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Spatial, temporal and structural variations of a *Posidonia oceanica* seagrass meadow facing human activities

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Abstract

The Bay of Saint-Cyr (Provence, France, Mediterranean Sea) is the site of two harbours, coastal urban development, trawling, boat anchoring and a sewage outfall. The *Posidonia oceanica* seagrass distribution was mapped with the help of aerial photographs, side scan sonar and GIS. In addition, the temporal variations of its distribution were studied by aerial photographs and GIS from 1955 to 2000. Finally, coverage and shoot density were measured via scuba-diving. This work reveals (i) the regression of the *P. oceanica* meadow at sites where harbours have been built, (ii) the occurrence of spaces within the meadow free of live *P. oceanica* (''intermattes''), which account for 8% of its surface area, (iii) a deep area where *P. oceanica* coverage and shoot density are low and (iv) evidence of regression, although modest, of the meadow at its lower limit. Nevertheless, the study site also exhibits an extensive and on the whole relatively healthy meadow whose limits have changed little over time.

Keywords: *Posidonia oceanica*; Aerial photography; Side scan sonar; GIS; Human impact

1. Introduction

The coexistence of various commercial and urban activities disrupts the stability of littoral ecosystems (UNEP, 1996). The regression of littoral seagrass beds recorded over the last few decades provides an illustration of this phenomenon (for review see Short and Wyllie-Echeverria, 1996). The management of seagrass meadows is an increasing priority in the light of the essential role they play from an ecological and sedimentary point of view (Kuo et al., 1996). In order to implement management measures, assessment of seagrass dynamics under the impact of human activities must be undertaken.

Among the different methods used to map seagrasses, aerial photography has been demonstrated to be the best method to map shallow meadows (Green et al., 1996; Ward et al., 1997; Pasqualini et al., 1998; Kendrick et al., 2002; Frederiksen et al., 2004) while side scan sonar appears to be particularly suitable for deeper ones (Siljeström et al., 1996; Pasqualini et al., 1999, 2000; Piazzi et al., 2000). These methods associated with Geographical Information System (GIS) constitute an efficient tool for seagrass management (Ferguson and Korfmacher, 1997; Robbins, 1997; Douven et al., 2003).

Although numerous studies have already focused on the dynamics of seagrasses under the impact of human activities, few have associated spatial, temporal and structural data. The aim of the present study is to assess the spatial, temporal and structural variations of a *Posidonia oceanica* (Linnaeus) Delile meadow at a site presenting a variety of human activities then to attempt to link the variations observed with the impact of these activities. *P. oceanica*, endemic to the Mediterranean, is by far the most abundant seagrass there, constituting vast meadows from the surface to a depth of 40 m (Duarte, 1991). Investigations were performed through (i) the present day cartography of the seagrass meadow via aerial photography, side scan sonar and GIS, (ii) the change of seagrass extension from 1955 to 2000, using ancient aerial photographs and GIS and (iii) two parameters suitable for plant vitality assessment, namely coverage and shoot density.

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2. Material and methods

2.1. Study site

The study site (Bay of Saint-Cyr, Provence, France, Mediterranean Sea; approximately 4 km^2) is located to the east of Marseilles, at a latitude between 43.155°N and 43.180°N and a longitude between 5.670°N and 5.690°N. In addition to a vast *P. oceanica* meadow, the area harbours some underwater cliffs with gorgonians and the precious red coral *Corallium rubrum*, subtidal reefs with photophilous algae and sand bottoms. Ecosystems of this site, in particular the *P. oceanica* meadow, are considered as subject to a level of anthropogenic pressure which is intermediate between that of pristine areas of the Port-Cros National Park (French Riviera) and that of the Marseilles harbour and sewage outfall area (Pergent-Martini and Pergent, 1996).

Human impact at the study site takes the form of the port facilities of La Ciotat (5 km westwards), two small pleasure boat harbours (Les Lecques with 431 boat places and La Madrague with 240 boat places), marine leisure activities (scuba-diving, recreational fishing, boating, cruising boats), trawling and coastal urbanisation. The percentage of man-made shoreline resulting from coastal development was 9% in the 1980s (Meinesz et al., 1990) and is 13% nowadays (Neil Alloncle, unpublished data).

Sewage treatment plant (23 000 population equivalent) has been existing since 1988, with a pipe discharging treated water at 40 m depth. Before that, a PCV pipe discharging untreated water.

2.2. Spatial data

The map of *P. oceanica* distribution was established using aerial photography (shallow areas, i.e. <10 m depth) and side scan sonar (deeper areas). The aerial color photograph (1/15 000) was taken on July 2001 from a plane equipped for vertical photography flying at 325 m, with a photogrammetric Zeiss camera (23 cm × 23 cm, focal 152 mm; film AGA P 200), according to a standardized protocol (Lefèvre et al., 1984). It was digitised (800 dpi; pixel of 0.5 m × 0.5 m) with an Agfa SnapScan 600® color scanner using Corel Photo Paint 8® software in 16.7 million colors. Pre-processing involved specific geometric correction in order to eliminate distortions in the photograph (Pasqualini et al., 1998). This correction was achieved by means of the extension Géoref-Image® Version 2.2b of the Geographic Information System (GIS) ArcView 3.2® software, from ‘‘orthophotoplans’’ (photographs adjusted from two color negatives taken with different optical axes with a geographical referencing accuracy of 1 m) of the Bd-ortho® (Institut Géographique National, France). Reference points were taken from the terrestrial parts of the photograph. Patches of seagrass were delimited by feature extraction process by means of ImageAnalysis® (extension of Arc view 3.2). Some pixels are selected within a homogeneous region identified as *P. oceanica*. These pixels are used to define the classification rule in each color band of the photograph. Pixels around these selected pixels are classified step by step. The classifier looks at the pixel values of the additional pixel to see if they fall within the determined range. If this is the case, they are included in the closed polygon which delimits the patch of seagrass. Additional polygons were delimited manually when they were visible, although not taken into account by Image-analysis. Side scan sonar images (EdgeTech DF 1000 DCI®) were obtained during the oceanographic campaign Posicart I of the vessel Téthys II in June 2000 (for rationale and principles of side scan sonar, see Pasqualini et al., 1998; Brown et al., 2002). The numerical data acquisition system is of the TEI ISIS type on a PC platform under Windows. The images obtained (sonograms) indicate the distribution and boundaries of the different substratum, sediment and seagrass bottoms which are characterised by different shades of grey. The sonograms were rectified with reference to a map indicating the location of the vessel’s route. The information obtained from the sonograms was manually transferred to the map. This map was then digitised using a color scanner. Possible misinterpretation of both the aerial photographs and the sonograms (e.g. patches of drifting dead *P. oceanica* leaves lying on a sand bottom) and doubtful points of interpretation were resolved by scuba ground truthing; 18 pinpoints and 7 transect dives were performed. Exact location of the dives was obtained by means of a Global Positioning System (GPS, Magellan 315®).

2.3. Temporal data

With the aim of assessing the dynamics of the *P. oceanica* meadow, the geographical database on ArcView 3.2® software was completed with earlier aerial photographs (dating from 1955, 1974 and 1979; Institut Géographique National) which were processed in the same way as the present aerial photograph, except for the resolution (according to scale with the aim of obtaining a pixel of 0.5 m × 0.5 m). Maps of changes in spatial distribution of *P. oceanica* near the two harbours of La Madrague and Les Lecques were made using Spatial Analyst® by multiplication of raster data. A more ancient photograph, dating from 1944 (US Air Force) was also used, but is not accurate enough for processing in the same way as the others.

2.4. Structural data

Structural data concerning the cover and the shoot density of *P. oceanica* were obtained via scuba-diving. The coverage corresponds to the percentage of the substrate covered by live *P. oceanica* in relation to the whole surface area. The coverage was measured by means of a 30 cm × 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, counted the number of squares occupied (more or less totally) by *P. oceanica*. At each sampling site, 30 measurements were performed at similar distance intervals (the same number of flipper strokes). The shoot density is the mean number of living *P. oceanica* shoots per surface area unit. At least five measurements were performed within a 20 cm × 20 cm frame

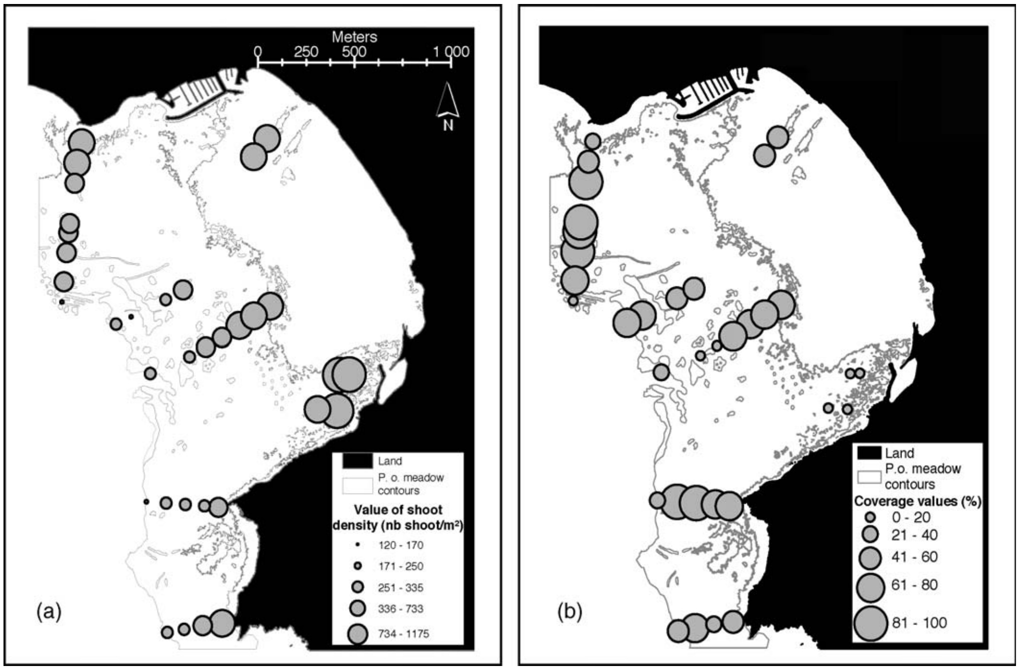

Fig. 1. Location of the sampling points and values for (a) shoot density and (b) coverage of the *P. oceanica* meadow in the study area.

at each sampling point (Pergent et al., 1995; Marcos-Diego et al., 2000). Measurement of coverage and shoot density was performed at 34 pinpoints in the study area (Fig. 1a and b). The category limits of coverage and shoot density were delimited with ''smart quantiles'' method of the software ArcGis, which constitute a trade off between equal intervals and quantiles methods.

Intermattes are spaces without live *P. oceanica* within the meadow. They are occupied by sand or more generally by dead matte. When *P. oceanica* dies, the rhizomes decay very slowly and may persist for centuries or even millennia: dead matte is constituted by the intertwined dead rhizomes the interstices of which are filled with sediment.

3. Results

A continuous *P. oceanica* meadow occupies most of the bay from the surface to 32–34 m depth, with the exception of a vast and shallow sandy area in the centre of the bay, that it to say a total surface area of approximately 191 ha (Fig. 2). On the basis of the structure and the vitality of the *P. oceanica* meadow, three geographic sectors can be defined within the area:

(1) In sector 1 (Fig. 2, S1), in the northern part of the bay, the *P. oceanica* meadow exhibits high coverage with few intermattes. Most of these intermattes, occupied by dead matte (15 intermattes, 1.5–1797 m^2 of surface area) are located close to the harbour of Les Lecques (Fig. 2, i). Fig. 3a and b shows the disappearance of *P. oceanica* from the area nowadays occupied by the harbour and the appearance of many intermattes between 1974 and 1979. This decline continues between 1979 and 2000 but is less marked. In the north-western part of the sector (Fig. 2, ii),

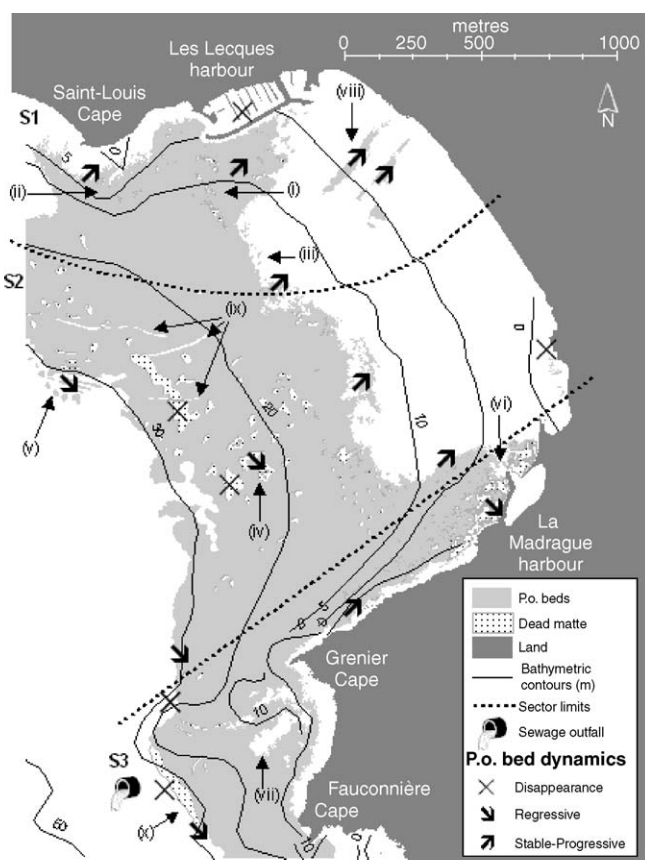

Fig. 2. Distribution and dynamics of the *P. oceanica* meadow in the Bay of Saint-Cyr. Arrows (i)–(x) indicate particular areas of interest (see text). S1, S2 and S3: sectors 1, 2 and 3, respectively.

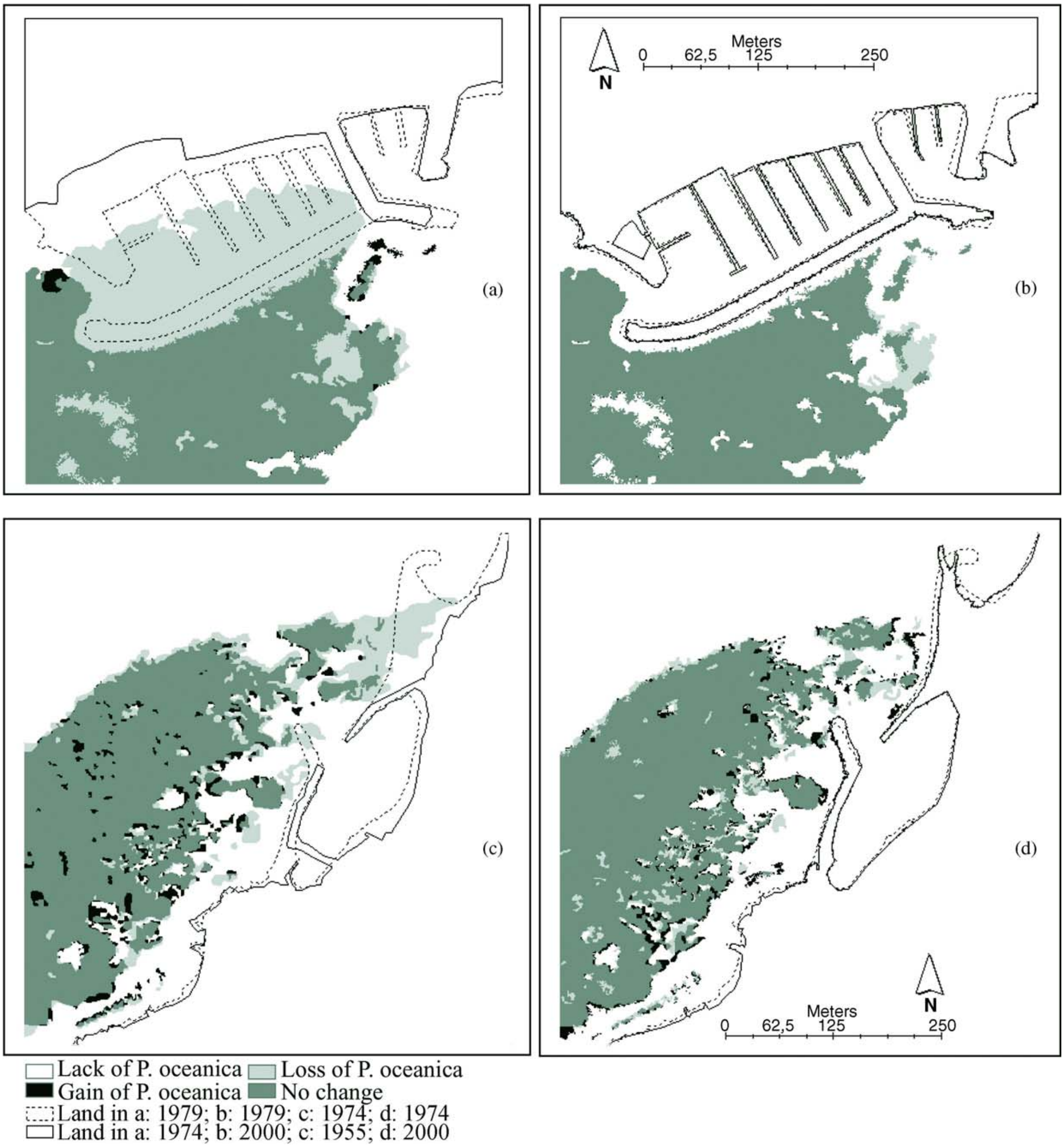

Fig. 3. Changes in spatial distribution of the *P. oceanica* meadow near Les Lecques harbour (a) between 1974 and 1979, (b) between 1979 and 2000, and near La Madrague harbour (c) between 1955 and 1974 and (d) between 1974 and 2000.

from 2 to 16 m depth, *P. oceanica* grows on exposed hard bottom with local coverage values of 40–45% (typical values for meadows on rock) and, according to the classification of Pergent et al. (1995), normal shoot density (Fig. 1a and b). With the exception of the latter zone, the meadow develops on sandy substrate with high coverage values of 80–90% and normal shoot density. The upper limit of the meadow is located at 14 m depth in the centre of the bay (Fig. 2, iii).

(2) The *P. oceanica* meadow in sector 2 (Fig. 2, S2) grows on sandy substrate between 14 and 32 m depth and exhibits lower coverage and many large intermattes of dead matte (about a hundred patches from 26 m^2 to about 1 ha of surface area). In contrast to sector 1, where most of the meadow exhibits high coverage values, in particular between 20 and 30 m depth, coverage values at these depths in sector 2 may be as low as 4–16% (Figs. 1b and 2, iv), where *P. oceanica* only subsists as patches within a dead matte area. The deeper limit of the meadow is sinuous and also exhibits, in particular in its northern part (Fig. 2, v), some dead matte areas with patches of *P. oceanica*.

(3) In sector 3 (Fig. 2, S3), the *P. oceanica* meadow grows on rock and small blocks down to 25 m depth and on sandy bottom below this depth. Along the southern coastline of the bay (between La Madrague harbour and cape Grenier), the meadow grows very close to the shore and exhibits high

coverage with few intermattes of dead matte, with the exception of the area located close to the harbour (Fig. 2, vi). In this area, the meadow takes the form of a mosaic of *P. oceanica* and dead matte with low coverage values (25%, Fig. 1b). A conspicuous regression of *P. oceanica* is evidenced between 1955 and 1974 (Fig. 3c) when the harbour of La Madrague was extended; the regression has continued between 1974 and 2000, though to a lesser extent (Fig. 3d). In this area, very high shoot density values (above normal values for this depth; Fig. 1a) have been recorded. Between the two capes of Fauconnière and Grenier, the *P. oceanica* meadow exhibits vast sandy intermattes (Fig. 2, vii) near its upper limit (the three major ones present a surface area of 1772 m^2, 6045 m^2 and 1.3 ha, respectively) and many smaller intermattes of dead matte near the deeper limit. A vast area (30 m width) of dead matte ending in an erosion scarp lies beyond the deep limit of the *P. oceanica* meadow (Fig. 2, x).

4. Discussion

The *P. oceanica* meadow occupies most of the Bay of Saint-Cyr, locally from close to sea level down to 32–34 m depth. The depth of the lower limit of the *P. oceanica* meadow of Saint-Cyr is close to that of meadows dwelling in very pristine waters, e.g. in the Port-Cros National Park, French Riviera, 34–38 m (Harmelin and Laborel, 1976) and in Corsica, 30–38 m (Meinesz et al., 1988; Pergent et al., 1995; Pasqualini et al., 2000).

In 2001, seagrass almost entirely absent from the centre of the bay between sea level and 12–14 m depth. This vast sandy area can be detected on the oldest aerial photographs of the study area (1944) and was roughly mapped by several authors (Marion, 1883; Blanc, 1975; Bourcier, 1980). In addition, there is no evidence of dead matte below the sand layer. It can thus be supposed that the lack of *P. oceanica* in this area is not due to the disappearance of the seagrass but to the existence of natural non-suitable conditions in this part of the bay, e.g. water movement generating sand waves (sediment input above 70 $dm^3\ m^{-2}\ a^{-1}$ results in the death *of P. oceanica*; Boudouresque and Jeudy de Grissac, 1983; Boudouresque et al., 1984), erosion by undertow currents (Blanc and Jeudy de Grissac, 1978) or resurgence of fresh water from the phreatic layer (*P. oceanica* is reportedly very sensitive to low salinity; Ben Alaya, 1972). The fact that *P. oceanica* is only present on a rocky outcrop (Fig. 2, viii) in this area suggests that sand movements may be responsible for this area being almost devoid of seagrass. In any case, the limits of this area do not seem to have changed conspicuously since at least 1944.

In contrast to several coastal areas in the Mediterranean (e.g. Augier and Boudouresque, 1970; Meinesz et al., 1991; Ramos-Esplá et al., 1994; Boudouresque, 2004), the Bay of Saint-Cyr did not exhibit a dramatic loss of *P. oceanica* despite the enlargement of the two harbours of Les Lecques and La Madrague. If the surface area directly covered by these harbours is not taken into consideration, intermattes cover a total area which represents 8% of the overall surface area of the meadow; this percentage is relatively weak when compared with strongly degraded meadows in the vicinity of large cities and commercial port facilities (Blanc, 1975; Blanc and Jeudy de Grissac, 1978; Boudouresque, 2004). Three decades after the extension of the Les Lecques harbour, *P. oceanica* persists in proximity to the port and even up against the very base of the seawall (Fig. 3a and b). This is a rather uncommon feature: many harbours have an indirect negative impact on surrounding seagrass meadows (Ruiz and Romero, 2003). In addition, no new intermatte has appeared between 1979 and 2000 (Fig. 3b) and shoot density and coverage values are high in the vicinity of the Les Lecques harbour. In the vicinity of La Madrague harbour, together with evidence of loss (see below), the meadow exhibits high values of shoot density (Fig. 1a) and zones where *P. oceanica* recolonises intermattes (Fig. 3c and d).

Nonetheless, the possibility that the intermattes within the Saint-Cyr meadow may be of natural origin is definitely invalidated for many of them. Most intermattes located close to the Les Lecques harbour appeared subsequently to the enlargement of the harbour (Fig. 3a). Concerning the area near the La Madrague harbour (Fig. 2, vi), a strong regression occurred between 1955 and 1974 (Fig. 3c). Few years later, Blanc and Jeudy de Grissac (1978) still observed the regression of *P. oceanica* meadow in this sector down to 10 m depth. Even if the phenomenon seems to be less marked at the present time, the map of changes in spatial distribution of *P. oceanica* between 1974 and 2000 (Fig. 3d) shows the appearance of new intermattes and the extension of those already existing. Three elongated sandy zones (Fig. 2, ix) clearly originated from anthropogenic activities such as trawling (which, though prohibited less than three nautical miles from the shore, is very commonly done along most of the Mediterranean shores; Ardizzone and Pelusi, 1984; Ramos-Esplá, 1984; Pasqualini et al., 2000), anchoring of large cruise boats or pleasure boats (Paillard et al., 1993; Ramos-Esplá et al., 1994; Martín et al., 1997; Francour et al., 1999).

As for a number of other areas in the Mediterranean Sea (Boudouresque et al., 2000), the lower limit of the *P. oceanica* meadow appears to be regressive in some parts of the Saint-Cyr bay. This regression is particularly marked in the northern part of the bay (Fig. 2, v), with the survival of only few patches of *P. oceanica* within a dead matte area. In the southern part of the bay (Fig. 2, x), a 1.1 ha strip of dead matte and large shallower intermattes located in the same area (Fig. 2, vii) may be linked to the proximity of the outfall of a sewage treatment plant, located at 40 m depth (Pergent-Martini and Pergent, 1996; Pergent-Martini et al., 1996; Argyrou et al., 1999).

In conclusion, in the Bay of Saint-Cyr, which harbours two small ports, a sewage outfall, trawling, boat anchoring and coastal urban development, the *P. oceanica* meadow occupies most of the suitable bottoms. The upper limit seems stable over time. In contrast, losses were observed at its lower limits though of weak importance when compared with other Mediterranean coastal areas. With the exception of the lower limit and the area which was directly covered by the harbours, the dead matte surface area is relatively modest. The results presented here give an indication of a possibly uncommon feature, a relatively healthy meadow which coexists with a variety of human activities.

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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.), First International Workshop on *Posidonia oceanica* Beds. GIS Posidonie Publication, Marseilles, pp. 63–72.

Argyrou, M., Hadjichristophorou, M., Demetropoulos, A., 1999. Ecological changes of soft-bottom macrobenthic assemblages in relation to the sewage outfall, in the Limassol bay Cyprus (Eastern Mediterranean). Oebalia 25, 61–88.

Augier, H., Boudouresque, C.-F., 1970. Végétation marine de l'île de Port-Cros (Parc National). V. La Baie de Port Man et le problème de la régression de l'herbier à Posidonie. Bull. Mus. Hist. Nat. Marseille 30, 145–164.

Ben Alaya, H., 1972. Répartition et conditions d'installation de *Posidonia oceanica* Delile et *Cymodocea nodosa* Ascherson dans le golfe de Tunis. Bull. Inst. Océanogr. Pêche Salammbô 2, 331–416.

Blanc, J.J., 1975. Recherches de sédimentologie appliquée au littoral rocheux de la Provence aménagement et protection. Centre Nation. Expl. Océans Publication, Paris, p. 163.

Blanc, J.J., Jeudy de Grissac, A., 1978. Recherches de géologie sédimentaire sur les herbiers à Posidonies du littoral de la Provence. Centre Nation. Expl. Océans Publication, Paris, p. 185.

Boudouresque, C.-F., 2004. The erosion of Mediterranean biodiversity. In: Rodríguez-Prieto, C., Pardini, G. (Eds.), The Mediterranean Sea. An Overview of its Present State and Plans for Future Protection. Universitat de Girona Publication, pp. 53–112.

Boudouresque, C.-F., Jeudy de Grissac, A., 1983. L'herbier à *Posidonia oceanica* en Médi-terranée: les interactions entre la plante et le sédiment. J. Rech. Océanogr. 8, 99–122.

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, 328–331.

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.), First International Workshop on *Posidonia oceanica* Beds. GIS Posidonie Publication, Marseilles, pp. 185–191.

Bourcier, M., 1980. Evolution récente des peuplements macrobenthiques entre La Ciotat et les îles des Embiez (côtes de Provence). Processus de contamination du benthos entre bassins côtiers voisins. Thétys 9, 197–206.

Brown, C.J., Cooper, K.M., Meadows, W.J., Limpenny, D.S., Rees, H.L., 2002. Small-scale mapping of sea-bed assemblages in the eastern English Channel using sidescan sonar and remote sampling techniques. Est. Coast. Shelf Sci. 54, 263–278.

Douven, W.J.A.M., Buurman, J.J.G., Kiswara, W., 2003. Spatial information for coastal zone management: the example of the Banten Bay seagrass ecosystem. Indonesia. Ocean. Coast. Manage. 46, 615–634.

Duarte, C.M., 1991. Seagrass depth limits. Aquat. Bot. 40, 363–377.

Ferguson, R.L., Korfmacher, K., 1997. Remote sensing and GIS analysis of seagrass meadows in North Carolina, USA. Aquat. Bot. 58, 241–258.

Francour, P., Ganteaume, A., Poulain, M., 1999. Effects of boat anchoring in *Posidonia oceanica* seagrass beds in the Port-Cros National Park (northwestern Mediterranean Sea). Aquat. Conserv.: Marine Freshwater Ecosyst. 9, 391–400.

Frederiksen, M., Krause-Jensen, D., Holmer, M., Sund Laursen, J., 2004. Long-term changes in area distribution of eelgrass (*Zostera marina*) in Danish coastal waters. Aquat. Bot. 78, 167–181.

Green, E.P., Mumby, P.J., Edwards, A.J., Clark, C.D., 1996. A review of remote sensing for the assessment and management of tropical coastal resources. Coast. Manage. 24, 1–40.

Harmelin, J.G., Laborel, J., 1976. Note préliminaire sur la morphologie de l'herbier profond de posidonies *Posidonia oceanica* (Linné) Delile, à Port-Cros. Trav. Sci. Parc. Nat. Port-Cros 2, 105–113.

Kendrick, G.A., Aylward, M.J., Hegge, B.J., Cambridge, M.L., Hillman, K., Wyllie, A., Lord, D.A., 2002. Changes in seagrass coverage in Cockburn Sound, Western Australia between 1967 and 1999. Aquat. Bot. 73, 75–87.

Kuo, J., Phillips, R.C., Walker, D.I., Kirkman, H., 1996. Seagrass Biology. University of Western Australia Publication, Nedland, p. 334.

Lefèvre, J.R., Valério, C., Meinesz, A., 1984. Optimisation de la technique de photographie aérienne pour la cartographie des herbiers de Posidonies. In: Boudouresque, C.-F., Meinesz, A., Fresi, E., Gravez, V. (Eds.), Second International Workshop on *Posidonia* Beds. GIS Posidonie Publication, Marseilles, pp. 49–55.

Marcos-Diego, C., Bernard, G., García-Charton, J.A., Pérez-Ruzafa, A., 2000. Methods for studying impact on *P. oceanica* meadows. In: Goñi, R., Harmelin-Vivien, M., Badalamenti, F., Le Diréach, L., Bernard, G. (Eds.), Introductory Guide to Methods for Selected Ecological Studies in Marine Reserves. GIS Posidonie Publication, Marseilles, pp. 57–62.

Marion, A.F., 1883. Esquisse d'une topographie zoologique du Golfe de Marseille. Ann. Mus. Hist. Nat. Zoologie Marseille 1, 7–108.

Martín, M.A., Sánchez-Lizaso, J.L., Ramos-Esplá, A.A., 1997. Cuantificación del impacto de las artes de arrastre sobre la pradera de *Posidonia oceanica* (L.) Delile, 1813. Publ. Espec. Inst. Esp. Oceanogr. 23, 243–253.

Meinesz, A., Bellone, E., Lefèvre, J.R., Astier, J.M., 1990. Impact des aménagements construits sur le domaine maritime de la région Provence-Alpes-Côte d'Azur. DRAE-PACA Publication, Marseilles, p. 38.

Meinesz, A., Caye, G., Charbonnel, E., Lefèvre, J.R., 1988. Localisation de la limite des herbiers à *Posidonia oceanica* et observations sur sa fructification, dans la Réserve Naturelle des Iles Lavezzi: missions 1986. Trav. Sci. Parc. Nat. Rég. Rés. Nat. Corse 14, 53–70.

Meinesz, A., Lefèvre, J.R., Astier, J.M., 1991. Impact of coastal development on the infra-littoral zone along the southeastern Mediterranean shore of continental France. Mar. Pollut. Bull. 23, 343–347.

Paillard, M., Gravez, V., Clabaut, P., Walker, P., Blanc, J.J., Boudouresque, C.-F., Belsher, T., Urscheler, F., Poydenot, F., Sinnassamy, J.M., Augris, C., Peyronnet, J.P., Kessler, M., Augustin, J.M., Le Drezen, E., Prudhomme, C., Raillard, J.M., Pergent, G., Hoareau, A., Char-bonnel, E., 1993. Cartographie de l'herbier de Posidonie et des fonds marins environnants de Toulon à Hyères (Var, France). In: Reconnaissance par sonar latéral et photographie aérienne. Notice de présentation, IFREMER and GIS Posidonie Publication, Marseilles, p. 36 + 3 maps.

Pasqualini, V., Clabaut, P., Pergent, G., Benyoussef, L., Pergent-Martini, C., 2000. Contribution of side scan sonar to the management of Mediterranean littoral ecosystems. Int. J. Remote Sens. 21, 367–378.

Pasqualini, V., Pergent-Martini, C., Clabaut, P., Pergent, G., 1998. Mapping of *Posidonia oceanica* using aerial photographs and side scan sonar: application off the Island of Corsica (France). Est. Coast. Shelf Sci. 47, 359–367.

Pasqualini, V., Pergent-Martini, C., Pergent, G., 1999. Environmental impacts identification along the Corsican coast (Mediterranean Sea) using image processing. Aquat. Bot. 65, 311–320.

Pergent, G., Pergent-Martini, C., Boudouresque, C.-F., 1995. L'utilisation de l'herbier à *Posi-donia oceanica* comme indicateur biologique de la qualité du milieu littoral en Méditerranée: état des connaissances. Mésogée 54, 3–29.

Pergent-Martini, C., Pergent, G., 1996. Spatio-temporal dynamics of *Posidonia oceanica* beds near a sewage outfall (Mediterranean, France). In:

Kuo, J., Philips, R.C., Walker, D.S., Kirkman, H. (Eds.), Proceedings of the International Workshop on Seagrass Biology, Australia, pp. 299–306.

Pergent-Martini, C., Rico-Raimondino, V., Pergent, G., 1996. Impact des nutrients sur les herbiers à *Posidonia oceanica*. Données préliminaries. J. Rech. Océanogr. 21, 35–39.

Piazzi, L., Acunto, S., Cinelli, F., 2000. Mapping of *Posidonia oceanica* beds around Elba Island (western Mediterranean) with integration of direct and indirect methods. Oceanol. Acta 23, 339–346.

Ramos-Esplá, A.A., 1984. Cartografía de la pradera superficial de *Posidonia oceanica* en la bahía de Alicante (SE, Espana). In: Boudouresque, C.-F., Jeudy de Grissac, A., Olivier, J. (Eds.), First International Workshop on *Posidonia oceanica* Beds. GIS Posidonie Publication, Marseilles, pp. 57–61.

Ramos-Esplá, A.A., Aranda, A., Gras, D., Guillen, J.E., 1994. Impactos sobre las praderas de *Posidonia oceanica* (L.) Delile en el SE español: necesidad de establecer herramientas de ordenamiento y gestión del litoral.In: Pour qui la Méditerranée au 21° siècle? Villes des rivages et environnement littoral en Méditerranée. Okéanos, Montpellier, pp. 64–69.

Robbins, B.D., 1997. Quantifying temporal change in seagrass aerial coverage: the use of GIS and low resolution aerial photography. Aquat. Bot. 58, 259–267.

Ruiz, J.M., Romero, J., 2003. Effects of disturbances caused by coastal constructions on spatial structure, growth dynamics and photosynthesis of the seagrass *Posidonia oceanica*. Mar. Poll. Bull. 46, 1523–1533.

Short, F.T., Wyllie-Echeverria, S., 1996. Natural and human-induced disturbance of sea-grasses. Environ. Conserv. 23, 17–27.

Siljeström, P.A., Rey, J., Moreno, A., 1996. Characterization of phanerogam communities (*Posidonia oceanica* and *Cymodocea nodosa*) using side-scan-sonar images. ISPRS J. Photogrammetry Remote Sens. 51, 308–315.

UNEP, 1996. Etat du milieu marin et littoral de la région méditerranéenne. UNEP MAP Tech. Rep. 101, 1–148.

Ward, D.H., Markon, C.J., Douglas, D.C., 1997. Distribution and stability of eelgrass beds at Izembek Lagoon, Alaska. Aquat. Bot. 58, 229–240.