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Assessment of the conservation status of seagrass (*Posidonia oceanica*) meadows: implications for monitoring strategy and the decision-making process

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Abstract

Posidonia oceanica (L.) Delile is a seagrass endemic to the Mediterranean Sea and constitutes meadows which are the basis of a highly diverse and productive ecosystem. However, the *Posidonia* ecosystem is threatened by anthropogenic perturbations. A simple index is developed to detect areas adversely affected by an industrial wastewater discharge. Using ordinal scaling four class intervals were established which indicated four different conservation states, and allowed the study area to be divided into four distinct zones. Such zonation is proposed as a means of improving the monitoring strategy for use as an early-warning and early control tool for conservation management of the meadows. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Posidonia oceanica; Conservation index; Zonation; Decision-making process

1. Introduction

Since the Cretaceous, seagrass beds have occupied coastal habitats along tropical, temperate and subarctic regions (Brasier, 1975; Eva, 1980; Larkum et al., 1989). Seagrasses support complex food webs by virtue of both their physical structure and their primary production and are best known for their role as breeding grounds and nurseries for fish and shellfish populations (Mazella et al., 1992; Ruckelshaus and Hays, 1998). The plants filter suspended sediments and nutrients from the coastal waters, stabilize sediments and serve to damp wave action (Jeudy de Grissac, 1984; Durako et al., 1987). Seagrasses are the basis for an important detrital food chain (Short and Wyllie-Echeverria, 1996).

Posidonia oceanica (L.) Delile is a seagrass endemic to the Mediterranean Sea. It is a photophilic species, and its distribution in coastal waters is a function of the available light and the plant's limited resistance to agitation of the water column (Ros et al., 1985). *Posidonia* meadows also support a highly productive and very diverse ecosystem (Bay, 1984; Romero, 1985), which is considered as the climax community on soft substrata of the Mediterranean infralittoral zone (Pérès and Picard, 1964).

In the Mediterranean Sea, loss of biodiversity can be traced to many causes, such as, pollution, modification of the coastal area, excessive exploitation of biological resources and the introduction of exotic species (Cognetti and Curini Galleti, 1993; Cognetti, 1999). With respect to the *Posidonia* ecosystem, regression of meadows and loss of biodiversity has been due, fundamentally, to the increase in human activities along the coast, such as discharge of urban and industrial wastewaters, construction of ports, beach regeneration and illegal fishing techniques (Pérès and Picard, 1975; Ruiz et al., 1993). Recently, displacement of *Posidonia* meadows by the tropical alga *Caulerpa taxifolia* has also been highlighted (Ribera et al., 1996). As a result, *Posidonia* meadows now constitute a threatened natural habitat and are included in the EC Habitats Directive as priority natural habitats, whose protection requires special areas of conservation to be designated (EEC, 1992).

To protect and conserve *Posidonia* meadows, it is first necessary to establish their state of conservation. Evaluation of their conservation status serves as the basis for the design of the most effective, and cost-effective, monitoring strategy. Data collected through monitoring programmes should enable optimal conservation management of the meadows and allow the results of management practices to be evaluated and modified when and where necessary (Grumbine, 1994). In this paper,

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an index has been applied to evaluate the conservation status of meadows of *P. oceanica*. Application of ordinal scale methodology to this index has enabled a zonation of the study area to be proposed. This zonation serves as the basis for the development of a monitoring strategy, which in turn can serve as an early warning and control tool for the conservation management of the meadows.

2. Study area and methods

2.1. Study area

The study area is situated in the southeast of Spain (Fig. 1) on the eastern coast of Almería, to the south of the Sierra Almagrera. An organic chemicals factory is sited there, which discharges wastewater to the sea. The study area was chosen because the single polluting source is well defined and because wastewater discharges represent one of the main types of perturbation to *Posidonia* meadows in the Mediterranean (Pérès and Picard, 1975).

To the north of the factory *P. oceanica* extends continuously from the shoreline down to a depth of 25–30 m. South of the factory, the distribution of *P. oceanica* is more discontinuous. In the vicinity of the village of Villaricos the outer edge of the meadow is found at 20 m depth. At the mouth of the River Almanzora (Fig. 1) *Posidonia* is absent because of erosion caused by the riverine flow and because of the high turbidity characterizing the waters there as a result of terrestrial sediment input into the sea. In particular, the Almanzora River is a floodway with a very unpredictable flow

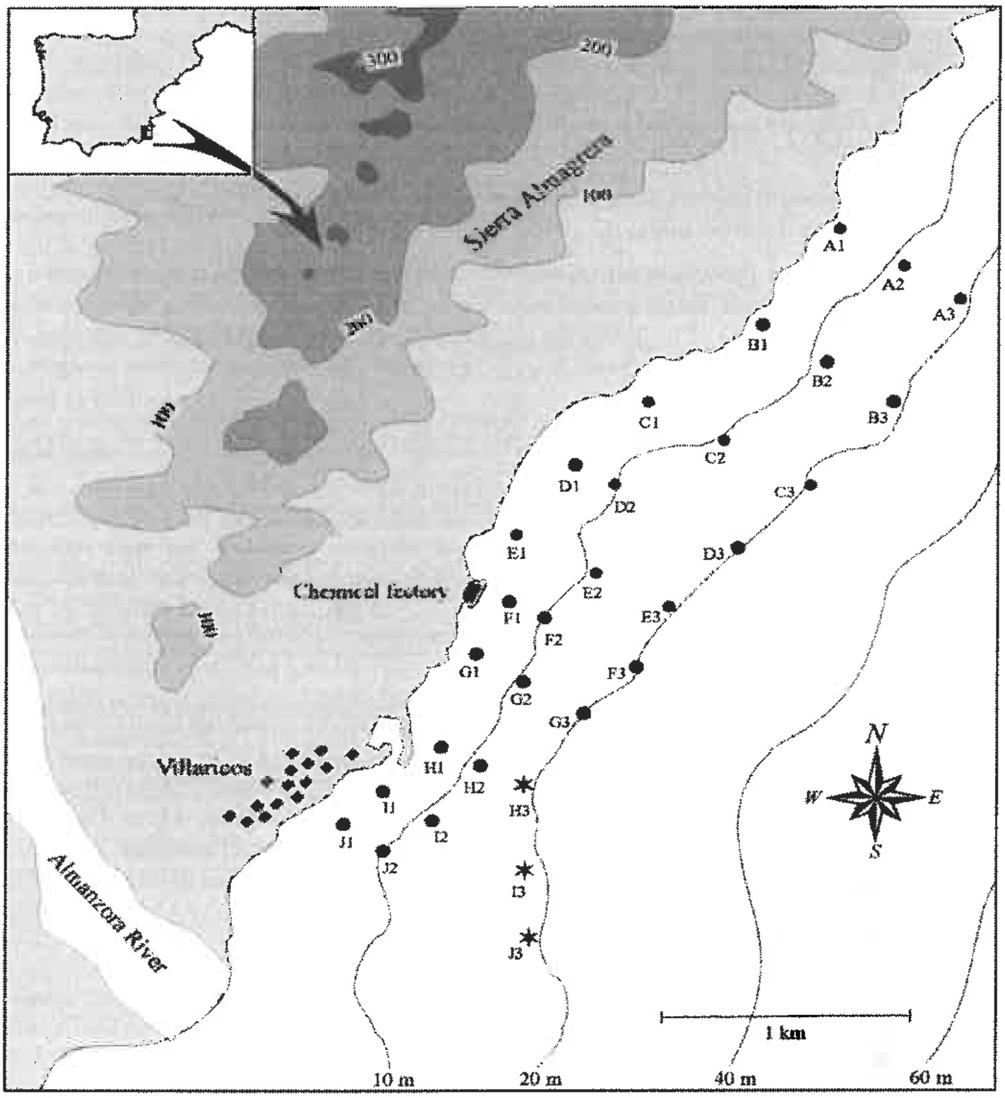

Fig. 1. Study area and sampling stations. (●) Sampling stations colonized by *Posidonia* meadows; (*) stations not colonized by *Posidonia*.

regime, in which the bed can be dry for most of the year, but which can sporadically swell to carry large flood flows.

2.2. Sampling design

Ten sampling transects (A–J) out from the shore were established in the study area (Fig. 1). In each transect, three sampling stations were chosen to be representative of the three main bathymetric ranges: station No. 1 lay in the 5–6 m depth range, station No. 2 in the 9–15 m depth range and station No. 3 lay at 19–21 m. The presence of *Posidonia* at the sampling stations had previously been checked during a preliminary survey. Since *Posidonia* was not found at stations H3, I3 and J3, data could only be collected from 27 of the total 30 sampling stations originally planned.

Three underwater transects, each having a length of 25 m, were laid at each sampling station by SCUBA diving. The percentage cover of live and dead *Posidonia* was determined according to the procedure recommended by Sánchez Lizaso (1993). The proportion of substratum (sand and rock) not colonized by *Posidonia* was also recorded. Five measurements of shoot density, leaf length and leaf width were made "in situ" for each transect (Sánchez Lizaso, 1993). Shoot density was determined using a quadrat of 20×20 cm.

Phenols have been used as a measure of water pollution. Five water samples were collected, at each sampling station, over the *Posidonia* meadow by a Van Dorn bottle. Phenols were determined according to Apha-awwa-wpcf (1989).

2.3. Conservation index

To establish the conservation status and establish the degree of alteration that the *Posidonia* meadow has undergone, the following index was used, based on criteria established by Sánchez Poveda et al. (1996):

$$\mathrm{CI} = \frac{L}{L + D}$$

where L is the percentage cover of live *Posidonia, D* is the percentage cover of dead *Posidonia* determined for each transect and CI is the conservation index. The index ranges between values of 0 (maximum state of alteration or minimum state of conservation, where only dead seagrass is present), and 1 (maximum state of conservation).

In order to use the index, it is necessary to consider the entire transect. The transect could be formed by a proportion of live *Posidonia*, a proportion dead, and a proportion of sand and rock substrate — the latter being very important for determining the uncolonized proportion. Depending on the uncolonized substratum, the percentage cover of live and dead *Posidonia* will be higher or lower.

The index will be of greater use when it can be combined with an independent measure of pollution, in our case, phenol content of the water. Accordingly, the correlation of the index to morphometric and structural variables was calculated, and a comparison indicated that the index showed the closest correlation with phenols. This feature makes the application of the index more robust for evaluation of the conservation status of *Posidonia* meadows.

2.4. Ordinal scaling

To establish intervals representing different states of conservation of *Posidonia* meadow, ordinal scaling has been applied to the conservation index (CI) values. Ordinal ranking has been extensively used in environmental policy analysis (Nijkamp, 1980), ecological investigations (Boesch, 1977) and classification procedure (Karydis, 1992). Four intervals were assigned as follows:

1. CI values $< (\bar{x} - 1/2\ s)$
2. CI values from $(\bar{x} - 1/2\ s)$ to $\bar{x}$
3. CI values from $\bar{x}$ to $(\bar{x} + 1/2\ s)$
4. CI values $> (\bar{x} + 1/2\ s)$

where the mean ($\bar{x}$) and standard deviation (s) were calculated taking into account all CI values.

2.5. Numerical analysis

In order to compare the behaviour of the conservation index with other variables that also represent the state of conservation of the meadow, principal components analysis was applied. The variables selected were: conservation index, leaf length and width, density, water depth and distance from the shore.

All statistical calculations were done using the Statgraphics program v. 4.0.

3. Results

3.1. Evaluation of the conservation status of the *Posidonia* meadows

Only one sampling station had 100% live seagrass while another 10 had values >70% (Table 1). Uncolonized substrate varied from 0 to 63.3% with a mean of 24.3%. Among the 27 sampling stations, 13 had a CI >0.9 and 10 <0.07. Phenol levels varied from 0.05 to 0.5 mg/l (Table 1). Density at two sampling stations exceeded 1000 shoots/m^2 whilst it varied between 200 to 833 shoots/m^2 at a further 17 stations. Leaf length >60 cm were recorded at five sampling stations and 11 stations recorded values <20 cm. Leaf width varied from 0 to 11.7 mm with a mean of 8.2 mm (Table 2).

The biplot obtained from ordination analysis (Fig. 2) shows that the first factor, which explains 63.68% of the variance (Table 3), is positively correlated with conservation index, leaf length, leaf width and distance from the coast and negatively correlated with phenols. As distance from the coast increases, so does the conservation value; longer and wider leaves also correspond to higher values of the index. In contrast, an increase in the phenol content of the coastal waters, and thus in the degree of pollution, is related to a drop in the conservation index as well as in the length and width of the leaf. This first axis therefore represents the degree of conservation of the meadow. Positive values represent a good state of conservation whilst negative ones suggest a regression of the meadow, due to coastal pollution, and a poor state of conservation. The second factor, which explains 23.03% of the variance (Table 3), is positively correlated with density of the meadow and negatively correlated with depth. The axis highlights the fact that as water depth and distance from the shore increase, so the density of the *Posidonia* meadows decreases (Romero, 1985; Sánchez Lizaso, 1993).

Table 1
Percentage cover of live *Posidonia* (L), dead *Posidonia* (D), substratum not colonized by *Posidonia* (S), values of the conservation index (CI) and phenols at the respective sampling stations[a]

Sampling station	L (%)	D (%)	S (%)	CI	Phenols (mg/litre)	
					$\bar{x}$	s
A1	84.0	0	16.0	1	0.05	0.01
A2	86.7	0	13.3	1	0.05	0.01
A3	100	0	0	1	0.05	0.01
B1	83.1	0	16.9	1	0.05	0.01
B2	84.2	0	15.8	1	0.05	0.01
B3	93.5	0	6.5	1	0.05	0.01
C1	78.7	6.7	14.6	0.92	0.05	0.01
C2	88.9	0	11.1	1	0.05	0.01
C3	58.7	1.0	40.3	0.98	0.05	0.01
D1	33.7	56.0	10.3	0.38	0.2	0.1
D2	74.0	6.4	19.6	0.92	0.05	0.02
D3	63.3	0	36.7	1	0.05	0.01
E1	2.7	66.5	30.8	0.04	0.3	0.1
E2	74.0	1.4	24.6	0.98	0.05	0.02
E3	69.4	2.4	28.2	0.97	0.05	0.02
F1	0	81.3	18.7	0	0.5	0.2
F2	4.9	31.8	63.3	0.13	0.4	0.2
F3	35.6	12.1	52.3	0.75	0.1	0.1
G1	0	72.0	28.0	0	0.4	0.2
G2	4.7	64.0	31.3	0.07	0.3	0.1
G3	88.6	1.3	10.1	0.98	0.05	0.03
H1	0	69.0	31.0	0	0.3	0.1
H2	1.6	76.0	22.4	0.02	0.2	0.1
I1	0	73.2	26.8	0	0.2	0.1
I2	1.5	70.0	28.5	0.02	0.2	0.1
J1	0	65.0	35.0	0	0.2	0.1
J2	7.5	68.0	24.5	0.1	0.2	0.1

[a] $\bar{x}$, mean; s, standard deviation.

With the exception of stations A1, B1 and C1, all the shallowest stations are placed at the negative extreme of the axis 1 (Fig. 2), with values of the conservation index of 0–0.38 and elevated phenols concentrations of 0.2–0.5 mg/l (Table 1). These sampling stations were found at a depth of about 5 m and indicate the adverse effect of the wastewater discharge on the meadow. The intermediate stations (2) are separated into two distinct groups. Those located in the vicinity of the chemical factory and south of it, are placed on the negative end of axis 1 and have conservation indices of between 0.02 and 0.13. Here, the phenol content varied from 0.2 to 0.3 mg/l. Those located north of the factory are placed at the extreme positive end of the axis and have conservation index values >0.9, and elevated values of leaf length and width, with phenols concentrations of around 0.05 mg/l. This difference in grouping suggests the influence of the predominant current flow along a northeast to southwest direction and similar dispersion of the wastewater plume.

The deepest stations (3) are located at the extreme positive end of the axis 1 and have conservation index values of between 0.75 and 1. The concentrations of phenols of these coastal waters varied between 0.05 and 0.1 mg/l. With respect to the second axis, stations A1, B1 and C1, not directly affected by the discharge, are in 5 m water and yield the highest shoot density values and show low phenols values (Tables 1 and 2). The principal components analysis and the values of the index suggest that the effect of the discharge on the meadow are limited to a coastal strip very close to the factory, and that in waters having depths of 10 m or more the *Posidonia* meadow is in a better state of conservation. The principal components analysis also highlights the negative relationship between phenols, an independent measure of coastal pollution, and the conservation index.

The coefficient of correlation between phenols and the conservation index (−0.86; $P<0.05$) indicates a moderately strong relationship between the variables. A linear model was developed with the aim of describing this relationship. The equation of the fitted model is:

$$\text{Phenols} = 0.30 - 0.25\text{CI} \quad (P < 0.01)$$

therefore, the relationship between phenols and the conservation index suggests that the conservation index can be used to map the effects of pollution without necessarily monitoring each pollution discharge.

3.2. Application of conservation index to zoning

Application of the ordinal scaling to conservation index values differentiated between four distinct zones representing four states of conservation of the meadow

Table 2
Values of *P. oceanica* morphometric parameters and respective depth and distance of sampling stations from the shore[a]

Sampling station	Density (shoots/m²)		Leaf length (cm)		Leaf width (mm)		Depth (m)	Distance from the shore (m)
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s		
A1	1058	312	29.0	12.0	10.3	0.5	5	150
A2	450	35	68.7	1.2	9.3	0.5	14	400
A3	358	31	84.3	4.0	10.3	0.5	20	600
B1	1070	225	27.3	10.1	10.0	0.4	5	100
B2	490	85	68.2	3.7	9.8	0.5	14	370
B3	347	80	85.1	2.5	10.1	0.5	20	700
C1	833	101	15.3	1.2	11.3	0.5	5	100
C2	408	31	50.0	5.4	10.0	0	14	400
C3	283	59	63.3	13.6	11.0	0	20	750
D1	544	72	12.0	2.1	9.7	0	5	175
D2	321	56	45.6	4.6	10.8	0.2	10	400
D3	225	47	51.2	3.9	11.4	0.3	20	975
E1	217	92	11.7	1.7	9.0	0	5	200
E2	183	82	47.0	10.6	10.0	0	15	500
E3	158	31	50.7	5.2	10.5	0.4	21	850
F1	0	0	0	0	0	0	5	75
F2	383	42	6.0	0.8	9.3	0.9	10	200
F3	242	31	39.7	8.7	11.7	0.5	20	750
G1	0	0	0	0	0	0	6	100
G2	183	35	22.3	3.5	8.7	0.2	11	300
G3	225	30	39.7	2.6	10.3	0.2	19	650
H1	0	0	0	0	0	0	6	150
H2	200	35	19.0	1.1	10.0	0.2	12	400
I1	0	0	0	0	0	0	6	100
I2	250	37	5.0	0.8	9.0	0.4	9	350
J1	0	0	0	0	0	0	6	100
J2	250	41	5.0	0.6	9.0	0.3	9	350

[a] $\bar{x}$, mean; s, standard deviation.

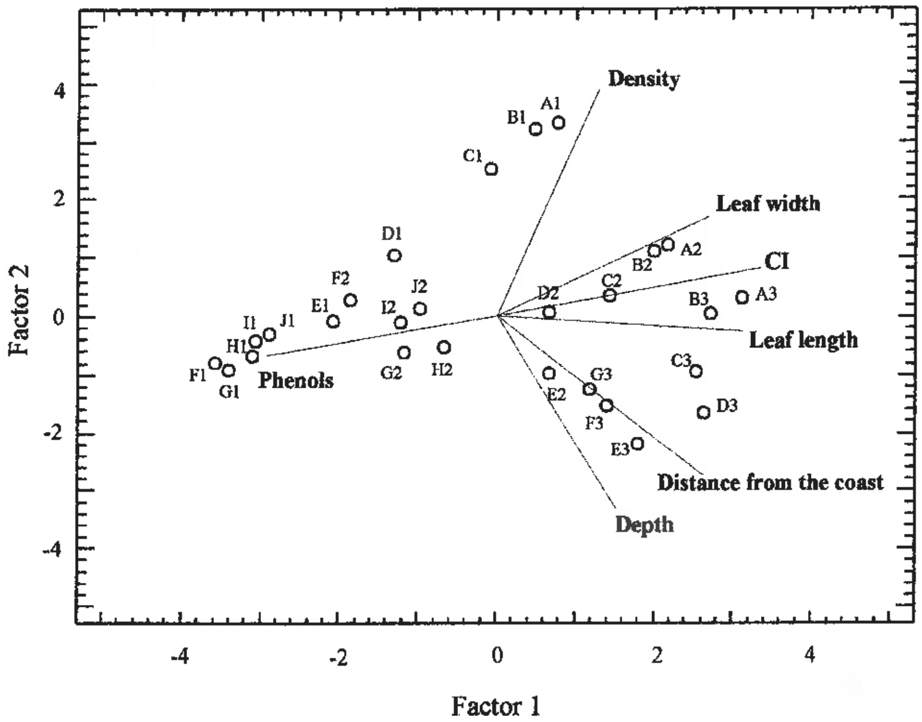

Fig. 2. Biplot from the principal component analysis.

Table 3
Statistical summary of the principal component analysis

Component	Eigenvalue	Percent of variance	Cumulative percentage
1	4.46	63.68	63.68
2	1.61	23.03	86.71
3	0.45	6.46	93.17

Table 4
Ordinal scaling of the Conservation Index (CI) value and respective zones assigned

	Zone assigned	CI value
$<(\bar{x} - 1/2\ s)$	1	<0.33
$(\bar{x} - 1/2\ s)$ and $(\bar{x})$	2	0.33–0.56
$(\bar{x})$ and $(\bar{x} + 1/2\ s)$	3	0.56–0.79
$(\bar{x} - 1/2\ s)$	4	>0.79

(Table 4). Zone 1, identified by conservation index values of <0.33, indicates an advanced degree of regression; zone 2, with conservation index values of 0.33–0.56, represents an impacted meadow; zone 3, with conservation index values of 0.56–0.79 indicates a low to moderate conservation status; zone 4, characterized by conservation index values >0.79 indicates a high state of conservation.

The results obtained after applying the ordinal scaling permit a zonation of the study area (Fig. 3). The zonation differentiates four areas: zone 4 is located to the north of the factory and represents where the conservation status of the meadow is high; zone 1 to the south of the factory represents where the degree of conservation is least. Between these two zones lie three sampling points, D1, F3 and G3, which correspond to zones 2, 3 and 4, respectively.

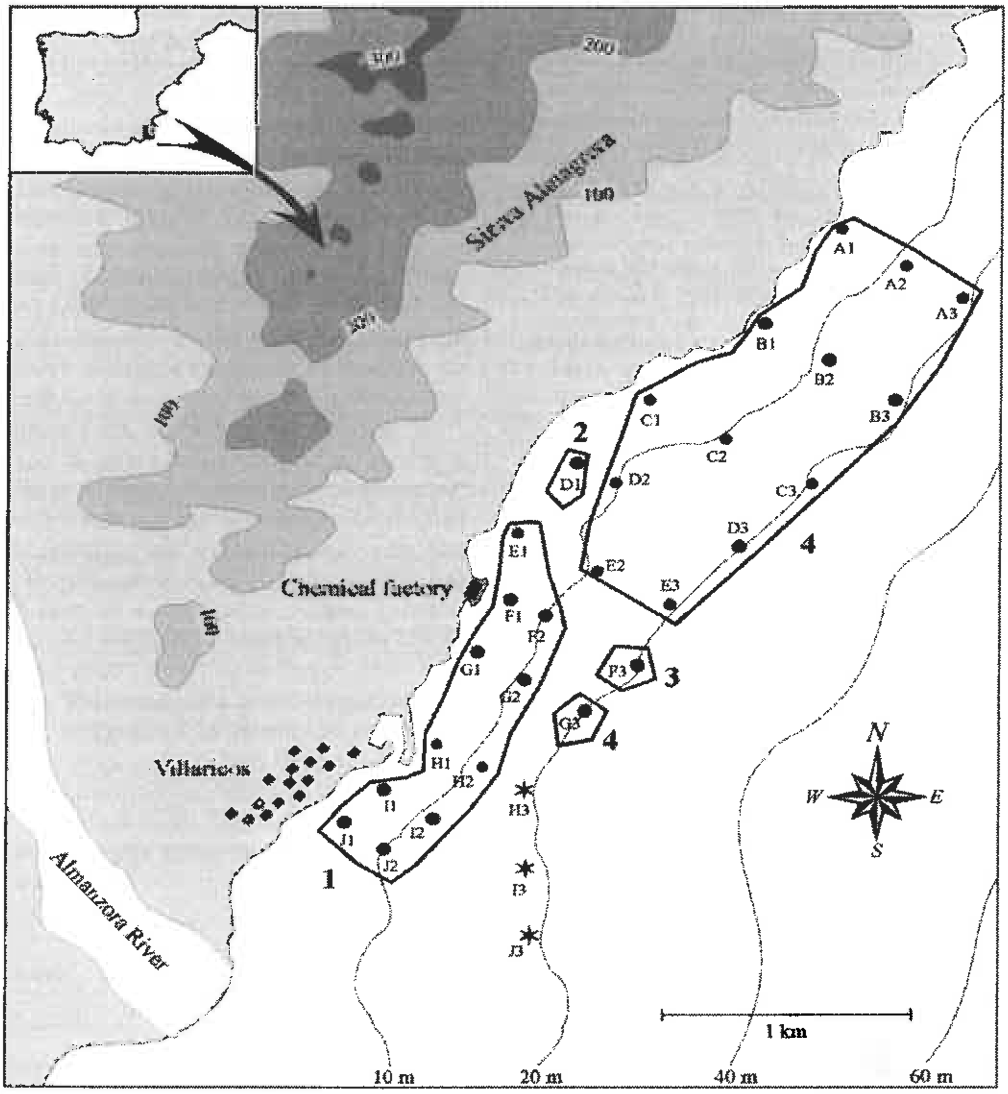

Fig. 3. Zonation of the study area based on conservation index values after ordinal scaling.

4. Discussion

Zonation facilitates decision making on monitoring and sampling aspects. Since the source of pollution is localized, it is clear that sampling frequency should be greater at stations along the "border" between zones (i.e. D2, E2, E3, E1, F2 and G2) than at stations within zones. The "border" stations serve as alarm systems because they respond faster to environmental changes in comparison with stations distant from the perturbation or those located in the centre of the zone. The sampling frequency also needs to be greater in areas represented by only a single sampling station.

Within conservation programmes for *Posidonia* meadows, the methods and zonation scheme proposed can be utilized as an early warning and/or control tool in the decision-making processes. In an early warning system, information from the monitoring program can indicate changes in the environment that may need remedial action. In our case, a change in the status assigned to a particular sampling station would provide this warning information, e.g. a change of station E2 from status 4 to status 3 (Fig. 3). In an early control system, information from the monitoring program can be used to check whether remedial action is successful or not, and to evaluate the predicted or expected consequences of specific measures or activities. Recently, the factory has begun to reduce the contaminant load, and consequently it is expected that some of the monitoring stations will indicate recovery of the meadow. The degree of such a recovery would be shown by a change in the status calculated for a particular sampling station, e.g. station F3 changes from status 3 to status 4 (Fig. 3).

The index and zonation based on ordinal scaling as used in the present study may be useful in monitoring *P. oceanica* in the Mediterranean, not only in areas affected by human activities, but also in coastal areas that suffer natural perturbations. Ecological monitoring can be considered part of a regulatory system in which decision makers and managers of natural spaces are the controllers (Gray et al., 1991; Spellerberg, 1991; Kremen et al., 1994). The design of a monitoring strategy is one of the main components of ecological monitoring programmes (Vos et al., 2000). The zonation and monitoring strategy would vary according to the study area and the type of perturbation, but the results obtained would contribute towards better conservation management of the meadows.

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