institutions and actors involved in its use and administration. These administrative tools, unconnected due to their sectoral character, are unable to generate comprehensive planning for the whole environment of the lagoon and have not been able to avoid the current problems. The approach developed from an integrated perspective leads us to propose an expanded scope of work in order to develop integral planning and environmental management of the Mar Menor. This new “real” scope developed through GIS-LIDAR methods would take into account all the activities linked to the lagoon (agriculture, extinct mining, etc.) and orographic factors like wadis, expanding the number of municipalities affected from the initial four of the coastal perimeter to a total of ten. (Fig. 9).

The method presented therefore offers us an objective and exportable analysis, although it is not a closed formula nor is universally adaptable to any context yet. It has thus allowed us to develop an integrated approach to the Mar Menor case study and its quantitative spatiotemporal analysis with GIS indicators assessing the main causes of the current state of its waters and proposing a new spatial framework beyond the current protected area. This may help to solve, with environmental planning, complex problems such as this one that cannot be attributed to a single origin. Although in this regard, its formulation should still be further developed through its application to different cases in future studies to establish more detailed criteria for its application. In this case study of the Mar Menor, possible interesting lines of future research work could be to differentiate among the contributions from agriculture those which are superficial (easier to solve in the short term) from those which are underground (to which it is more difficult to find solutions); or to study the vulnerability of urban singular areas like La Manga due to other factors (currently secondary but maybe more important in the future) such as flooding or climate change, by using innovative specific GIS indicators present in the scientific literature (Martinez-Graña et al., 2016).

6. Conclusions

Traditional environmental planning, by itself, may sometimes be an insufficient instrument for the proper protection of the territory if it is not harmonized with the territorial context in which the spaces to be protected are located. In complex ecological stressed configurations cases, one must consider spatial-temporal behavior patterns of territory and open the analysis to other fields of scientific knowledge, not only to those belonging to biology and ecology, so the process of environmental planning reaches a comprehensive analysis of the problems associated with the processes of anthropization.

This article presents a very illustrative case of this problem, the Mar Menor in south-eastern Spain, a singular environment that despite accumulating various figures of environmental protection, has recently undergone an intensive phenomenon of eutrophication causing important social alarm. This process was historically related mainly to the process of urban transformation of the coast of the lagoon. Through a methodology based in an integrated approach and GIS spatiotemporal indicators, it has been detected that agricultural land transformation in

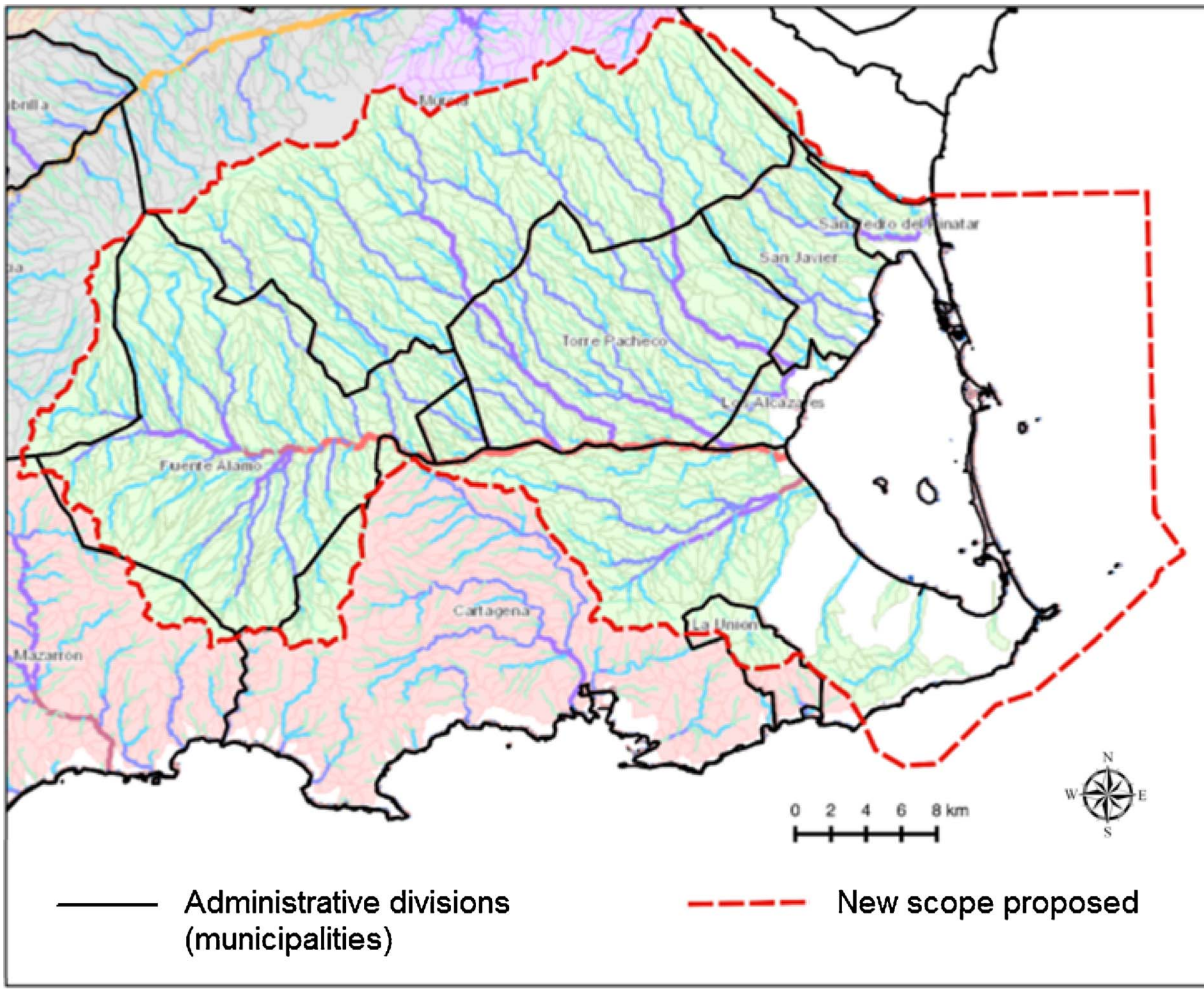


Fig. 9. Real scope of influence of the issues of the Mar Menor proposed, based on the GIS diagnosis carried out where the main focus is set in agricultural links with the lagoon.

the Campo de Cartagena area neighboring the lagoon has a stronger correlation with the current environmental impacts on the Mar Menor. Although it does exist, the correlation between coastal urbanization transformation and the impacts analyzed in the Mar Menor is much weaker. This situation does not imply that urban transformation of the coast does not generate environmental impacts in the Mar Menor, but that the derivate effects of agriculture growth in the Campo de Cartagena on its waters could globally be much higher than those produced by coastal urbanization in the case of the evaluated parameters. Perhaps an analysis of these characteristics could have served in the past to avoid the current important eutrophication issues of the Mar Menor, prioritizing the importance of the impacts to be analyzed. In any case, it is demonstrated that the current figures of protection of the lagoon are inefficient, being centered in the surface area itself and its contour, whereas the main cause of the present impacts lies very far from the scope of action of this environmental protection. An important conclusion of this situation is therefore that the consequences of activities that do not have a direct territorial link on a protected area cannot be properly inserted in the environmental planning process if the analysis and diagnosis is not implemented from the perspective of territorial management. In this sense, a more efficient new scope of the problem has been proposed.

Of particular interest is consequently the need to implement GIS study Indicators of analysis of spatiotemporal patterns of behavior in singular and complex stressed areas associated with the Natura 2000 network; this has an important practical translation to processes of land transformation. In this sense, the methodology proposed presents some advantages over other traditional methods of environmental assessment: it establishes objective and quantifiable numerical evaluations of impacts whose origin is sometimes not easy to detect and correlates different impacts (allowing to export and compare similar cases) and it permits to accurately analyze complex environmental stressed contexts where the anthropization origin of a protected area may be linked to spatiotemporal transformations associated to territories physically separated from the environment assessed.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2017.08.015.

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