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Monitoring methods for *Posidonia oceanica* seagrass meadows in Provence and the French Riviera

Charles F. BOUDOURESQUE, Guillaume BERNARD, Patrick BONHOMME, Eric CHARBONNEL, Laurence LE DIRÉACH and Sandrine RUITTON

UMR 6540 CNRS, Centre d'Océanologie de Marseille, and GIS Posidonie, Campus universitaire de Luminy, case 901, 13288 Marseille cedex 9, France

Abstract. The *Posidonia oceanica* meadow constitutes a key ecosystem in the sublittoral zone of the Mediterranean, from both an ecological and physical equilibrium perspective. In addition, it harbors a very high species diversity. *Posidonia oceanica* beds are very sensitive to disturbances caused by human activity (*e.g.* coastal development, pollution, turbidity, anchoring, etc.) and their loss has been observed in a number of regions. The aim of the monitoring of *P. oceanica* meadows along the Provence and French Riviera coasts is (i) to evidence possible new losses and (ii) to evaluate through a biological indicator the efficiency of regional policies (*e.g.* setting up of sewage treatment plants, reduction in industrial and domestic pollution levels in the rivers flowing towards the Mediterranean, establishment of Marine Protected Areas, banning of new harbors and reclamations). Monitoring tools operate at three scales: (i) system scale (aerial photographs, measurement of bottom cover, permanent transects), (ii) meadow scale (*e.g.* photographs of *Posidonia* around cement markers positioned along meadow limits, shoot-density, permanent quadrats) and (iii) shoot scale (*e.g.* plagiotopic to orthotropic rhizome ratio, laying bare of the rhizomes, lepidochronology, leaf epiphytes, leaf biometry). Several monitoring programs are based on these tools, or some of them. The Posidonia Monitoring Network (PMN; RSP in French) is the most extensive. It was set-up in 1984 and concerns 33 survey sites. Between 1984 and 1999, the percentage of sites at which the *P. oceanica* meadow was seen to be in expansion increased from 21 to 42%. This is consistent with the increase in the percentage of sewage which is processed in treatment plants, from less than 10% in the early 1980s and close to 100% today.

Résumé. L'herbier à *Posidonia oceanica* est l'un des écosystèmes majeurs du littoral de la Méditerranée, en raison de son importance écologique et de son rôle dans les équilibres sédimentaires littoraux. Par ailleurs, c'est un "point chaud" pour la diversité spécifique. Les herbiers à *P. oceanica* sont très sensibles aux perturbations humaines (*e.g.* aménagement littoral, pollution, turbidité, ancrage, etc.) et leur régression concerne une grande partie de la Méditerranée. Les objectifs de la surveillance des herbiers à *P. oceanica* sur le littoral de la Provence et de la Côte d'Azur sont (i) de mettre en évidence d'éventuelles nouvelles régressions et (ii) d'évaluer, au moyen d'un indicateur biologique, l'efficacité de la politique régionale (*e.g.* la mise en service de stations de traitement des eaux, la réduction de la pollution apportée par les bassins versants et les fleuves, la création d'Aires Marines Protégées et l'interdiction des endigages et de la création de nouveaux ports). Les outils de surveillance se situent à trois échelles : (i) l'échelle de l'écosystème (photographies aériennes, recouvrement, transects permanents), (ii) l'échelle de l'herbier (*e.g.* photographies de *Posidonia* devant des balises mises en place à la limite de l'herbier, densité des faisceaux, carrés permanents) et (iii) l'échelle du faisceau (*e.g.* rapport entre rhizomes plagiotropes et orthotropes, déchaussement des rhizomes, lépidochronologie, épibiontes des feuilles, biométrie des feuilles). Un certain nombre de programmes de surveillance sont basés sur ces outils, ou sur une partie d'entre eux. Le "Réseau de Surveillance Posidonies" (RSP) est le plus important ; il a été mis en place en 1984 et concerne 33 sites. Entre 1984 et 1999, le pourcentage de sites où *P. oceanica* a été en expansion est passé de 21 à 42%. Ce résultat est cohérent avec l'accroissement du pourcentage des eaux usées traitées dans des stations d'épuration, qui est passé de 10% au début des années 1980s à près de 100% aujourd'hui.

INTRODUCTION

Posidonia oceanica (Linnaeus) Delile is a flowering plant (Magnoliophyta, Embryobionta, Plantae) endemic to the Mediterranean Sea. It constitutes broad meadows in the sublittoral zone, from the sea-level down to 25-40 m depth (according to water limpidity). The *P. oceanica* meadow constitutes a key ecosystem in the Mediterranean, from the biological, physical equilibrium and economic points of view, offering very high primary production, export of a large part of this production (as dead leaves) to other ecosystems, a spawning site and nursery for many species of crustaceans and fishes of economic importance, control of sediment fluxes and protection of beaches against erosion. In addition, it harbors a very high species diversity: 20-25% of the species known from the Mediterranean can be found in the *P. oceanica* ecosystem (Molinier and Picard, 1952; Picard, 1965a; Boudouresque and Meinesz, 1982; Boudouresque *et al.,* 1994b).

The *P. oceanica* meadows are very sensitive to disturbance caused by human activity. As a result, in the course of the 20th century, and more especially since the 1960s, the loss of *P. oceanica* beds has been observed in a number of regions. This regression has been particularly dramatic in the vicinity of major urbanized zones and port facilities: Barcelona (Spain), Marseilles, Toulon, Nice (France), Genoa, Naples (Italy), Athens (Greece), Gabès (Tunisia), etc. (Boudouresque and Meinesz, 1982; Astier, 1984; Pérès, 1984; Gravez *et al.,* 1992; Chessa and Fresi, 1994; Bianchi and Peirano, 1995). The main causes of this loss are as follows: coastal development (ports, reclamations), groynes which alter sediment transport, beach replenishment, pollution, fish farming, water turbidity which reduces available light at depth, anchoring, illegal trawling and blast fishing (Meinesz *et al.,* 1981, 1982; Ardizzone and Pelusi, 1984; Augier *et al.,* 1984; Boudouresque and Meinesz, 1982; Boudouresque and Jeudy de Grissac, 1983; Meinesz *et al.,* 1991; Bianchi and Peirano, 1995; Boudouresque *et al.,* 1995; Delgado *et al.,* 1999; Pasqualini *et al.,* 2000; Diviacco *et al.,* 2001; Ruiz and Romero, 2001).

Due to its ecological role and to growing concern about its decline, *P. oceanica* is now a protected species in Spain and France. It is listed in Appendix I of the Bern and Barcelona international Conventions. In addition, *Posidonia* beds feature in Appendix I (natural habitat types of Community interest whose conservation requires the designation of special areas of conservation) of the European Community Council Directive 92/43/EEC of 21 May 1992. Finally, according to the Action Plan for the Conservation of Marine Vegetation in the Mediterranean Sea (United Nations Environment Programme), particular attention must be paid to *P. oceanica* (Pergent, 1991; Boudouresque *et al.,* 1994a, 1996; RAC/SPA, 1999).

The purpose of the monitoring of *P. oceanica* meadows is twofold. (i) To monitor a high value natural heritage in order to quickly detect any new loss. (ii) To utilize this ecosystem as a biological indicator in order to allow overall assessment of the quality of the littoral marine environment and to evaluate the efficiency of regional policies, e.g. the setting up of sewage treatment plants, the reduction in industrial and domestic pollution levels in the rivers flowing towards the Mediterranean, the establishment of Marine Protected Areas (MPAs) and the banning of new harbors and reclamations (Boudouresque *et al.,* 1990, 1994a; Charbonnel *et al.,* 1993; Pergent *et al.,* 1995; Boudouresque *et al.,* 2000).

MONITORING TOOLS

The monitoring tools for *Posidonia oceanica* meadows operate at three spatial scales: (i) system scale (aerial photographs, measure of bottom cover, permanent transects), (ii) meadow scale (cement markers laid down at the upper lower limits of the meadow, shoot density and permanent quadrats) and (iii) shoot scale (plagiotropic to orthotropic rhizome ratio, laying bare of the rhizomes, sediment granulometry, lepidochronology, biometry, leaf epiphytes and leaf biometry). These tools have been progressively improved as experience has been gained and scientific research techniques have evolved (Charbonnel *et al.,* 1993; Niéri *et al.,* 1993a; Boudouresque *et al.,* 2000).

Cement markers

A dozen or so permanent cement markers are laid down at the lower limit (every 5 m) and at the upper limit (every 5-15 m) of the *P. oceanica* meadow (Harmelin, 1976; Meinesz, 1977). A buoy is placed above each marker in order to make it easier to locate for divers (Fig. 1, 2). A 0.5 m high "photo-stand" is placed 1.5 m ahead of each marker, facing the meadow limit. During the field survey, three photographs of the marker, a graduated scale and the surrounding meadow are taken from the top of the "photo-stand" (Fig. 3); the camera is equipped with a 15 or a 35 mm lens (Charbonnel *et al.,* 2000a).

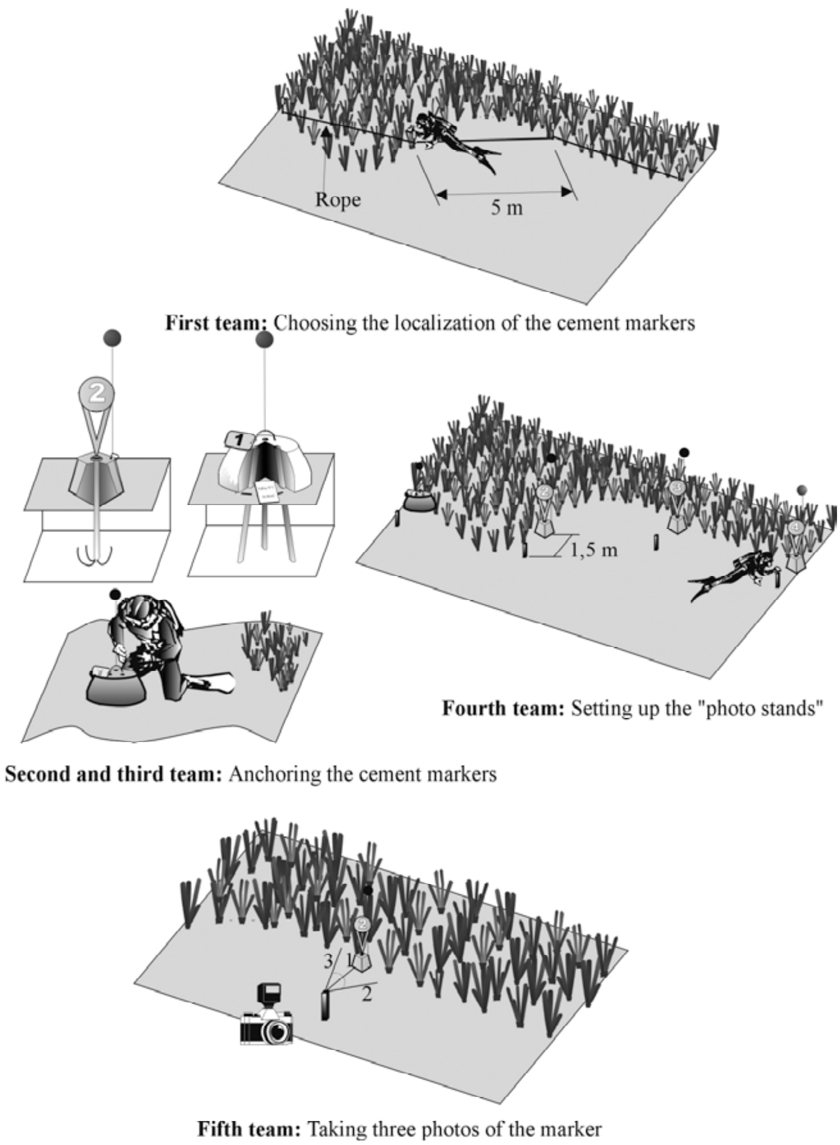

Fig. 1. Five teams of divers are involved in the setting up and first survey of a set of cement markers. From Charbonnel *et al.* (2000a), modified.

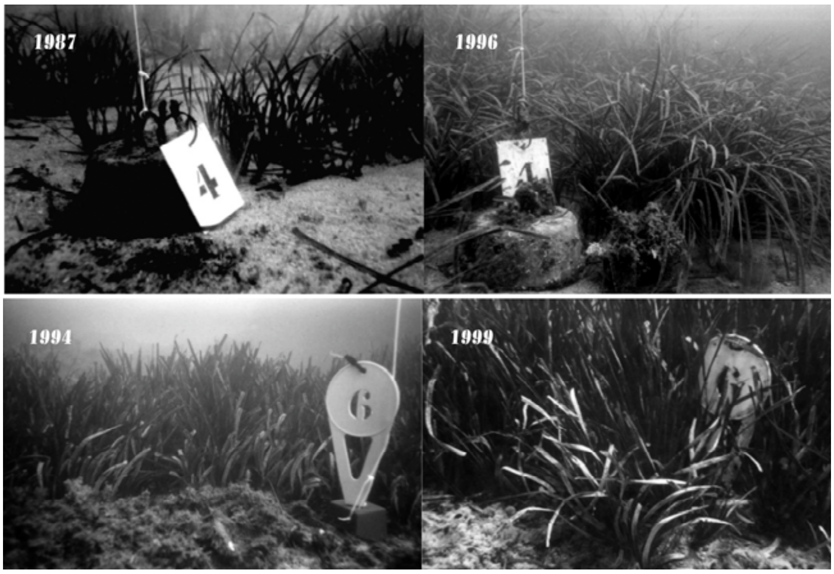

Fig. 2. Cement marker Nr 4 at the lower limit of a *Posidonia oceanica* meadow, Niolon (West to Marseilles), 26 m depth. 1987 (above left) and 1996 (above right): the meadow is in expansion (photos CQEL 13). Cement marker Nr 6 at the upper limit of a *P. oceanica* meadow, Cassis (East to Marseilles), 10 m depth. 1994 (below left) and 1999 (below right): the meadow is in expansion (photo E. Charbonnel).

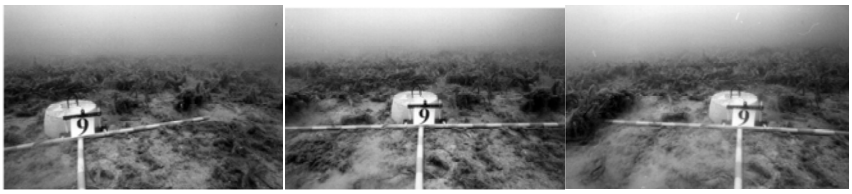

Fig. 3. Cement marker Nr 9, at the lower limit of a *P. oceanica* meadow, Golfe Juan (near Nice), 31 m depth. During each field survey, three photographs of the marker, a graduated scale and the surrounding meadow are taken from the top of the "photo-stand" (photo A. Meinesz).

Aerial photographs

Selected shallow (< 10-15 m) sites are monitored by means of aerial photographs, according to a standardized protocol (altitude, lens, angle, time of day, definition, contrast, etc.). The monochrome photographs (stereoscopic pairs; scale 1/4 500) are digitalized and processed by computer in order to obtain a 1/1 000 scale map ("orthophotoplan"). This processing technique is analogous with that used for orthophotography, and involves geometrical rectification or transformation on the basis of accurately located landmarks. On the basis of these orthophotoplans, the boundaries of the benthic structures are then identified. While a light area generally indicates a patch of sand, a dark area might indicate either the presence of a *P. oceanica* bed, or accumulations of dead *P. oceanica* leaves on the sea floor; intermediate shading usually corresponds to "dead matte[1]" or photophylous algal communities on rocks. Subsequently, these boundaries are validated *in situ* by divers ("ground truth") (Lefèvre *et al.,* 1984; Niéri *et al.,* 1993; Pergent-Martini *et al.,* 1995a; Charbonnel *et al.,* 2000a).

Measurement of bottom cover and shoot density

The bottom cover is the mean percentage of substrate covered by the *P. oceanica* meadow (whatever the shoot density within the meadow or within patches of *P. oceanica*), with respect to the whole surface area (sand, mud, algal communities on hard bottoms, dead "matte" and live *Posidonia* meadow). In shallow healthy meadows, the *Posidonia* cover can be high (80-100%). In contrast, at the lower limit of healthy meadows and in meadows subject to strong human impact, the cover usually ranges between 5 and 40% (Pergent *et al.,* 1995; Charbonnel *et al.,* 2000a). The bottom cover is measured by means of a 30 cm x 30 cm see-through plastic slide divided into nine 100 cm^2 squares. The diver, swimming 3 m above the bottom and holding the slide at arm's length, counts the number of squares occupied (more or less totally) by *P. oceanica* (Fig. 4); 30 measurement is performed at similar distance interval (*e.g.* the same number of flipper strokes). Reproducibility is good: an ANOVA Kruskal-Wallis non-parametric test does not evidence significant differences between divers (Gravez *et al.,* 1995).

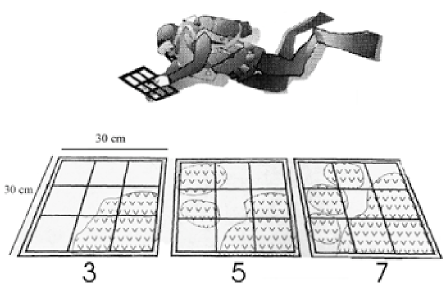

Fig. 4. Measure of the bottom cover by a diver swimming 3 m above the bottom and holding a see-through plastic slide at arm's length (above). Three examples of counting the number of squares occupied by *P. oceanica,* respectively 3, 5 and 7 (below). From Gravez *et al.* (1995).

The shoot density is the mean number of living *P. oceanica* shoots per surface area unit. Only bottom areas occupied by the meadow are taken into consideration (Giraud, 1977). The measurement is performed within 20 cm x 20 cm quadrats, with at least 30 replicates per site (Pergent-Martini and Pergent, 1996; Charbonnel *et al.,* 2000a). It is worth noting that depth explains 54% of the shoot density variability: it naturally declines with increasing depth (Table I; Pergent *et al.,* 1995). In addition, when isolated *P. oceanica* patches are easy to localize near a cement marker (see above), a census of the number of shoots is carried out.

Permanent transects

Permanent transects are set up perpendicular to the limits of *P. oceanica* meadows, or perpendicular to the isobaths. They are a few tenths to several hundred meters long. They are materialized by permanent cement markers every 50-100 m. During the field survey, a graduated line is laid between the markers. Communities crossed by the line (in fact a band of 2 m width) are noted: sand, mud, algal communities on hard bottoms, dead "matte" and live *Posidonia* meadow (Fig. 5). Limits are noted to within 20 cm, but actual accuracy does not exceed 50 cm, due to imprecision in the line positioning (Gravez *et al.,* 1992).

Table I. Subnormal, almost regular and regular density of *Posidonia oceanica* shoots, according to depth. From Pergent *et al.* (1995), modified.

Depth (m)	subnormal density	almost regular density	Regular density
1	< 822	822-934	> 934
5	< 413	413-525	> 525
10	< 237	237-573	> 573
15	< 134	134-246	> 246
20	< 61	61-173	> 173
25	< 4	4-116	> 116
30	-	< 70	> 70
35	-	< 31	> 31
40	-	-	> 1

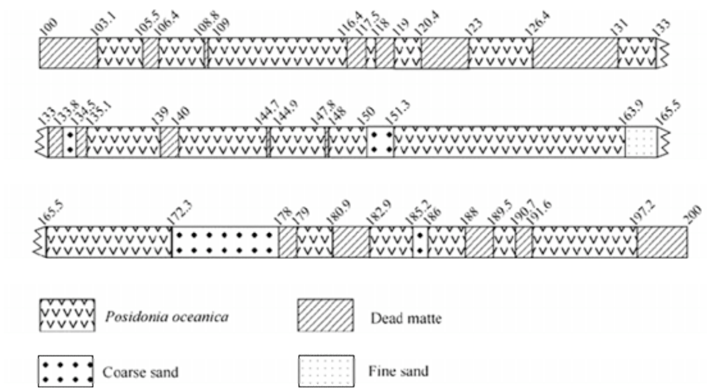

Fig. 5. An example of communities crossed by the graduated line laid between cement markers, along a permanent transect in the Prado Bay, Marseilles (metres 100 through 200).

[1] Intertwined living and dead *P. oceanica* rhizomes, together with the sediment which fills the interstices, constitute the "matte". Rhizomes decay little and can persist within the matte for millennia. As a result, when *P. oceanica* shoots die, a so-called "dead matte" still occupies the bottom (Boudouresque & Meinesz, 1982)

Permanent quadrats

Permanent quadrats are materialized by 8 cement markers (at the corners and in the middle of the sides). They usually measure 6 m x 6 m (Fig. 6; Gravez *et al.,* 1992).

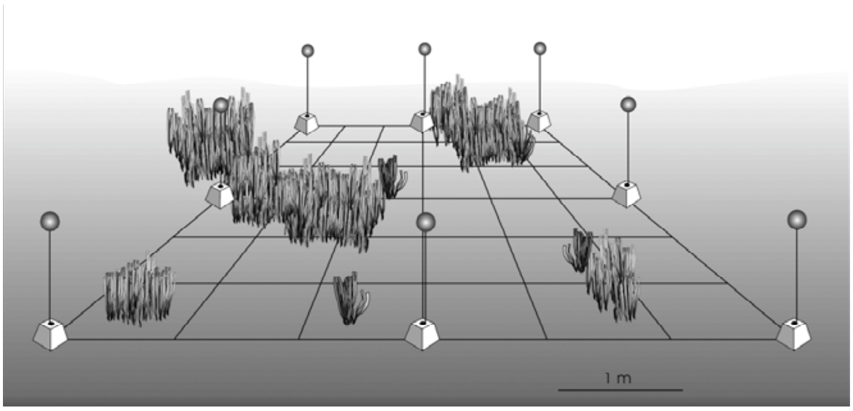

Fig. 6. Sketch of a permanent quadrat set up in a degradated *P. oceanica* meadow.

Larger quadrats (10 m x 10 m) have also been set up (Boudouresque *et al.,* 1981); however, mapping them was too time-consuming. During field surveys, the permanent quadrat is divided by ropes into squares of 1 m^2. Within each square, communities occurring (the same as above) are mapped to an accuracy of 20 cm (Fig. 7; Gravez *et al.,* 1992).

Tools at shoot scale

At the limit of the meadow and of *P. oceanica* patches*,* the occurrence of plagiotropic shoots (rhizomes growing horizontally) is evidence of health, since it expresses a tendency to colonize (or re-colonize) neighboring areas (Table II and Fig. 8; Charbonnel *et al.,* 2000a).

Fig. 8. Plagiotropic shoots (rhizomes growing horizontally) at the lower limit of a *P. oceanica* meadow. Photo C.F. Boudouresque.

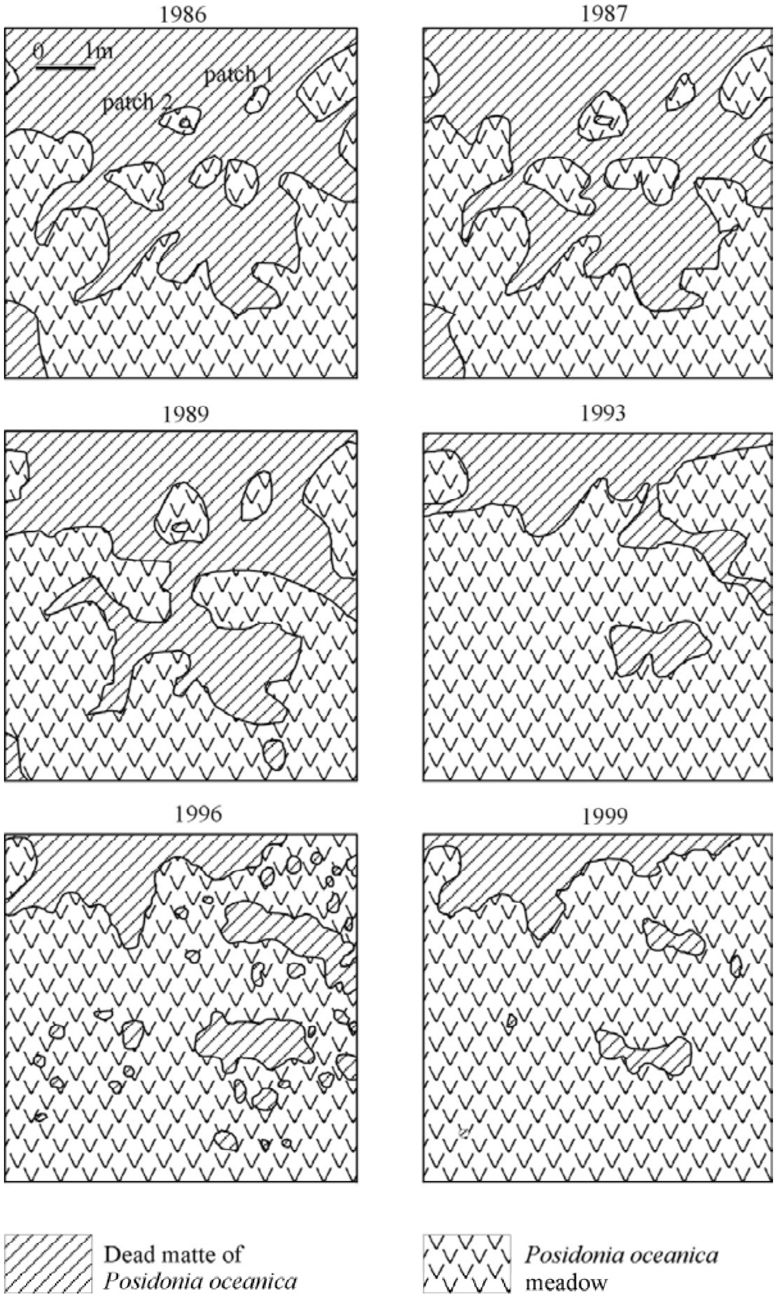

Fig. 7. A set of surveys (1986 through 1999) of the permanent quadrat PQ1 set up at 10 m depth, in the Prado Bay (Marseilles, Bouches-du-Rhône). See Fig. 11 for localization. From Gravez *et al.* (1999).

Table II. Measuring the vitality of *Posidonia oceanica,* at the limit of a meadow, as the percentage of plagiotropic shoots compared to all shoots, either plagiotropic (creeping) or orthotropic (erect). From Charbonnel *et al.* (2000a).

Percentage of plagiotropic shoots	Interpretation
< 30%	Stable meadow
30 through 70%	Slight tendency to spread
> 70%	Clear tendency to spread

The laying bare of the rhizomes results from a deficit in the sediment balance of the meadow: the amount of sediment trapped by the leaf canopy together with the deposition of biogenic debris (*e.g.* mollusk shells, sea-urchin spines, coralline algae) is lower than the amount exported during strong water movement episodes. The laying bare is measured according to the Boudouresque *et al.* (1980) protocol. (i) Plagiotropic (creeping) rhizomes: the distance between the sediment (ground level) and the lower part of the rhizomes. (ii) Orthotropic (erect) rhizomes: the distance between the sediment and the basis of the lowest external leaf, reduced by 2 cm (Fig. 9).

Fig. 9. The laying bare of orthotropic (erect) rhizomes, at the lower limit of a *P. oceanica* meadow. In the foreground, some shoots are dead. Note also the occurrence of three individuals of *Holothuria* sp. (sea cucumbers). Photo C.F. Boudouresque.

The granulometry (grain size distribution) of the sediment is indicative of water movement. Sediment traps (Gardner, 1980) provide information about sediment balance and siltation. Sediment balance can account for *P. oceanica* loss: indeed, according to Boudouresque *et al.* (1984), when the sediment balance is over 6-7 cm/a, the *P. oceanica* shoots die. In addition, sand waves can bury the meadow, including the cement markers, which of course results in the regression of the *P. oceanica* meadow limit.

When *P. oceanica* leaves die, only the blade falls away; the sheath remains attached to the rhizome. Sheath thickness, together with its anatomical structure, show cyclical variations according to insertion rank along the rhizomes. These cyclical variations have a chronological significance with each cycle corresponding to a one-year period. This phenomenon appears to resemble variations observed in tree ring thickness (dendrochronology). By analogy, the study of these cyclical variations has been termed "lepidochronology" (Crouzet, 1981; Crouzet *et al.,* 1983; Pergent *et al.,* 1989; Pergent, 1990). In addition to the chronological significance of *P. oceanica* sheath cycles, other parameters are recorded by the sheaths: growth rate of the rhizomes, number of leaves produced during an annual cycle, primary production and their change from year to year, according to sedimentation rate, water quality and climatic parameters. As a result, lepidochronology provides a tool for back-dating past events (Calmet *et al.,* 1988; Pergent *et al.,* 1992; Pergent-Martini and Pergent, 1994; Pergent-Martini, 1998).

Posidonia oceanica leaves constitute a substrate for epiphytes: Fucophyceae (mainly Ectocarpales), Rhodophyta (mainly Acrochaetiales and Corallinales), Bryozoa, Hydrozoa, etc. Their biomass exhibits a seasonal cycle, with a maximum from March to September (Thélin and Bedhomme, 1983). This biomass is higher at those sites presenting high nutrient and/or organic matter levels (Jupp, 1977; Pergent-Martini *et al.,* 1995b, 1999). Epiphyte biomass thus provides information concerning environmental quality and facilitates assessment of the range of impact of a natural or artificial discharges (outfall), aquaculture facilities, river mouth. However, due to its seasonal variations, comparisons must be restricted to measurements performed at an identical period of the year (Pergent-Martini *et al.,* 1999). In addition, herbivore pressure lowers the epiphyte biomass, so that interpretation must be undertaken with caution.

Leaf biometry corresponds to a set of measurements which are used to describe a seagrass bed. Several indices are generated based on the biometric measurements: (i) Number of leaves per shoot. (ii) Length of adult leaves (leaves whose growth is over). (iii) Leaf surface area per shoot (expressed in cm^2). (iv) Leaf area index (LAI, in m^2/m^2). And (v) Coefficient A (percentage of leaves having lost their apex). Parameters (i) through (iv) provide information as to the vegetative development of the plant, whereas Coefficient A can indicate either the level of herbivore pressure (characteristic grazing marks) or the prevailing hydrodynamic conditions (mainly for shallow sites) (Drew and Jupp, 1976; Giraud, 1977, 1979; Giraud *et al.,* 1979; Panayotidis and Giraud, 1981; Meinesz and Boudouresque, 1982; Pergent-Martini *et al.,* 1999).

As for the epiphyte biomass, due to seasonal variations, comparisons must concern an identical period of the year.

THE MAIN MONITORING SYSTEMS

Various sets of the above mentioned tools are combined for monitoring systems, either at local or regional scale.

The Posidonia Monitoring Network

The Posidonia Monitoring Network (PMN; in French: RSP, Réseau de Surveillance Posidonies) is the main monitoring system of *P. oceanica* beds in Provence and the French Riviera (Région Provence-Alpes-Côte d'Azur). It was set up in 1984, at the request of the regional government of the Provence and French Riviera region, and is a joint project involving the elected representatives, the state maritime services (Bouches-du Rhône, Var and Alpes-Maritimes departments) and the scientists from the GIS Posidonie NGO (Non-Governmental Organization) (Boudouresque *et al.,* 1990; Charbonnel *et al.,* 1993; Niéri *et al.,* 1993; Boudouresque *et al.,* 2000).

In 1984, 24 monitoring sites were selected along the 650 km of the Provence and French Riviera coastline. An additional 9 sites were added in 1994, bringing the number of sites monitored by the PMN to 33 (Fig. 10). These sites are either located (i) in sensitive areas (where human impact is high and where *P. oceanica* seagrass beds are likely to regress), (ii) in reference areas which are *a priori* not exposed to high levels of human impact and where the seagrass beds are likely to be either stable or on the increase, or finally (iii) in zones presenting intermediate characteristics (Boudouresque *et al.,* 2000; Charbonnel *et al.,* 2000a). The PMN survey sites are located at the two extremes of the *P. oceanica* bathymetric range: at its upper growth limit (15 sites) and its lower growth limit (18 sites). It is at these limits that the seagrass bed is most sensitive to changes in environmental conditions. The tools used are: aerial photographs validated by ground truth, photography of the cement markers laid down at the limits, measurement of bottom cover, shoot density, laying bare of the rhizomes, plagiotropic to orthotropic rhizome ratio, lepidochronology and leaf biometry.

Given the slow growth rate of *P. oceanica,* the monitoring of each site is performed every three years. The chronology of the PMN activities has thus been as follows: 1984-87 period (selection of the sites and assessment of initial conditions), 1988-90 period (first-time return to the sites), 1991-93 period (second return), 1994-96 period (third return) and 1997-99 (fourth return) A fifth period (2000-2002) is on-going

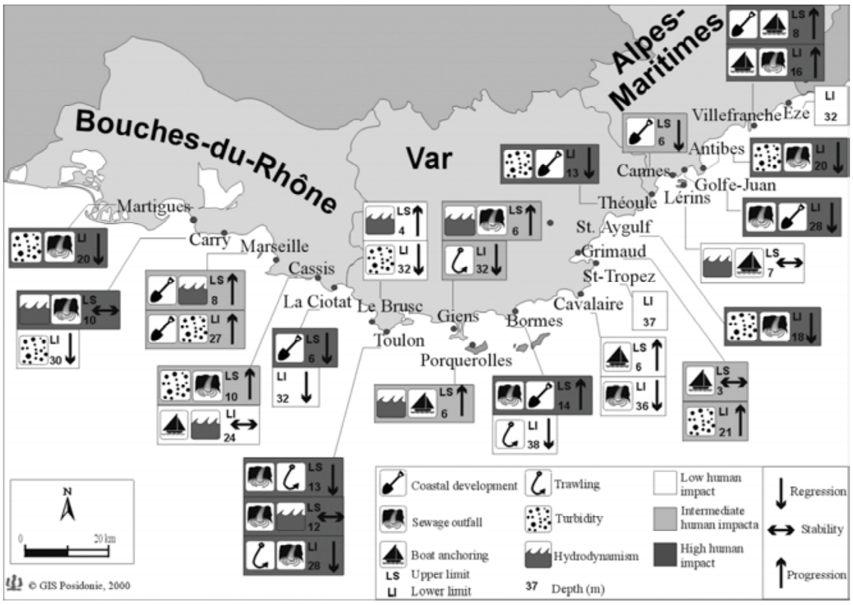

Fig. 10. Location of the 33 sites surveyed by the Posidonia Monitoring Network (PMN) in the Provence and French Riviera region. For each site, main threats and mean trends of *Posidonia* meadows. From Boudouresque *et al.* (2000).

(Boudouresque *et al.*, 1990; Charbonnel *et al.,* 1993; Niéri *et al.,* 1993a; Charbonnel *et al.,* 1994, 1995a, 1995b; Boudouresque *et al.,* 2000; Charbonnel *et al.,* 2000b, 2001; Ruitton *et al.,* 2001b).

Over the 15 years of monitoring, *P. oceanica* seagrass bed dynamics have exhibited two opposite trends (Table III). At its upper growth limit, a steady decrease in the number of losses can be observed. Conversely, at its lower limit, losses of *P. oceanica* beds are on the increase. Overall, from 1988-90 to 1997-99, the percentage of limits either undergoing loss or stable has decreased (79% à 59%), with a corresponding increase in limit extension (Table III; 21% à 42%). For each site and each period, a dynamic score has been ascribed as follows: 0 = very extensive loss; 1 = extensive loss; 2 = slight loss; 3 = stability; 4 = slight expansion; 5 = important expansion. The H_0 hypothesis (no change between 1988-90 and 1997-99) is rejected for the upper limits (Table IV; McNemar test for the significance of changes and binomial test; Siegel, 1956). Closer scrutiny of the data, however, reveals that noticeable differences occur between the different regions (*e.g.* East *vs* West of the monitored area), and that the changes in a given site are not always constant; alternating phases of loss and expansion can occur (Boudouresque *et al.,* 2000).

Table III. Changes with time in *P. oceanica* meadows (loss, stability or expansion) as a percentage of the 24 sites initially set-up in 1984-1986 by the PMN, during the 5 survey periods. Note that the 2000-2002 period is incomplete. From Boudouresque *et al.* (2000), updated.

		1988-1990	1991-1993	1994-1996	1997-1999	2000-2002
Loss	Upper limit	42	25	17	17	8
	Lower limit	50	45	67	67	67
	All sites	**46**	**35**	**42**	**42**	**38**
Stability	Upper limit	50	42	58	33	50
	Lower limit	17	36	8	0	0
	All sites	**33**	**39**	**33**	**17**	**25**
Expansion	Upper limit	8	33	25	50	42
	Lower limit	33	18	25	33	33
	All sites	**21**	**26**	**25**	**42**	**38**

Table IV. Changes with time in the mean dynamic score (see text) of the sites surveyed by the PMN, at the upper limit and at the lower limit of *P. oceanica* meadows. Computed from data in Charbonnel *et al.* (2001). NS = non- significant. Binomial test between 1988-90 and 1997-99. Note that the 2000-2002 period is incomplete.

	Number of sites	1988-1990	1991-1993	1994-1996	1997-1999	2000-2002	Binomial test
Upper limit	12	2.5	3.1	3.1	3.6	3.5	p = 0.002
Lower limit	12	2.4	2.4	1.9	2.2	2.3	NS

The Marseilles Prado Bay monitoring system

Prado Bay (Marseilles) was in the past occupied by a vast *P. oceanica* meadow (Marion, 1883; Picard, 1965b). Subsequently, this meadow has been subject to severe impact due to human activities, namely artificial beaches, two harbors devoted to pleasure craft, turbidity induced by the construction of these harbor facilities, industrial pollution brought by a coastal river and industrial and domestic pollution from an untreated sewage outfall located at Cortiou, 10 km upstream of the dominant current (Niéri *et al.,* 1986; Pergent and Pergent, 1988). In 1980, the water of the coastal river was diverted to the Cortiou discharge. In 1987, the setting up of a primary treatment plant for the raw sewage, following prior treatment of industrial waste, led to a significant decrease in the levels of pollution (Bellan *et al.,* 1999; Soltan *et al*., 2001).

The Prado Bay monitoring system was set up in 1986, at the request of the Marseilles municipal council. The monitoring tools are 2 permanent transects, 4 permanent quadrats, a set of permanent cement markers at the lower limit of the meadow, measurement of the bottom cover, mapping of the meadow (based upon bottom cover and krieging methods) and sediment traps (Fig. 11; Niéri *et al.,* 1986, 1993b ; Gravez *et al.,* 1992, 1995). Since 1988, *i.e.* one year after the setting up of the treatment plant, *P. oceanica* has exhibited a steady and conspicuous spread (Fig. 7; Gravez *et al.,* 1995, 1997, 1999).

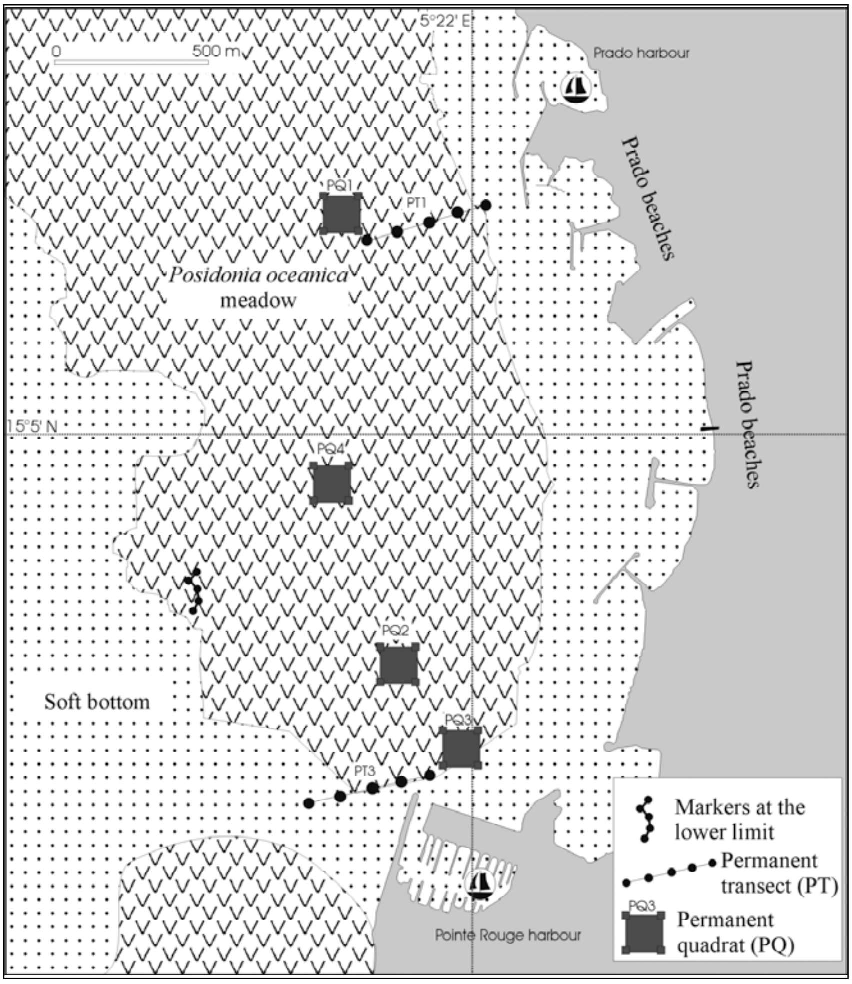

Fig. 11. Location of the sites surveyed within the framework of the Marseilles Prado Bay monitoring system. From Gravez *et al.* (1999).

Other monitoring systems

Several other monitoring systems for *P. oceanica* meadows have been set up along the Provence and French Riviera coast: Riou archipelago, near Marseilles (Pergent-Martini, 1994; Pergent-Martini *et al.,* 1995; Pergent-Martini and Pergent, 1996; Pergent-Martini *et al.,* 2000), Gulf of Giens, near Hyères (Gravez *et al.,* 1988, 1993; Charbonnel *et al.,* 1995c, 1997; Bernard *et al.,* 2000), the Maure coast, betwwen Cavalaire and Saint-Tropez (Bonhomme *et al.,* 2000) and Cap-Martin, between Monaco and Nice, in a site colonized by the introduced green alga *Caulerpa taxifolia* (Ruitton *et al.,* 2001a).

CONCLUSIONS

The high environmental, ecological and economic value of *Posidonia oceanica* meadows, together with the need for evaluation of the efficiency of the conservation measures that have been implemented, make monitoring a necessity. A wide range of tools is today available for this purpose.

Along the Provence and French Riviera coasts, these tools are combined in different ways to form monitoring systems, in accordance with a variety of local or regional objectives, and are today routinely used. The most important of these monitoring systems is the Posidonia Monitoring Network (PMN), which encompasses the whole coastline of the region. Within the framework of these systems, beyond the initial conservation objective, *P. oceanica* is utilized as a biological indicator of the overall quality of the marine environment (Pergent-Martini *et al.,* 1993, 1999; Pergent *et al.,* 1995)

In the Provence and French Riviera region, the percentage of urban sewage which undergoes treatment, and the percentage of pollution removed from both river-waters flowing into the Mediterranean and waste waters, has risen from less than 10 and 5% in the early 1980s to approximately 95 and 50% today, respectively. The trend in pollutant levels in littoral waters over this period is often difficult to interpret due to the very high variability of the values recorded. Conversely, on the basis of a biological indicator, the Posidonia Monitoring Network (PMN) has clearly demonstrated an overall improvement in the situation (Boudouresque *et al.,* 2000).

Thus, the monitoring systems based upon *P. oceanica* are able to provide the elected representatives, local authorities and administrations responsible for the management of coastal regions with useful, relatively inexpensive and easy to use tools to provide overall assessment of the quality of the marine environment.

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REFERENCES

ARDIZZONE D., PELUSI P., 1984. - Yield and damage evaluation of bottom trawling on *Posidonia* meadows. In: Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds), *International Workshop on Posidonia oceanica beds,* GIS Posidonie publ., Marseille, Fr, 1: 63-72.

ASTIER J.M., 1984. – Impact des aménagements littoraux de la rade de Toulon, liés aux techniques d'endigage, sur les herbiers à *Posidonia oceanica.* In: Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds), *International Workshop on Posidonia oceanica beds,* GIS Posidonie publ., Marseille, Fr, **1**: 255-259.

AUGIER H., MONNIER-BESOMBES G., SIGOILLOT G., 1984. - Influence des détergents sur *Posidonia oceanica* (L.) Delile. In: Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds), *International Workshop on Posidonia oceanica beds,* GIS Posidonie publ., Marseille, Fr, 1: 407-418.

BELLAN G., BOURCIER M., SALEN-PICARD C., ARNOUX A., CASSERLEY S., 1999. - Benthic ecosystem changes associated with wastewater treatment at Marseille: implications for the protection and restoration of the Mediterranean shelf ecosystem. *Water Environment Research,* 71 (4): 483-493.

BERNARD G., CADIOU G., ESCOFFIER B., LE DIREACH L., BONHOMME P., CHARBONNEL E., 2000. - *Surveillance de l'herbier à Posidonia oceanica du golfe de Giens (Var, France).* GIS Posidonie publ., Fr.: 61 pp.

BIANCHI C.N., PEIRANO A., 1995. - *Atlante delle Fanerogame marine della Liguria. Posidonia oceanica e Cymodocea nodosa.* Centro Ricerche Ambiente Marino, ENEA publ., La Spezzia, Ital.: 146 pp.

BONHOMME P., CHARBONNEL E., ESCOFFIER B., CADIOU G., BERNARD G., 2000. – *Mise en place d'un système de surveillance de l'herbier de Posidonie sur le littoral des Maures dans le cadre de l'observatoire marin du SIVOM du littoral des Maures. Rapport final*. GIS Posidonie publ., Fr.: 58 pp.

BOUDOURESQUE C.F., ARRIGHI F., FINELLI F., LEFÈVRE J.R., 1995. - Arrachage des faisceaux de *Posidonia oceanica* par les ancres: un protocole d'étude. *Rapp. Commiss. internation. Mer Médit.,* 34: 21.

BOUDOURESQUE C.F., BERTRANDY M.C., BOULADIER E., FORET P., MEINESZ A., PERGENT G., VITIELLO P., 1990. - Le Réseau de surveillance des herbiers de Posidonies mis en place en région Provence-Alpes-Côte d'Azur. *Rapp. Commiss. internation. Mer Médit.,* 32 (1): 11.

BOUDOURESQUE C.F., CHARBONNEL E., MEINESZ A., PERGENT G., PERGENT-MARTINI C., CADIOU G., BERTRANDY M.C., FORET P., RAGAZZI M., RICO-RAIMONDINO V., 2000. - A monitoring network based on the seagrass *Posidonia oceanica* in the northwestern Mediterranean Sea. *Biol. mar. medit.,* 7 (2): 328-331.

BOUDOURESQUE C.F., GIRAUD G., PANAYOTIDIS P., 1980. - Végétation marine de l'île de Port-Cros (Parc national). XIX. Mise en place d'un transect permanent. *Trav. sci. Parc nation. Port-Cros, Fr.,* 6: 207-221.

BOUDOURESQUE C.F., GRAVEZ V., MEINESZ A., MOLENAAR H., PERGENT G., VITIELLO P., 1994a. - L'herbier à *Posidonia oceanica* en Méditerranée : protection légale et gestion. In: *Actes du colloque scientifique OKEANOS,* Maison de l'Environnement de Montpellier publ., Fr.: 209-220.

BOUDOURESQUE C.F., JEUDY DE GRISSAC A., 1983. - L'herbier à *Posidonia oceanica* en Méditerranée: les interactions entre la plante et le sédiment. *J. Rech. océanogr.,* 8 (2-3): 99-122.

BOUDOURESQUE C.F., JEUDY DE GRISSAC A., MEINESZ A., 1984. – Relations entre la sédimentation et l'allongement des rhizomes orthotropes de *Posidonia oceanica* dans la baie d'Elbu (Corse). In: Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds), *International Workshop on Posidonia oceanica beds,* GIS Posidonie publ., Marseille, Fr, 1: 185-191.

BOUDOURESQUE C.F., MEINESZ A., 1982. - Découverte de l'herbier de Posidonie. *Cah. Parc nation. Port-Cros,* Fr., 4: 1-79.

BOUDOURESQUE C.F., MEINESZ A., LEDOYER M., VITIELLO P., 1994b. - Les herbiers à Phanérogames marines. In: Bellan-Santini D., Lacaze J.C., Poizat C. (eds), *Les biocénoses marines et littorales de Méditerranée, synthèse, menaces et perspectives,* Muséum National d'Histoire Naturelle publ., Paris: 98-118.

BOUDOURESQUE C.F., MEINESZ A., PANAYOTIDIS P., 1981. - Mise en place d'un carré permanent dans un herbier de Posidonies. *Rapp. Commiss. internation. Mer Médit,* 27 (9): 245-246.

BOUDOURESQUE C.F., VAN KLAVEREN M.C., VAN KLAVEREN P., 1996. - Proposal for a list of threatened or endangered marine and brackish species (plants, invertebrates, fish, turtles and mammals) for inclusion in appendices I, II and III of the Bern Convention. *Council of Europe, Document S/TPVS96/TPVS48E, 96A*: 1-138.

CALMET D., BOUDOURESQUE C.F., MEINESZ A., 1988. - Memorization of nuclear atmospheric tests by rhizomes and scales of the Mediterranean seagrass *Posidonia oceanica* (Linnaeus) Delile. *Aquatic Botany,* 30: 279-293.

CHARBONNEL E., BERNARD G., GRAVEZ V., BONHOMME P., FRANCOUR P., BOUDOURESQUE C.F., 1997. - *Surveillance de l'herbier à Posidonia oceanica du golfe de Giens (Var-France). Rapport du troisième suivi*. Syndicat intercommunal Hyères-Carqueiranne pour l'assainissement de la baie de Giens et GIS Posidonie publ., Marseille, Fr.: 97 pp.

CHARBONNEL E., BOUDOURESQUE C.F., BERTRANDY M.C., FORET P., MEINESZ A., PERGENT G., PERGENT-MARTINI C., RICO-RAIMONDINO V., VITIELLO P., 1993. - Le Réseau de Surveillance Posidonies en Région de Provence-Alpes-Côte d'Azur (Méditerranée, France): les premiers résultats. In: *Symp. internation. Protection du Milieu Marin contre la Pollution Urbaine,* Marseille, Fr., (3): 1-10.

CHARBONNEL E., BOUDOURESQUE C.F., BERTRANDY M.C., MEINESZ A., PERGENT-MARTINI C., RICO(RAIMONDINO V., FORET P., RAGAZZI M., LECCIA G., 1994. - *Le réseau de surveillance Posidonies de la région Provence-Alpes-Côte d'Azur. Rapport 1993 (3° phase, 3° année).* GIS Posidonie publ., Fr.: 131 pp.

CHARBONNEL E., BOUDOURESQUE C.F., MEINESZ A., BERNARD G., BONHOMME P., PATRONE J., KRUCZEK R., COTTALORDA J.M., BERTRANDY M.C., FORET P., RAGAZZI M., LE DIREAC'H L., 2000a. - *Le Réseau de Surveillance Posidonies de la Région Provence-Alpes-Côte d'Azur. Première partie : présentation et guide méthodologique*. GIS Posidonie publ., Marseille, Fr.: 76 pp.

CHARBONNEL E., BOUDOURESQUE C.F., MEINESZ A., BONHOMME P., BERNARD G., PATRONE J., KRUCZEK R., COTTALORDA J.M., BERTRANDY M.C., FORET P., BRICOUT P., RAGAZZI M., CADIOU G., LE DIREAC'H L., 2000b. – *Le réseau de surveillance Posidonies de la région Provence-Alpes-Côte d'Azur. Seconde partie: résultats du suivi 1999.* GIS Posidonie publ., Marseille, Fr.: 142 pp.

CHARBONNEL E., BOUDOURESQUE C.F., MEINESZ A., BONHOMME P., BERNARD G., PATRONE J., KRUCZEK R., COTTALORDA J.M., BERTRANDY M..C., FORET P., BRICOUT P., RAGAZZI M., MARRO C., SERRE C., LE DIREAC'H L., 2001. - *Le Réseau de Surveillance Posidonies de la Région Provence-Alpes-Côte d'Azur. Résultats du suivi 2001.* Région PACA, Agence de l'Eau, DDE, GIS Posidonie publ.: 119 pp.

CHARBONNEL E., BOUDOURESQUE C.F., MEINESZ A., PERGENT-MARTINI C., RICO-RAIMONDINO V., BERTRANDY M.C., FORET P., RAGAZZI M., LECCIA G., 1995a. - *Le réseau de surveillance Posidonies de la région Provence-Alpes-Côte d'Azur. Rapport 1994 (4° phase, 1° année).* GIS Posidonie publ., Fr.: 167 pp.

CHARBONNEL E., BOUDOURESQUE C.F., MEINESZ A., PERGENT-MARTINI C., RICO-RAIMONDINO V., SAN MARTIN G., BERTRANDY M.C., FORET P., RAGAZZI M., LECCIA G., 1995b. - *Le réseau de surveillance Posidonies de la région Provence-Alpes-Côte d'Azur. Rapport 1995 (4° phase, 2° année).* GIS Posidonie publ., Fr.: 193 pp.

CHARBONNEL E., GRAVEZ V., ABELLARD O., BOUDOURESQUE C. F., REMONNAY L., 1995c. – *Surveillance de l'herbier à Posidonia oceanica du golfe de Giens (Var-France). Second suivi.* Syndicat Intercommunal Hyères-Carqueiranne pour l'assainissement de la baie de Giens and GIS Posidonie. GIS Posidonie publ., Marseille, Fr.: 106 pp + 8 pp.

CHESSA L.A., FRESI E., 1994. - Conservazione e gestione delle praterie di Posidonia. In: Monbailliu X., Torre A. (eds), *La gestione degli ambienti costieri e insulari del Mediterraneo*, Edizione del Sole publ., Ital.: 103-127.

CROUZET A., 1981. - Mise en evidence de variations cycliques dans les écailles de *Posidonia oceanica* (Potamogetonaceae). *Trav. sci. Parc nation. Port-Cros,* Fr., 7: 129-135.

CROUZET A., BOUDOURESQUE C.F., MEINESZ A., PERGENT G., 1983. - Evidence of the annual character of cyclic changes of *Posidonia oceanica* scale thickness (erect rhizomes). *Rapp. Commiss. int. Mer Médit.,* 28 (3): 113-114.

DELGADO O., RUIZ J., PEREZ M., ROMERO J., BALLESTEROS E., 1999. - Effects of fish farming on seagrass (*Posidonia oceanica*) in a Mediterranean bay: seagrass decline after organic loading cessation. *Oceanologica Acta,* 32 (1): 109-117.

DIVIACCO G., SPADA E., VIRNO-LAMBERTI C., 2001. - *Le Fanerogame marine del Lazio. Descrizione e cartografia delle praterie di Posidonia oceanica e dei prati di Cymodocea nodosa.* ICRAM publ., Ital.: 113 pp + 14 maps

DREW E.A., JUPP B.P., 1976. - Some aspects of the growth of *Posidonia oceanica* in Malta. In: *Underwater Research,* Academic Press publ., London: 357-367.

GIRAUD G., 1977. - *Contribution à la description et à la phénologie des herbiers de Posidonia oceanica (L.) Delile*. Thèse Doct. Spécialité, Univ. Aix-Marseille II, Fr.: 150 pp.

GIRAUD G., 1979. - Sur une méthode de mesure et de comptage des structures foliaires de *Posidonia oceanica* (Linnaeus) Delile. *Bull. Mus. Hist. nat. Marseille,* 39: 33-39.

GIRAUD G., BOUDOURESQUE C.F., CINELLI F., FRESI E., MAZZELLA L., 1979. - Observations sur l'herbier de *Posidonia oceanica* (L.) Delile autour de l'île d'Ischia (Italie). *G. bot. ital.,* 113 (4): 261-274.

GRAVEZ V., BERNARD G., BONHOMME P., CADIOU G., COQUILLARD Y., DIVETAIN N., 1999. - *Surveillance de l'herbier de Posidonie de la baie du Prado (Marseille) - Suivi 1999.* Ville de Marseille, Direction de l'Environnement et des Déchets and GIS Posidonie, Marseille, Fr.: 45 pp.

GRAVEZ V., BERNARD G., BONHOMME P., PALLUY F., 1997. – *Surveillance de l'herbier de posidonie de la baie du Prado (Marseille). Deuxième phase, suivi 1997*. and GIS posidonie Ville de Marseille publ., Fr.: 46 pp.

GRAVEZ V., BOISSERY P., FRANCOUR P., SINNASSAMY J.M., BOUDOURESQUE C.F., 1993. – *Surveillance de l'herbier à Posidonia oceanica du golfe de Giens (Var, France). Premier suivi*. Syndicat Intercommunal Hyères-Carqueiranne pour l'assainissement de la baie de Giens and GIS Posidonie. GIS Posidonie publ., Marseille, Fr.: 59 pp.

GRAVEZ V., GELIN A., CHARBONNEL E., FRANCOUR P., ABELLARD O., REMONNAY L., 1995. - *Surveillance de l'herbier de Posidonie de la baie du Prado (Marseille) – Suivi 1995*. Ville de Marseille and GIS Posidonie publ., Marseille, Fr.: 56 pp.

GRAVEZ V., MARCHADOUR M., FRANCOUR P., BOUDOURESQUE C.F., BOULADIER E., SOURENIAN B., 1988. - L'herbier à Posidonia oceanica du golfe de Giens. In: *Rejets des effluents urbains dans le golfe de Giens, analyse de l'état initial*. BCEOM and GIS Posidonie publ., Marseille, Fr.: 113 pp.

GRAVEZ V., NIERI M., BOUDOURESQUE C.F., 1992. - *Surveillance de l'herbier de Posidonie de la baie du Prado (Marseille). Rapport de synthèse 1986-1992.* Direction Générale des Services techniques de la Ville de Marseille and GIS Posidonie publ., Marseille, Fr.: 80 pp.

HARMELIN J.G., 1976. - L'herbier de posidonies de Port-Cros régresse-t-il ? Mise en place de jalons témoins à sa limite. *Trav. sci. Parc nation. Port-Cros,* Fr., 2: 189-190.

JUPP B.P., 1977. - The effects of organic pollution on benthic organisms near Marseille. *Internation. J. Environm. Studies,* 10: 119-123

LEFEVRE J.R., VALERIO C., MEINESZ A., 1984. - Optimisation de la technique aérienne pour la cartographie des herbiers de posidonies. In: Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds), *International Workshop on Posidonia oceanica beds,* GIS Posidonie publ., Marseille, Fr, 1: 49-55.

MARION A.F., 1883. - Esquisse d'une topographie zoologique du golfe de Marseille. *Ann. Mus. Hist. nat. Marseille, Zool.,* 1: 108 pp + 1 map.

MEINESZ A., 1977. - Balisage de la limite inférieure de l'herbier de *Posidonia oceanica* en rade de Villefranche-sur-mer (Alpes-Maritimes, France). *Rapp. Comm. int. Explor. Mer Médit.*, 24 (6): 143-144.

MEINESZ A., ASTIER J.M., BODOY A., CRISTIANI G., LEFÈVRE J.R., 1982. - Impact de l'aménagement du domaine maritime sur l'étage infralittoral des Bouches-du-Rhône (France, Méditerranée occidentale). *Vie Milieu,* 32 (2): 115-124.

MEINESZ A., ASTIER J.M., LEFÈVRE J.R., 1981a. - Impact de l'aménagement du domaine maritime sur l'étage infralittoral du Var, France (Méditerranée occidentale). *Ann. Inst. océanogr.,* 57 (2): 65-77.

MEINESZ A., LEFÈVRE J.R., ASTIER J.M., 1991. - Impact of coastal development on the infralittoral zone along the southern Mediterranean shore of continental France. *Mar. Poll. Bull.*, 23: 343-347.

MOLINIER R., PICARD J., 1952. - Recherches sur les herbiers de Phanérogames marines du littoral méditerranéen français. *Ann. Inst. océanogr.,* 27 (3): 157-234.

NIÉRI M., BOUDOURESQUE C.F., AUGIER H., GRAVEZ V., 1986. - *Mise en place du système de surveillance de l'herbier de posidonies de la baie du Prado (Marseille). Observations initiales*. SOMICA and GIS Posidonie publ., Marseille, Fr. : 64 pp.

NIÉRI M., CHARBONNEL E., BOUDOURESQUE C.F., BERTRANDY M.C., FORET P., MEINESZ A., PERGENT G., PERGENT-MARTINI C., RICO-RAIMONDINO V., 1993a. - Les objectifs du Réseau de Surveillance Posidonies mis en place en région Provence-Alpes-Côte d'Azur. In: Boudouresque C.F., Avon M., Pergent-Martini C. (eds), *Qualité du milieu marin - Indicateurs biologiques et physico-chimiques,* GIS Posidonie publ., Marseille, Fr. : 73-87.

NIÉRI M., GRAVEZ V., BOUDOURESQUE C.F., SINNASSAMY J.M., 1993b. - Le système de surveillance de l'herbier à *Posidonia oceanica* de la baie du Prado (Marseille, France). Les carrés permanents. In: *Colloque international sur la pollution marine,* Ville de Marseille publ., Fr. : 1-10.

PANAYOTIDIS P., GIRAUD G., 1981. - Sur un cycle de renouvellement des feuilles de *Posidonia oceanica* (Linnaeus) Delile dans le golfe de Marseille. *Vie Milieu,* 31 (2): 129-136.

PASQUALINI V., CLABAUT P., PERGENT G., BENYOUSSE L., PERGENT-MARTINI C., 2000. - Contribution of side scan sonar to the management of Mediterranean littoral ecosystems. *Intern. J. Remote Sensing,* 21 (2): 367-378.

PÉRÈS J.M., 1984. - La régression des herbiers à *Posidonia oceanica.* In: Boudouresque C.F., Jeudy de Grissac A., Olivier J. (eds), *International Workshop on Posidonia oceanica beds,* GIS Posidonie publ., Marseille, Fr. : 445-454.

PERGENT G., 1990. - Lepidochronological analysis of the seagrass *Posidonia oceanica* (L.) Delile: a standardized approach. *Aquatic Botany,* 37: 39-54.

PERGENT G., 1991. - La protection légale de la Posidonie en France: un outil efficace - Nécessité de son extension à d'autres pays méditerranéens. In: Boudouresque C.F., Avon M., Gravez V. (eds), *Les espèces marines à protéger en Méditerranée,* GIS Posidonie publ., Marseille, Fr. : 29-33.

PERGENT G., BOUDOURESQUE C.F., CROUZET A., MEINESZ A., 1989. - Cyclic changes along *Posidonia oceanica* rhizomes (lepidochronology) : present state and perspectives. *Marine Ecology PSZN,* 10 (3): 221-230.

PERGENT G., PERGENT C., 1988. - *Localisation et état de l'herbier de posidonies sur le littoral PACA: Bouches du Rhône*. DRAE-PACA and GIS Posidonie publ., Marseille, Fr. : 53 pp.

PERGENT G., PERGENT-MARTINI C., 1991. - Leaf renewal cycle and primary production of *Posidonia oceanica* in the bay of Lacco Ameno (Ischia, Italy) using lepidochronological analysis. *Aquatic Botany,* 42: 49-66.

PERGENT G., PERGENT-MARTINI C., BOUDOURESQUE C.F., 1995. - Utilisation de l'herbier à *Posidonia oceanica* comme indicateur biologique de la qualité du milieu littoral en Méditerranée: état des connaissances. *Mésogée,* Fr., 54: 3-27.

PERGENT G., PERGENT-MARTINI C., RICO-RAIMONDINO V., 1992. - Evaluation of past primary production of *Posidonia oceanica* using lepidochronological data. *Rapp. Commiss. internation. Mer Médit.,* 33: 47.

PERGENT-MARTINI C., 1994. - *Impact d'un rejet d'eaux usées urbaines sur l'herbier à Posidonia oceanica, avant et après la mise en service d'une station d'épuration*. Thèse Doctorat Univ. Corté, Corse : 191 pp.

PERGENT-MARTINI C., 1998. - *Posidonia oceanica*: a biological indicator of past and present mercury contamination in the Mediterranean Sea. *Mar. environm. Res.,* 45 (2): 101-111.

PERGENT-MARTINI C., PASQUALINI V., PERGENT G., 1995a. - Monitoring of *Posidonia oceanica* meadows near the outfall of the sewage treatment plant at Marseille (Mediterranean – France). *EARSeL Advances in Remote Sensing,* 4 (1): 128-134.

PERGENT-MARTINI C., PASQUALINI V., PERGENT G., 2000. - *Impact de la station d'épuration de la Ville de Marseille sur l'herbier à Posidonia oceanica du secteur de Cortiou*. Contrat Ville de Marseille/GIS Posidonie, GIS Posidonie publ., Corté, Fr. : 36 pp.

PERGENT-MARTINI C., PERGENT G., 1994. - Lepidochronological analysis in the Mediterranean seagrass *Posidonia oceanica*: state of the art and future developments. *Oceanologica Acta,* 17 (6): 673-681.

PERGENT-MARTINI C., PERGENT G., 1996. - Spatio-temporal dynamics of *Posidonia oceanica* beds near a sewage outfall (Mediterranean, France). In: Kuo J., Phillips R.C., Walker D.S., Kirkman H. (eds), *Seagrass Biology: Proceedings of an international Workshop.*, Australia : 299-306.

PERGENT-MARTINI C., PERGENT G., FERNANDEZ C., FERRAT L., 1999. - Value and use of *Posidonia oceanica* as a biological indicator. In: *MEDCOST 99-EMECS 99 Joint Conference* : 73-89.

PERGENT-MARTINI C., PERGENT C., RICO-RAIMONDINO V., 1993. - *Posidonia oceanica* beds, a biological indicator of the marine environment quality. In: *Actes du colloque scientifique "Pour qui la Méditerranée au 21° siècle? Le système littoral méditerranéen,* Okeanos, Montpellier : 207-212.

PERGENT-MARTINI C., RICO-RAIMONDINO V., PERGENT G., 1995b. - Nutrient impact on *Posidonia oceanica* seagrass meadows : preliminary data. *Mar. Life,* 5 (2): 3-9.

PICARD J., 1965a. - Importance, répartition et rôle du matériel organique végétal issu des prairies de posidonies. *Rapp. Commiss. internation. Mer Médit.*, 18 (2): 91-92.

PICARD J., 1965. - *Recherches qualitatives sur les biocoenoses marines des substrats meubles dragables de la region marseillaise*. Thèse Doct. Univ. Aix-Marseille, Fr. : 160 pp + 1 map.

RAC/SPA, 1999. - *Action plan for the conservation of marine vegetation in the Mediterranean Sea*. United Nations Environment Programme, Mediterranean Action Plan publ., Tunis, Tunisia : 48 pp.

RUIZ J.M., ROMERO J., 2001. - Effects of *in situ* experimental shading on the Mediterranean seagrass *Posidonia oceanica*. *Mar. Ecol. Progr. Ser.,* 215: 107-120.

RUITTON S., BOUDOURESQUE C.F., BONHOMME P., BERNARD G., CADIOU G., ESCOFFIER B., 2001a. - *Compétition entre l'algue introduite Caulerpa taxifolia et la Phanérogame marine Posidonia oceanica en Méditerranée nord-occidentale: suivi pluriannuel de deux carrés permanents*. Conseil Régional PACA and GIS Posidonie publ., Marseille, Fr. : 45 pp.

RUITTON S., CHARBONNEL E., BOUDOURESQUE C.F., MEINESZ A., BONHOMME P., BERNARD G., PATRONE J., KRUCZEK R., COTTALORDA J.M., BERTRANDY M.C., FORET P., BRICOUT P., RAGAZZI M., CADIOU G., THIBAUT T., 2001b. - *Le Réseau de Surveillance Posidonies de la Région Provence-Alpes-Côte d'Azur. Seconde partie: résultats du suivi 2000*. Région PACA, Agence de l'Eau, DDE and GIS Posidonie publ., Marseille, Fr. : 129 pp.

SIEGEL S., 1956. - *Nonparametric statistics for the behavorial sciences*. McGraw-Hill book company inc. publ., New York: xvii + 312 pp.

SOLTAN D., VERLAQUE M., BOUDOURESQUE C.F., FRANCOUR P., 2001. - Changes in macroalgal communities in the vicinity of a Mediterranean sewage outfall after the setting up of a treatment plant. *Mar. Poll. Bull.,* 42 (1): 59-70.

THÉLIN I., BEDHOMME A.L., 1983. - Biomasse des épiphytes des feuilles de *Posidonia oceanica* dans un herbier superficiel. *Rapp. Commiss. internation. Mer Médit.,* 28 (3): 125-126.