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Decline of the seagrass *Posidonia oceanica* in response to environmental disturbance: a simulation-like approach off Liguria (NW Mediterranean Sea)

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Abstract

Posidonia oceanica is a slow-growing and long-lived Mediterranean seagrass, sensitive to reduction in water transparency that may damage or even kill the plant without possibility of recovery. Meadow decline has been evident especially in the northern Mediterranean Sea and is generally associated with human disturbance. In most cases the lack of information on *P. oceanica* distribution before disturbance does not allow the quantification of damage suffered by the meadows.

In this work we present an approach to quantify the decline of *P. oceanica* off Liguria. Seagrass bed distribution maps were analysed to mesoscale, working on the hypothesis that natural (rivers) and human (town and terrestrial links) disturbances had a cumulative, negative and long-term effect on *P. oceanica*. Curves of Disturbance (CD) were calculated comparing *P. oceanica* cover of defined physiographic units to five types of disturbance: river annual mean flows (m^3 s^{-1}), harbour surface (ha), coastal lengths (km) of towns and terrestrial links (roads and railways).

The curves allowed quantification of the decline of cover connected to each type of disturbance for each physiographic unit.

Keywords: disturbance, seagrass, *Posidonia oceanica*, Ligurian Sea.

Introduction

The importance of seagrasses in the maintenance of the coastal equilibrium, both from ecological and physical point of view, is accepted world-wide (Stevenson, 1988; Walker, 1989; Boudouresque & Meisnez, 1982). In the Mediterranean Sea *Posidonia oceanica* (L.) Delile colonises the sea-floor from 0 to 40 m depth and is very sensitive to environmental change (Mazzella & Buia, 1986). *P. oceanica* decline in coastal areas causes damage to littoral ecosystems and changes to the coast-line; the decline has been related to human impact and, in some cases, to variations in climatic conditions (Bellan-Santini & Picard, 1984; Blanc, 1975; Jeudy de Grissac, 1984; Jeudy de Grissac & Boudouresque, 1985; Blanc & Jeudy de Grissac, 1989; Pérès, 1984).

Monitoring of *P. oceanica* beds is becoming a useful tool to test the health of coastal environment and several countries have developed programs to study the distribution and the characteristics of seagrass beds (Benedito *et al.*, 1990; Boudouresque *et al.*, 1990; Mostafa *et al.*, 1990; Torres *et al.*, 1990).

The effect of different kinds of disturbances on seagrasses has been discussed by Clarke & Kirkman (1989) and Livingston (1984). Many studies have reported the decline of seagrass communities, but relatively few have linked these changes to human activity or natural stress, and very few have compared seagrass distribution before and after the disturbance event. These few studies were obtained by analysing historical maps, aerial photographs (Clarke & Kirkman, 1989; Sheperd *et al.*, 1989; Kirkman, 1990) or satellite image (Meisnez *et al.*, 1981).

Deep seagrass beds and turbid water may limit or nullify imagery techniques and the attempt to quantify seagrass cover. In these cases, aerial and satellite images are often integrated with or replaced by sonograms using side-scan sonar (Newton & Stefanon, 1975; Colantoni *et al.*, 1982; Gloux, 1984; Rey & Diaz Del Rio, 1989; Paillard *et al.*, 1993), an instrument used in large and medium scale *P. oceanica* survey (Meisnez *et al.*, 1981). Nevertheless the greatest problem arises when we want to quantify the areal extent of a perturbation (*sensu* Rykiel Jr, 1985 in: Clarke & Kirkman, 1989) and we do not have data prior the disturbance to compare with. In this paper we propose a theoretical approach, as applied to data on *P. oceanica* off Liguria (NW Italy). Large-scale sonogram analysis indicated a decline of beds close to human (towns, harbours, terrestrial links) and "natural" (rivers) sources of disturbance (Bianchi & Peirano, 1990, 1995). We did not have historic data on the extension of *P. oceanica* prior to the disturbance but old studies suggested that the seagrass occurred along all the coastline. So, to quantify and to relate seagrass decline to disturbance, we hypothesised that initially *P. oceanica* covered all the seafloors of the region between the surface and 20 m depth and with time each type of disturbance has caused a negative effect on the cover of *P. oceanica* meadows.

Material and methods

Study site

The inhabitants of Liguria have used sea routes for trade for many centuries; this was largely a response to the geomorphology of the region, characterised by high rocky coasts (Anselmi *et al.*, 1979). From the second half of the 19th century industrial development encouraged trade between the most important Ligurian harbours (Genova, Savona, Imperia) and Europe, leading to the rebuilding of Roman coastal roads and the construction of railways. The latter have had a major impact on the coast for half a century and have affected the social equilibrium dividing towns and villages. Sand from the beaches, gravel and clay from the rivers were used for construction and railway, and recently road tunnels were excavated throughout the region; along the railway line from Genova to La Spezia (89.5 km), for instance, 68 tunnels were excavated with a total length of 45 km (Coppedè, 1989). Excavated material was discharged into the sea without any control, creating ephemeral beaches or was used to build embankments to restrict coastal erosion that was probably induced by the same works. The amount of discharged material is unknown, but Fierro *et al.* (1974) report that dumping activities continued for nearly 24 years (since 1950) in eastern Liguria, and that in a two year period more than 240,000 m^3 of material were discharged along 8 km of coastline, approximately forty times greater than that discharged in the area by two rivers.

The construction of a military harbour at La Spezia, an international airport at Genova and numerous small tourist harbours resulted in the loss of seagrass beds, already limited by the narrowness of the continental shelf. In addition, all the rivers in the area over the last few decades have been canalised to prevent flooding, with an increase in water flow and sediment transport.

Survey methods

The seagrass distribution of Liguria was investigated in 1990 using the supply vessel M/n 'Vir Service' equipped with S.S.S. mod. Klein 590 (Bianchi & Peirano, 1990, 1995). The ship followed courses parallel to the coast between 5 and 40 m depth while the S.S.S. worked on a frequency of 100 kHz and with a range of 200 m on each side. *P. oceanica* meadows were directly observed with a Remotely Operated Vehicle (R.O.V. mod. Robertson Tritech Sprint 101). The deeper seagrass limits recognised with sonograms and with R.O.V. were classified following Colantoni *et al.* (1982) and Meisnez & Laurent (1978). The seagrass beds were mapped on a navigation chart to a scale 1:25,000.

Map analysis and mathematical approach

Side-scan sonar maps showed *P. oceanica* decline as large areas of dead 'matte' (i.e. the interlacing network of rhizomes, racemes and sediment within) or of erosion of the seagrass bed in front of towns, harbours, rivers, coastal roads and railways. For the purposes of this study two hypothetical sources of disturbance were considered giving rise to three forms of interaction with the seagrass beds in the area shown in Figure 1:

a) *P. oceanica* decline is identified by a well-defined, recognisable zone of dead matte or erosion in front of each source of impact. In this case the total decline D is the sum of the areas damaged by each single impact D = (D1+D2).

b) the areas D1 and D2 partially overlap; in this case the value of the total decline D is equal to the total damaged area of the seagrass bed but it is impossible to quantify the damage of each single impact D1 and D2.

c) One disturbance is so great that the decline D2 totally overlaps and masks the effect of the other disturbance D1. In this case the total decline D = D2.

Side-scan sonar maps showed that in Liguria the case c) was the most common, case b) occurred occasionally, while the case a) was virtually absent.

Working on the assumption that *P. oceanica* distribution between 0 and 20 m depth is closely related to hydrodynamic forces associated with coastal disturbances (Blanc & Jeudy de Grissac, 1989), we hypothesised:

Figure 1 a), b) and c): three cases of interaction between *P. oceanica* bed and two disturbances 1 and 2. D1 and D2 = damaged areas. d) Curves of Disturbances = CD1 and CD2; X1 and X2 = intensity of disturbance; P% = Percent *P. oceanica* cover.

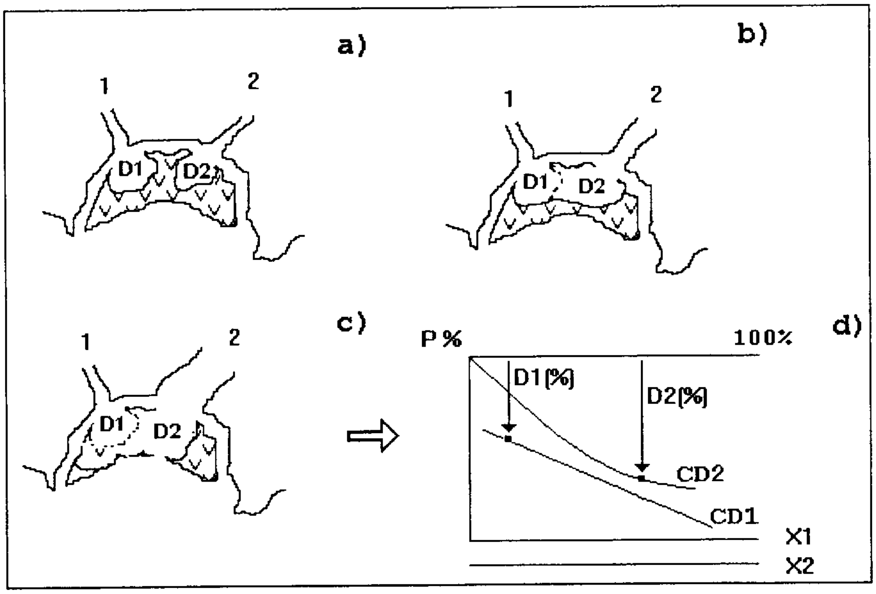
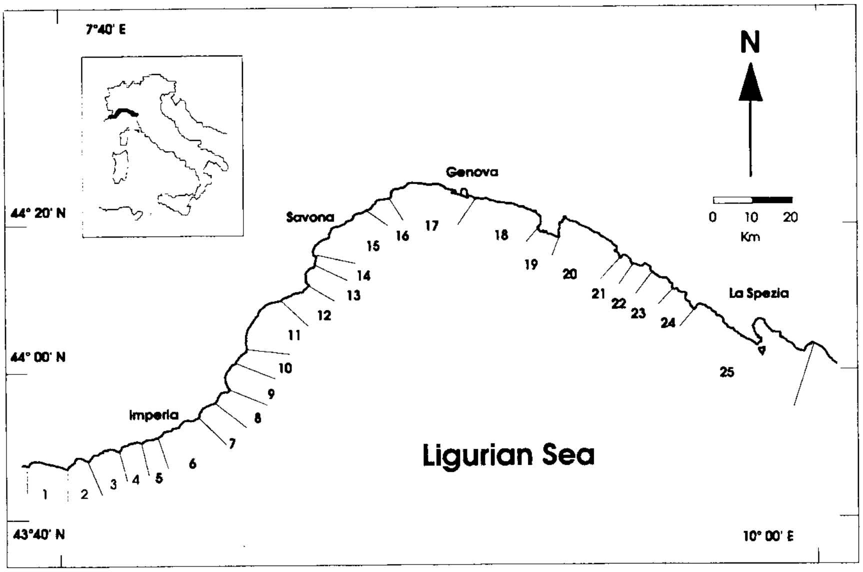


Figure 2 The coastline of Liguria province. Numbers indicate Physiographic Units (PU).



1) in the absence of disturbance *P. oceanica* covered the 100% of the seafloor between the surface and 20 m depth.

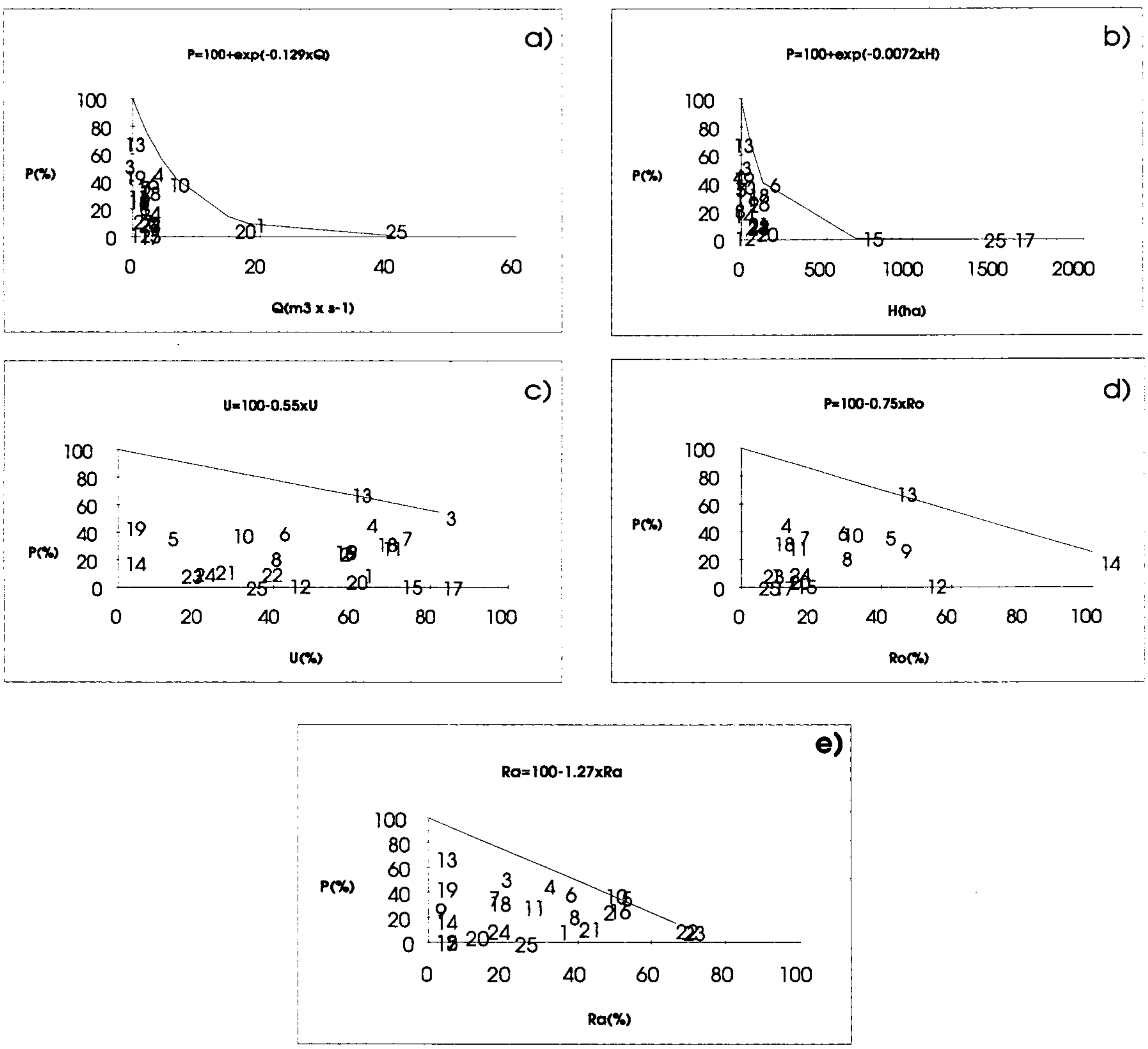
2) each one of the five major disturbances (town, railways, roads, harbours, rivers) had caused diminution of water transparency, a proportional diminution of seagrass cover (Neverauskas, 1988; Pirc, 1984; Duarte, 1991; Philippart, 1995) and the death of part the meadow without any possibility of recovery.

To relate *P. oceanica* decline to human (urbanisation, harbours, roads and railways) and "natural" (rivers) source of disturbance the surveyed area was subdivided in 25 physiographic units (PU) (Figure 2). Each length of coast delimited by a promontory or a cape and with an autonomous sedimentological budget was considered a PU. In the case of major harbours (Savona, Genova and La Spezia) or rivers with a known large influence on water transparency, the geographical limit of the PU was extended in the direction of known coastal drift (Onuf, 1994) as far as the first site where a *P. oceanica* meadow was found. The following measurements were made for each PU using a computer digitizer:

a) The present *P. oceanica* percentage cover (P).

b) The percentage length of coastal towns (U), considered representative of the urban disturbance on the coastal seagrass beds.

Figure 3 Graph of disturbance measured in each PU (on X axis) to *P. oceanica* percent cover (Y axis). The calculated Curve of Disturbances (CD) are shown with a line. a) annual average flow of rivers (Q); b) surface of harbours (H); c) percent length of coastal towns (U); d) percent length of coastal roads (Ro); e) percent length of coastal railways (Ra).



c) The percentage length of coastal railways (Ra) and roads (Ro) (except the ones included in the perimeter of urban areas). Values were considered representative of terrestrial link disturbances.

d) The surface of harbours (H). Values (ha) were considered representative of harbour disturbance.

The annual medium flow of rivers (Q) in $m^3 s^{-1}$ was considered representative of "natural" disturbance on seagrass distribution, though nearly all of them have been canalised.

A graph relating each type of disturbance, with measured disturbance values on X axis and P measures on Y axis of each PU is shown in Figure 3. The comparison of the distributions of the points on the five graphs with *P. oceanica* distribution maps showed that the point with greatest values of P corresponded to cases where there was a single dominant disturbance. In this case the curve or the line that fitted these points was designated as the Curve of Disturbances (CD) and was considered representative of the relationship between the impact and the seagrass decline. If it is assumed that the P values of each CD line were the percent cover of *P. oceanica* surviving at a given level of disturbance then the difference 100-P = D was the decline (as percent cover) of *P. oceanica* related to the disturbance (Figure 1d).

Results

Survey data indicated that *P. oceanica* meadows extended over a little less than 140 km of the coastline (nearly 42% of the length of the Ligurian coastline) and covered less than 4,800 hectares (10-15 % of the Ligurian sea floor between sea surface and 35 m depth).
The surface covered off western Riviera (Ventimiglia-Genova) is almost three times that off the eastern Riviera (Genova-La Spezia), where individual prairies were also smaller. The maximum depth of the lower limit was around 35 m, but receded to about 20 m in front of the areas with the highest urban and industrial development such as Genova and Savona. The upper limit, which in a few cases was still at the sea surface, was commonly below 10 m depth (Bianchi & Peirano, 1990). Beds of *Cymodocea nodosa* (a ruderal and pioneer species that replaces *P. oceanica*) extended over 114 km of the coastline and covered about 2,300 hectares, often growing on dead *P. oceanica* 'matte' (Bianchi & Peirano, 1995).

The plots of P values versus each one of the disturbance values (Q, H, U, Ro, Ra) measured in the PUs are shown in Figure 3 together with the five CD relationships, relating P to each one of the five disturbances. The comparison of the graphs with *P. oceanica* maps (Bianchi & Peirano, 1995) indicated that the points with greatest P values represented PUs where the considered disturbance had prevailed on the others. In the case of large rivers, for instance, maps provided evidence that interruptions of *P. oceanica* meadows were related to river flows, whereas other disturbances were insignificant. The computed CD relationships produced two exponential curves in relation to river flow and harbour areas and three linear equations in the case of roads and railways (Figure 3). Bianchi & Peirano (1995) showed that in front of rivers with Q values <15 $m^3 s^{-1}$ *P. oceanica* meadows were interrupted by erosional channels perpendicular to the coast. Where the flow rates were greatest *P. oceanica* disappeared and large areas were often colonised by *Cymodocea nodosa*. The hypothesis that the river created an interruption of *P. oceanica* meadows proportional to its flow was confirmed by the direct relationship (Figure 4) obtained by plotting average flows values of major Italian rivers flowing into the Ligurian and Tyrrhenian Sea versus the length (km) of *P. oceanica* meadow interruption in front of them. The data were derived from Bianchi *et al.* (1993) and unpublished sources.

Figure 4 Graph of mean annual flow (Q) of Italian major rivers (on X axis) to the length of interruptions (I) of *P. oceanica* meadows. Ligurian rivers: 1 = Lerone; 2 = Bisagno; 3 = Sansobbia and Letimbro; 4 = Centa; 5 = Entell; 6 = Roja; 7 = Magra. Rivers flowing in the Thyrrenian Sea: 8 = Volturno; 9 = Arno and Serchio; 10 = Tevere.

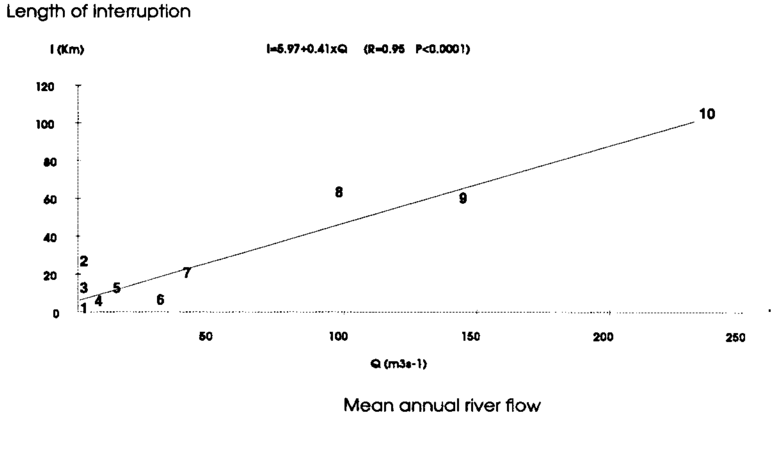


Table 1 Percent cover of *P. oceanica* (P) measured in each PU. For H, U, Q, Ro, Ra see the text. Du = Dumping; Ri = river with unknown flow; Pl = pipelines.

PU	cover	Type of disturbance							
	P	Q	H	U	Ra	Ro	other		
N°	0-20 m	$m^3 sec^{-1}$	ha	percent coastal length			Du	Ri	Pl
1	9.4	18.2		60.8	32.7	6.4		+	
2	25.5		4	54.9	45.1	0.0	+		
3	51.6		46	82.3	17.7	0.0	+	+	+
4	46.1	4.4		61.7	29.1	9.2	+	+	+
5	36.5		13	10.9	50.0	39.1		+	+
6	40.1	1.3	127	39.7	34.8	25.5			
7	36.7		13	71.0	14.5	14.5		+	
8	21.6		11	37.5	35.7	26.8		+	
9	26.9			56.4	0.0	43.6	+		
10	38.5	6.8	6	27.6	45.5	26.9	+		
11	29.3	0.5	8	65.6	23.3	11.1	+	+	
12	1.9		7	42.2	0.0	50.7	+	+	
13	68.0			57.7	0.0	42.3	+		
14	18.0			0.0	0.0	100.0	+		
15	1.6	0.9	671	70.7	15.9	13.5		+	
16	26.4	0.6		53.6	46.4	0.0	+	+	
17	0.7	2.3	1553	81.3	11.6	7.1		+	+
18	32.4			64.3	14.3	7.1		+	
19	43.9			0.0	0.0	0.0			
20	5.0	15.0	50	56.5	8.3	15.8	+		
21	11.9	1.4		23.2	38.4	0.0	+		
22	10.2			35.2	64.8	0.0	+	+	
23	9.0			14.4	66.8	0.0	+		
24	10.2			17.7	14.1	7.4	+	+	
25	0.4	40.6	1390	31.2	21.4	3.0	+	+	

An exponential relationship also relates surface of harbour (H) to percent cover of *P. oceanica* (Figure 3b) and confirms the similar declining effects observed in front of rivers and close to the harbours.

Terrestrial links (Ro and Ra) and town (U) can be compared because the same units are used for both disturbances (Figure 3c-e). The CD slopes showed that railway works had caused a greater decline of *P. oceanica* beds than road or urban works, and that 1 km of coastal road had been more destructive than 1 km of coastal town.

Damage related to other types of disturbance, such as the decline of *P. oceanica* in front of the numerous small sewage outfalls or connected to trawling and anchoring, could not be found at the scale of the present survey. This agrees with observations by Balduzzi *et al.* (1984), but such disturbances may be important on larger scale maps where there is greater detail (Balduzzi *et al.*, 1992; Sandulli *et al.*, 1992).

Dumping was more destructive and gaps caused by this activity were clearly recognisable in front of discharging sites shown on the maps of Bianchi & Peirano (1995). In some cases, side-scan sonar showed the presence of meadows buried under silt. In the surrounding benthos the meadows appeared ribbon-like, with lower depth limits that did not exceed 20 m.

Using each one of the five relationships the hypothetical P(hyp.) values were computed for each PU as were the associated declining effects D = 100-P(hyp.) in the absence of other disturbances. The maximum value of D in each PU (Dmax) was used to identify the major cause of disturbance (Table 2). The differences between Dmax and the true value of recent decline Dtot = 100-P of *P. oceanica* measured on the maps of Bianchi & Peirano (1995) for each PU was attributed to other

Table 2 Percentage *P. oceanica* decline (Dtot) measured on maps in each PU. Declines related to each disturbance (H, U, Q, Ro, Ra) were computed with the five CD relationships. Major values of decline (Dmax) are evidenced.

PU	Dtot	D related to each disturbance (%)					
N°	(%)	Q	H	U	Ra	Ro	A
1	90.6	90.4	0.0	33.5	41.6	4.8	0.2
2	74.5	0.0	3.3	30.2	57.3	0.0	17.2
3	48.4	0.0	28.7	45.2	22.5	0.0	3.2
4	53.9	43.3	0.0	33.9	37.0	6.9	10.7
5	63.5	0.0	9.2	6.0	63.5	29.4	0.0
6	59.9	15.1	60.2	21.8	44.1	19.2	-0.4
7	63.3	0.0	9.2	39.0	18.4	10.9	24.3
8	78.4	0.0	8.2	20.6	45.4	20.1	33.1
9	73.1	0.0	0.0	31.0	0.0	32.7	40.3
10	61.5	58.4	4.9	15.2	57.8	20.2	3.2
11	70.7	6.2	6.1	36.1	29.6	8.3	28.6
12	98.1	0.0	5.1	23.2	0.0	38.0	60.1
13	32.0	0.0	0.0	31.8	0.0	31.7	0.2
14	82.3	0.0	0.0	0.0	0.0	75.0	7.3
15	98.4	19.2	99.2	38.9	20.1	10.1	-0.8
16	73.6	6.8	0.0	29.5	59.0	0.0	14.6
17	99.3	24.9	100.0	44.7	15.2	5.3	-0.7
18	67.6	0.0	0.0	35.3	18.2	5.4	32.2
19	56.1	0.0	0.0	30.9	0.0	0.0	25.2
20	95.0	85.5	30.7	31.1	10.5	11.9	9.6
21	88.1	15.6	0.0	12.8	48.8	0.0	39.3
22	89.8	0.0	0.0	19.4	82.3	0.0	7.5
23	91.0	0.0	0.0	7.9	84.8	0.0	6.2
24	89.8	0.0	0.0	9.8	17.9	5.6	71.9
25	99.6	99.5	100.0	17.2	27.1	2.2	-0.4

causes of disturbance not quantified (see Table 1). Taking this further, Dtot-Dmax = A, where A is decline related to non-significant disturbances plus the error of the estimate.

Values of A were considered to mainly an expression of the effects of dumping. This disturbance was found everywhere and appeared to be dominant. To test the validity of A values we used two approaches:

a) There should be a relationship between P and A.

b) Using maps from Bianchi & Peirano (1995) the percent decline of *P. oceanica* meadows (D) in front of discharging sites was calculated and compared with values of A.

In the first case we found a direct relationship between ln (A) and P ($R = 0.705$, $P = 0.003$) with a standard error of Y estimates equal to 13.4%. In the second case we estimated that in the 4 sites with more apparent dumping damages the average difference between the observed decline and A was 10.7% (with a standard error equal to 6.95).

Conclusions

The general decline of *P. oceanica* meadows observed by Bianchi & Peirano (1995) is clearly correlated to impacts from disturbances. Small rivers or harbours caused gaps in facing *P. oceanica* beds and clearings and channels in nearby meadows. The *P. oceanica* meadows next to town, ports and terrestrial links have been eroded by long-shore and rip currents altered by coastal defensive works (Blanc, 1975; Blanc & Jeudy de Grissac, 1989; Góngora Gonzáles *et al.*, 1995)

Dead *P. oceanica* was replaced in most places by *C. nodosa* (Pérès & Picard, 1964). The greatest occurrence of *C. nodosa* was in front of rivers, but colonisation was limited in depth to less than 20 m so that the actual biomass was less than the potential *P. oceanica* biomass.

At a working scale of 1:25,000 the CD relationships described make it possible to quantify the past decline of *P. oceanica* caused by human or natural disturbances. They also may be useful in predicting future changes. Given knowledge of the chronological succession of events within each PU, e.g. if a coastal railway line was built before or after a coastal road, then it is possible to indicate i) which disturbance created the greatest damage using D values, ii) the relative diminution of *P. oceanica* cover connected to each type of disturbance from the difference between the 'D' values, and iii) the expected percent decline of the meadow can be calculated for future works.

Obviously, this approach has several limitations: some working hypothesis, as the presence of 100% *P. oceanica* cover in the case of absence of disturbance, might be revisited in some regional situations and tested by applying the method to other species of seagrasses. The limits of the individual PUs may be re-defined in the presence of local or new type of disturbances (see, for example, the blowout movements in Clarke & Kirkman, 1989). The method has to be optimised for lower working scales, where coastline variations may affect percent cover estimates. CD relationships have to be tested again and improved for unknown disturbances such as dumping. Finally, the method proposed here has to be used in conjunction with a good knowledge and analysis of the historical changes of the local marine environment.

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