Monitoring of *Posidonia oceanica* meadows near the outfall of the sewage treatment plant AT Marseilles (Mediterranean - France)

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ABSTRACT

The beds of *Posidonia oceanica*, a marine phanerogam plant endemic to the Mediterranean, showed a marked decline near the sewage outfall of the city of Marseilles. The construction of a sewage treatment plant in 1987 provided an opportunity to establish a zero state (reference state) for the environment. Since that date, regular monitoring has been carried out in the area. Expansion in depth range (i.e. meadow lower limit) and the surface area covered by the *Posidonia oceanica* meadow are estimated from aerial photographs using two procedures : orthophotoplans and image processing. The simultaneous use of these two techniques, and additional field data, provides a basis for judging their respective advantages and disadvantages. Observations over the past seven years show that the regression of the meadow in this area has stopped.

1. INTRODUCTION

The earliest maps of the Marseilles area, dating from the end of the 19th century (Marion, 1883), show well-developed *Posidonia oceanica* (L.) Delile beds, occupying virtually the whole of the seabed from 0 to 30 m depth and with an estimated area of about 793 ha. Inputs of untreated sewage from the city of Marseilles into the Calanque de Cortiou from the beginning of the century onwards resulted in massive decline of the P. oceanica beds in this area (Blanc & Jeudy de Grissac, 1978). A map produced by Jeudy de Grissac et al. (1986) from existing documents gave an area of 449 ha, or a decline of 43% compared to the beginning of the century. The opening of the city of Marseilles' sewage treatment plant in November 1987 provided an opportunity to establish a reference state (zero state) for the environment and to carry out regular monitoring of the position of the P. oceanica beds from that date on.

The area occupied by the *P. oceanica* beds was estimated using aerial photographs. Aerial photography has in fact been widely used for several years (i) to monitor the distribution and dynamics of aquatic phanerogam communities (Blanc & Jeudy de Grissac, 1978; Kelly, 1980; Cambridge & Mc Comb, 1984; Meinesz & Lefèvre, 1984; West et al., 1985; Meinesz et al., 1988) and (ii) to estimate their biomass (Meulstee et al., 1986; Belsher, 1985).

Since the opening of the sewage treatment plant, two processing techniques were tested simultaneously to monitor patterns of change in benthic structures : (i) the technique of orthophotoplans, which has been used for several years for biocenosis mapping (Nieri et al., 1993) and (ii) image processing, which is widely used for processing satellite data (Seyler, 1986; Courboules et al., 1988).

2. MATERIAL AND METHODS

Processing was carried out using photographs taken, every two years, between August 1987 and April 1994, in an area near the sewage outfall of the city of Marseilles **(Fig. 1)**. Over the whole of the area studied, 43 dives were carried out using scuba equipment in order to identify the nature of the assemblages and the types of sea bottom. These ground-truth (field sampling) are essential, whatever type of processing is carried out later. A theodolite laser is used for positionning.

Orthophotoplan technique

The monochrome photographs (stereoscopic pairs) are digitalised and processed by computer in order to obtain a 1/1000 scale map ("orthophotoplan" in NIERI et al., 1993. This processing technique is analogous with that used for orthophotography, and involves geometrical rectification or transformation on the basis of accurately located landmarks.

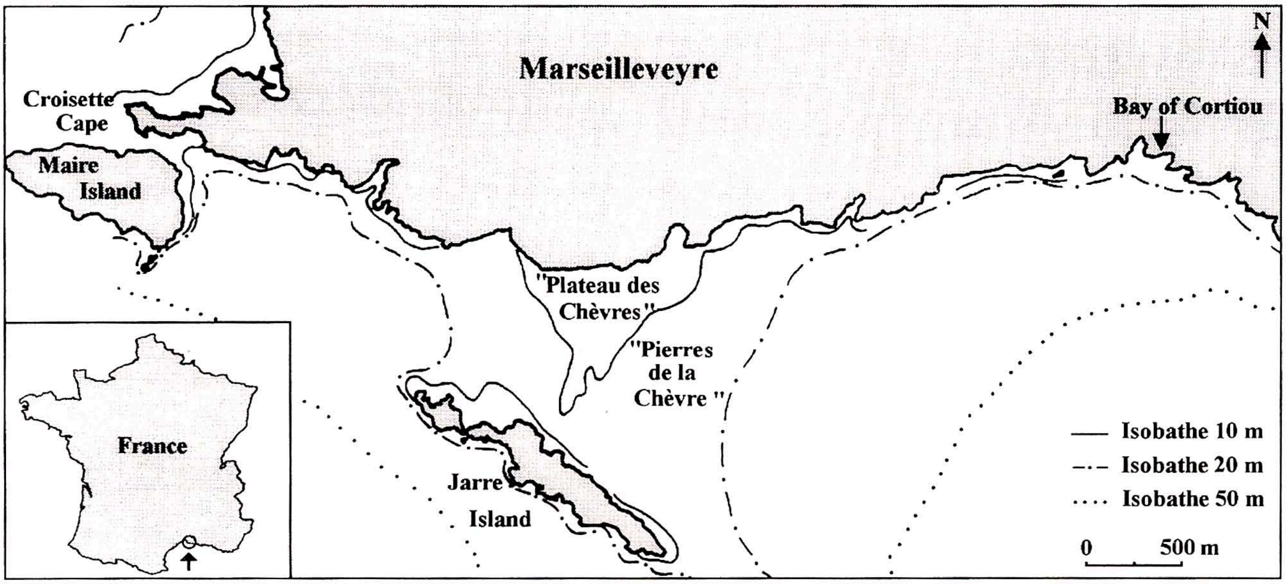

Figure 1 - Map showing the position of the site studied. ↓ : localization of the sewage outfall

On the basis of these orthophotoplans, the boundaries of the benthic structures are then identified. These boundaries correspond to changes in the grey-tone or in light intensity on either side of a more or less regular contour. They do not necessarily represent the areas of contact between different biocenoses. While a light area generally indicates a patch of sand, a dark area might indicate either the presence of a *P. oceanica* bed, or dead "matte" (assemblage of intermingled dead rhizomes with sediment), or photophilous communities on rocks or accumulations of dead *P. oceanica* leaves on the sea floor (Boudouresque et al., 1985; Calvo et al., 1993). This process results in a map (1/1000 scale) with polygons corresponding to the assumed position of the various assemblages.

Image Processing

The colour photographs are digitalised (Canon CLC 10 driven by a 486 DX2-66 microcomputer) by means of IMAGE-IN SCAN & PAINT software. Maximum resolution allowed is 400 points per inch, in 16.8 millions colours, which represents a pixel of 25 cm for an aerial photograph at 1/10 000. It is modulated according to the size of the image and the required pixel. A higher resolution can be obtained by means of software interpolation. For each point or pixel of the photograph, there is a corresponding vector of properties, formed from density for each base colour of the three spectral bands (red, green, blue) .

The image processing, then carried out (MULTISCOPE software from Matra Cap Systems), is essentially the same as for the satellite images. A mask is applied to the land area (in black), and the contrast of the image is enhanced (Hummel, 1977). The image is then processed to optimise the information. A Principal Component Analysis is applied to the green and blue planes, since they contain most information concerning the assemblages to identify. Plane 2, which results from this PCA, provides interesting data on the surface depth zone. By crossing with the green and blue planes (coloured composition), formations can be more clearly distinguished to a depth of 15 m. On the basis of land data, reference polygons are digitalised. Hypercube classification is applied to the coloured composition. By this means, the data contained in the polygons can be applied to the whole image (Courboules et al., 1992). Geometrical adjustment is applied to the resulting image. This is done by reference to the IGN 1/25 000 scale map (Océ-Graphics digitalising tablet).

3. RESULTS AND DISCUSSION

The ortophotoplan technique provided a map showing the distribution of the *P. oceanica* meadow in 1989 and in 1992 (**Fig. 2**). The seagrass meadow is present throughout most of the mapped area. The littoral zone is occupied by sandy deposits that partly mask rock slabs and dead "matte", or rock-based photophilous assemblages. In this zone, the meadow only appears in the form of isolated patches. In the centre of the map, the meadow develops on hard substrate. In the eastern area, a rocky reef, known as "Les Pierres de la Chèvre", is clearly visible. In the southwest, a circular sandy structure with a radius of 60 m is

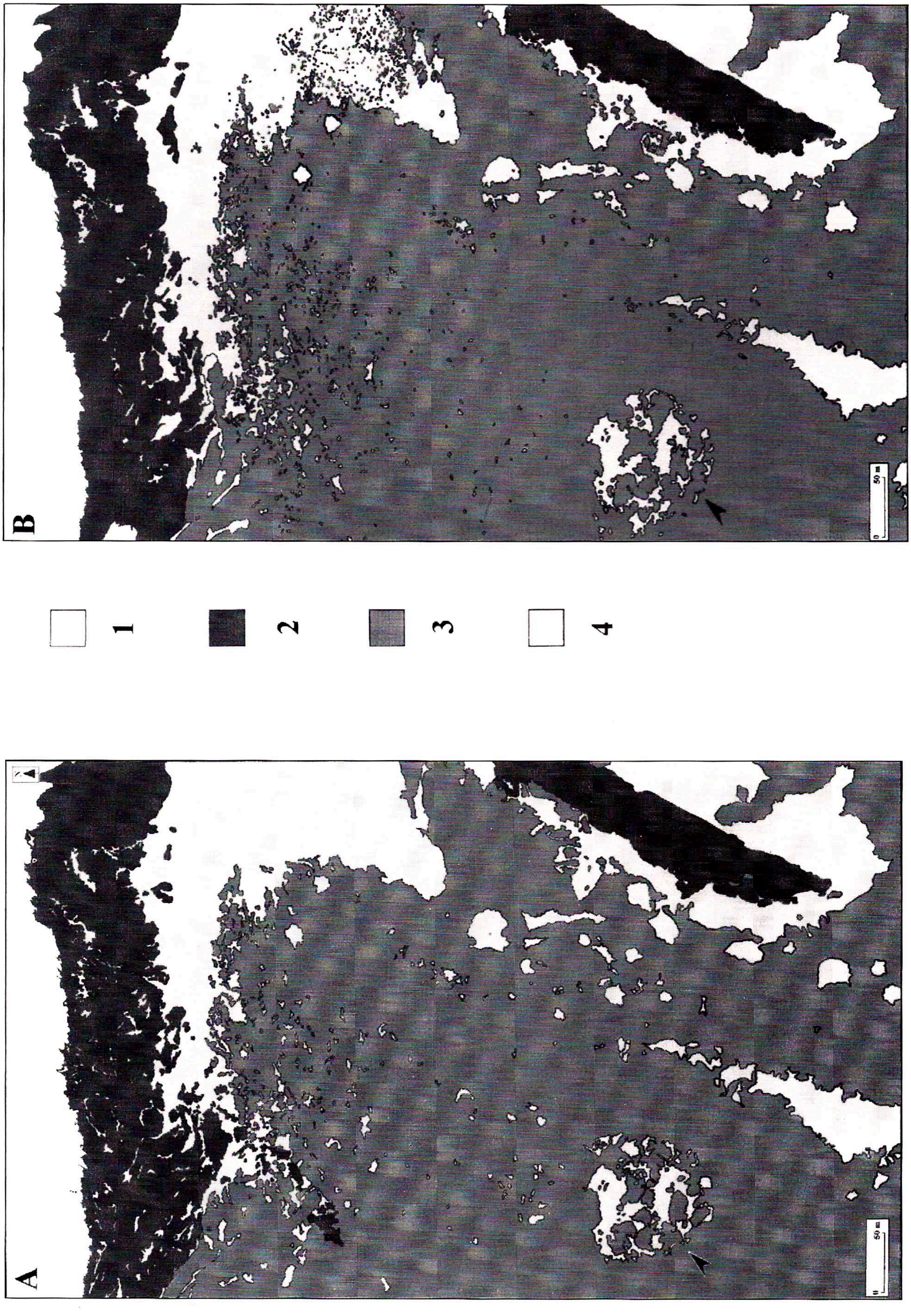

Figure 2 - Map of the main benthic assemblages on the "Plateau des Chèvres", achieved by "orthophotoplan", based on photographs taken in 1989 (A) and 1992 (B) (1: Land; 2 : Rocks; 3 : Meadow of P. oceanica; 4 : Sand)

See plate V at end of volume

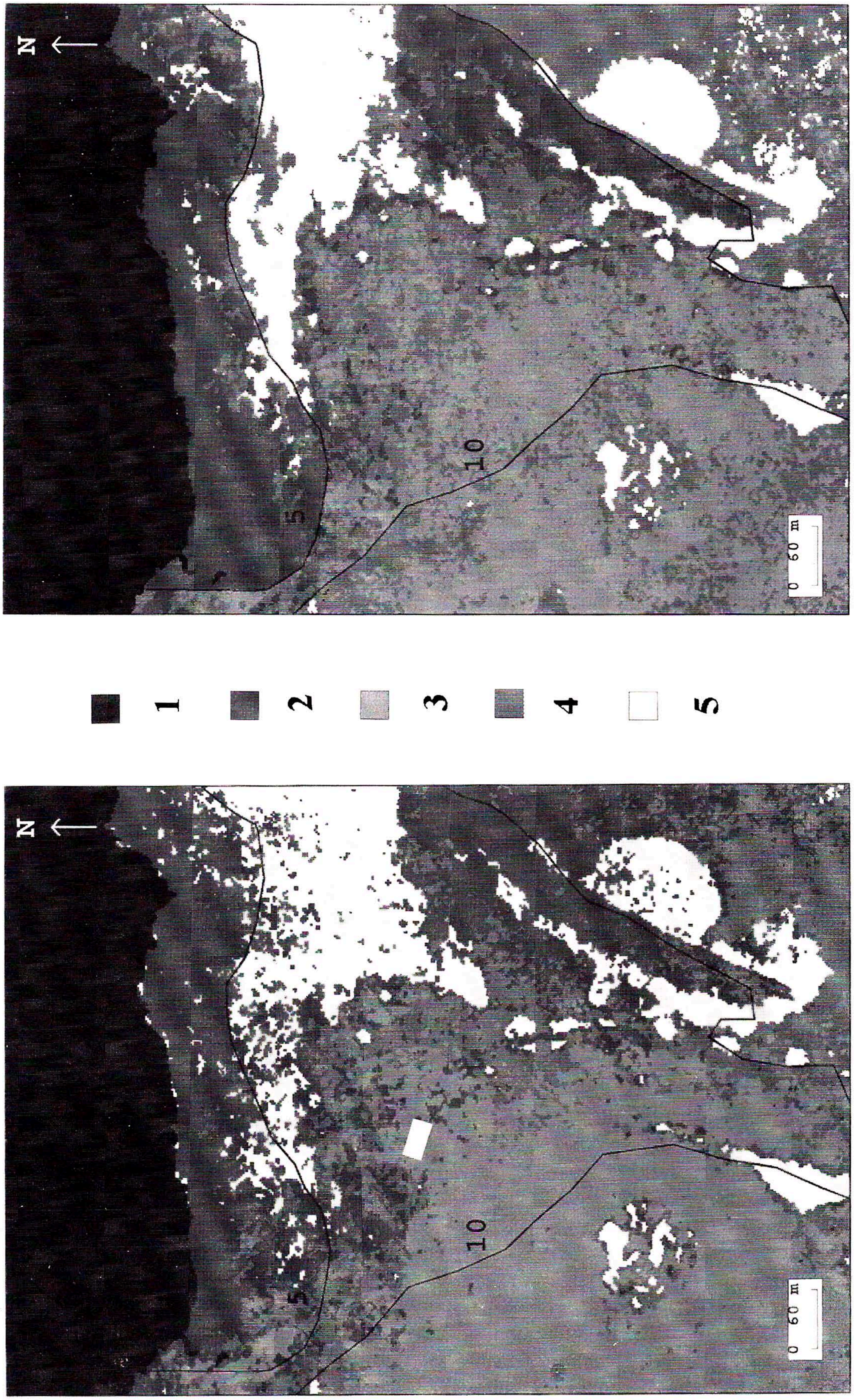

Figure 3 - Map of the main benthic assemblages on the "Plateau des Chèvres", obtained by image processing based on 1994 photographs; (1: Land; 2 : Rocks; 3 : Meadow of P. oceanica; 4 : Dead "matte" and meadow of P. oceanica; 5 : Sand)

See plate VI at end of volume

apparent within the meadow. This patch, which resembles a formation resulting from the explosion of a bomb in the bay of Villefranche-sur-Mer during the Second World War (Meinesz & Lefèvre, 1984), can no doubt be explained by some similar event.

If the two orthophotoplans are superimposed, discrepancies in the position of certain benthic structures are apparent over the map as a whole. These discrepancies, which are not apparent at the centre of the picture, may reach as much as five meters at the edge. Comparison of several specific areas shows some significant changes. For example, on the 1992 map **(Fig. 2B)**, there is a decrease in the size of the sandy patches in the northern area. Whereas some patches seem to have disappeared, others appear have been colonised by *P. oceanica*. Similarly, many patches that were not spotted during previous photography, are now clearly visible **(Fig. 2B)**. The variations observed in the distribution of the *P. oceanica* beds are about 0.9 ha. It would appear that in this area, there has been a slight progression of the meadow. This development might be explained solely by *P. oceanica*'s seasonal growth patterns. In other words, the difference between the times of year when the photographs were taken (February 1989 / July 1992) results in underestimation of the sandy patches on the pictures taken in summer (maximum leaf length in this season *in* Molinier & Zevaco, 1961; Ott, 1979; Caye & Rossignol, 1983). Nevertheless, in contrast to other phanerogams, the density of *P. oceanica* does not show significant seasonal fluctuations (Caye & Rossignol, 1983). In addition, the leaves of *P. oceanica* persist throughout the year; only the length varies according to the season (Pergent & Pergent-Martini, 1988). While these changes may result in some inaccuracy in estimating the surface area occupied, they cannot be the cause of major misinterpretation.

Image processing on the same area **(Fig. 3A)** reveals comparable structures (e.g. the "Pierres de la Chèvre" rocky reef, bomb crater). Nevertheless, differences in interpretation do appear locally. Image processing appears to favour rocky formations at the expense of other assemblages or types of bottom. This can probably be explained by the fact that a given assemblage may present different spectral signatures, depending on the depth (PIRAZZOLI, 1982; BELSHER et al., 1988).

There are two possible explanations: (i) either the polygons of the various assemblages are quite distinctive (in tone and intensity) and certain intermediate pixels that do not belong to any of the classes are not taken into account and appear as white, (ii) or the plots are very close together, and these intermediate pixels are attributed to an assemblage (meadow or sand) which is not necessarily their own. This is the case, for example, for the photophilous assemblages on hard substrates, which, at about 10 m depth, give a spectral signature that is very similar to that of the *P. oceanica*. beds. It is possible to reduce the impact of this artefact, by applying a different treatment for each bathymetric layer (from 0 to 5 m, from 5 to 10 m and below 10 m; **Fig. 3B**). Yet despite this improvement, errors of interpretation persist.

Taking the results as a whole, both techniques present certain advantages and disadvantages. Image processing combines greater objectivity of interpretation - and therefore greater suitability for reproduction - with more rapid processing. But there is still confusion over the classification of certain pixels. On the other hand, the orthophotoplan technique is more accurate for identification of benthic structures (interpretation and limits) but parallax errors make it difficult to use for monitoring over time. It should be stressed that this geometrical rectification problem applies to both techniques when one is working on geographically limited areas (about 40 ha). The reference landmarks are generally few and far between, and are usually restricted to one part of the image.

In order to (i) assess the relative accuracy of the two processing techniques and (ii) monitor the patterns of change over time of a typical structure, a quantitative comparison was carried out in the vicinity of the bomb crater **(Fig. 4)**.

The resolution of the scanner was adjusted to obtain an identical scale for the two processing techniques (pixel equal to 1 m^2) for all the photographs. In 1987, the estimation of surface areas was similar (0.49 ha and 0.50 ha respectively). The two techniques also give similar results for change over time since 1987, with a decrease in area of sandy patches in favour of the seagrass meadow **(Fig. 4)**. Nevertheless, the accuracy of image processing seems to depend to a large extent on the definition of the polygons. A simulation based on the 1994 image shows that, depending on the degree of accuracy and number of polygons, estimates of sandy areas may vary between 0.36 ha and 0.45 ha. The surface area chosen (0.43 ha) corresponds to the classification of the maximum number of pixels (98.7%) while taking into account as far as possible the field data.

4. CONCLUSION

A monitoring system put into operation following the opening of the city of Marseilles' sewage treatment plant has

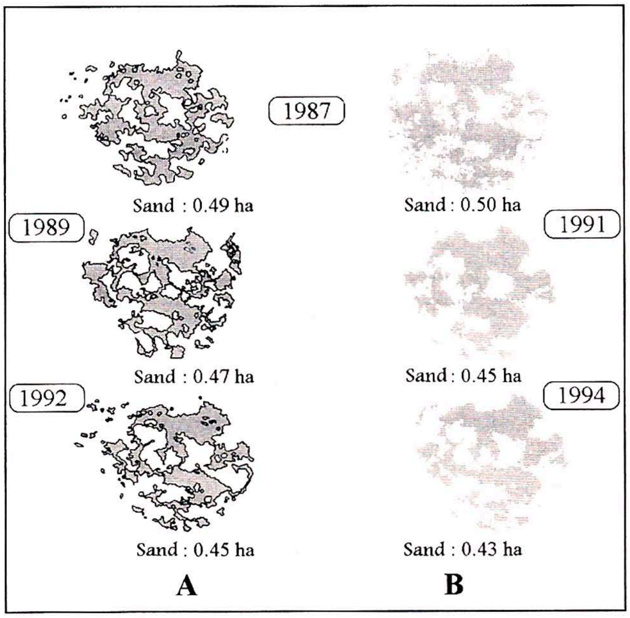

Figure 4 - Dynamics of seagrass bed coverage around the bomb crater on the "Plateau des Chèvres", by "orthophotoplan" (A), and by image processing (B)

provided a basis for assessing the impact of the plant on the distribution of the benthic communities.

Whereas up until the 1980s, a major regression of the *P. oceanica* beds was recorded in this area (Blanc & Jeudy de Grissac, 1978), these communities have apparently become stable since 1987. In addition, some areas appear to show evidence of recolonisation by this seagrass. There seems to be a link between these findings and the decrease in suspended matter and the overall improvement in the water quality that has been recorded since that date (Grotte, 1989; **Tab. I**). These changes have been detected by both of the techniques used (orthophotoplan or visual interpretation, and image processing or digital interpretation).

Table 1 - Changes in the chemical composition of the water discharges in the area of the Marseilles sewage plant before and after its opening (from Anonymous, 1991). * : element added during the depuration treatment

Parameters	1987 (before the opening)	1990 (epurated water)
Suspended matter	67.2 $t.j^{-1}$	12.1 $t.j^{-1}$
Total Nitrogen (N-NTK)	13.8 $t.j^{-1}$	12.3 $t.j^{-1}$
Lead	21.2 $kg.j^{-1}$	1.7 $kg.j^{-1}$
Cadmium	1.2 $kg.j^{-1}$	0.2 $kg.j^{-1}$
Zinc	501.0 $kg.j^{-1}$	14.7 $kg.j^{-1}$
Total Iron	182.0 $kg.j^{-1}$	389.8 $kg.j^{-1*}$

The simultaneous use of the two techniques has made it possible to compare their potential value and limitations. Our results confirm that if the data obtained by teledetection techniques (satellite images, aerial photography) are of value for rapid mapping of underwater plant assemblages (Walker, 1989), their potential depends on the degree of accuracy required and of the size of the area to be studied :

- for extensive areas (greater than 1 000 ha), digital interpretation of aerial photographs or satellite pictures is a powerful tool, since it combines a high degree of accuracy (pixel less than or equal to 30 m) with rapidity of processing. The orthophotoplan technique, on the other hand, is not suitable (accuracy of adjustment, cost, processing time) under these circumstances.
- For intermediate-sized areas (10 ha to 1 000 ha), image processing and orthophotoplans both provide valid results. Whereas image processing has the advantage of rapid interpretation, the orthophotoplan technique provides a more accurate record.
- For small areas (less than 10 ha) the orthophotoplan technique is the most suitable, with satisfactory adjustment, accuracy to less than 1 m and lower variability.

Whatever the processing technique employed, the quality of the photographs is of primary importance, since poor photographic quality can result in errors of interpretation. In addition, for monitoring over time, the time of year when the photographs are taken should be taken into account.

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