P.S.Z.N. I.: Marine Ecology, 9 (2): 157–165 (1988)
Accepted: February 18, 1988

ISSN 0173-9565

Simulation of SPOT Satellite Imagery for Charting Shallow-Water Benthic Communities in the Mediterranean

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With 4 figures

Key words: Benthos, remote sensing, satellite images, charting, Mediterranean.

Abstract. In order to simulate SPOT-type satellite imagery, remote sensing of the Bay of San Cyprianu (Corsica) was carried out using a radiation sensor mounted in an aircraft. The resulting simulated image was calibrated using a chart of the benthos produced by SCUBA diving. We show that remote sensing by satellite should be able to resolve certain bottom types and benthic communities in water down to a depth of 12 m.

Problem

Charting of shallow-water benthic communities, indispensable to the knowledge and management of the littoral zone, is slow and often complicated using currently available methods such as: the interpretation of aerial photographs (ORTH & MOORE, 1983; MEINESZ & SIMONIAN, 1983); underwater observation using SCUBA (GILI & ROS, 1985) or submarines (MEINESZ & LAURENT, 1978, 1982); the interpretation of sidescan sonar surveys (MEINESZ *et al.*, 1981; COLANTONI *et al.*, 1982). Surveys using these methods are able to cover only small areas. As a result, only relatively few charts of benthic communities are available for the Mediterranean. Furthermore their distribution is very unequal, being concentrated around research centers such as Banyuls, Marseille, Nice or Naples, or in protected areas like Port-Cros, Scandola (Corsica), or the Medes Islands.

BELSHER *et al.* (1985) carried out an introductory study of the Bay of Santa Giulia, as part of a preliminary evaluation of SPOT satellite imagery for surveying the upper limit of underwater vegetation cover in the Mediterranean.

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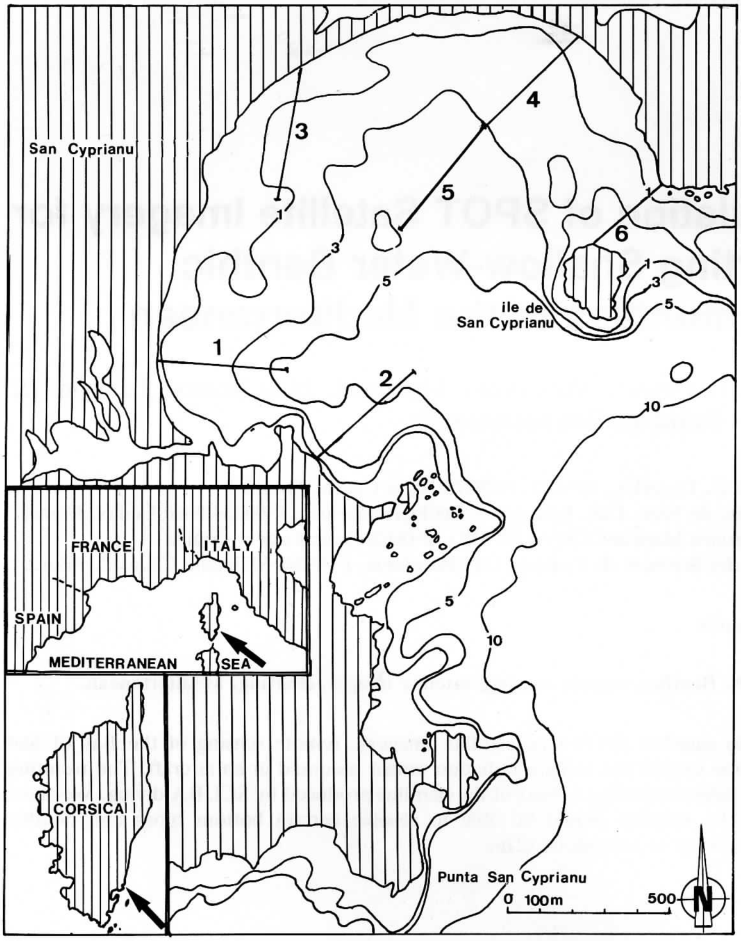

Fig. 1. The Bay of San Cyprianu, including a bathymetric chart. The position of transects is shown.

The present study compares different methods of processing the SPOT data, both with aerial photographs and with ground-truth data derived using SCUBA diving.

Aerial simulated SPOT data was acquired over the region of Porto Vecchio, south-eastern Corsica, and this study considers the Bay of San Cyprianu, which lies within this region (Fig. 1).

In this paper we present the data obtained before the launch of the SPOT satellite (February 21, 1986).

Material and Methods

To simulate SPOT imagery, electromagnetic radiation was detected using a *Daedalus* radiometer mounted in an aircraft of the IGN (Institut Geographique National) at an altitude of 4000 m between 10 : 55 and 11 : 44 GMT on September 2, 1980.

In the IFREMER (Institut Français pour la Recherche et l'Exploration de la Mer) laboratory for image processing, Brest, (using the COMTAL system, GIPSY package), a coloured composite image was created from the different recorded images. This composition gave a resolution of 20 m in the multispectral mode and 10 m in the panchromatic mode. The terrestrial part of the image was suppressed by a treshold technique, using reflectance values captured on the XS3 channel (infrared).

On a composite image obtained from mixing channels XS1 (green), XS2 (red), and XP (panchromatic), image enhancement was carried out by equalization of the respective distributions. In an offshore part of the study area, a strong swell was clearly perturbing the data. As the background noise from this swell could not be filtered out, the sector affected was hidden by a mask produced in interactive mode.

Fig. 2. Aerial photograph showing positions of transects (Photograph taken by IGN).

A Principal Component Analysis (PCA) of the pixels from channels XS1, XS2, and XS3 was carried out. Geographical information on the terrestrial part was derived from channel XP and laid over the above-mentioned mask which hid the land.

In order to obtain information on the nature and limits of different underwater communities in the bay, a black and white aerial photograph supplied by the IGN was used. This photograph was taken in good weather and at a suitable time of day (ORTH & MOORE, 1983; LEFEVRE *et al.*, 1984).

The different benthic communities discernible on this photograph (Fig. 2) were interpreted in the light of point observations and of six 200 to 400 m transects (Fig. 3). The location of these transects was chosen after examining both the aerial photograph and the simulated-SPOT data; they were surveyed by SCUBA diving using the method of MEINESZ & SIMONIAN (1983):

A weighted, marked, 400 m long ground line comprises the transect. The line is unrolled, then extended along the bottom from an inflatable boat. The positions of the two extremities of the transect are fixed using horizontal sextant angles. Two divers follow the ground line; one measures the depth, generally every 5 m, using a measuring tape fixed to a surface buoy (precision ± 5 cm); the other notes the distance along the line, the nature and state of the benthos, and the type of bottom. Altogether 2200 m of transect were thus surveyed, and 480 soundings – at depths of between 0 and −8 m (Fig. 4) – were positioned.

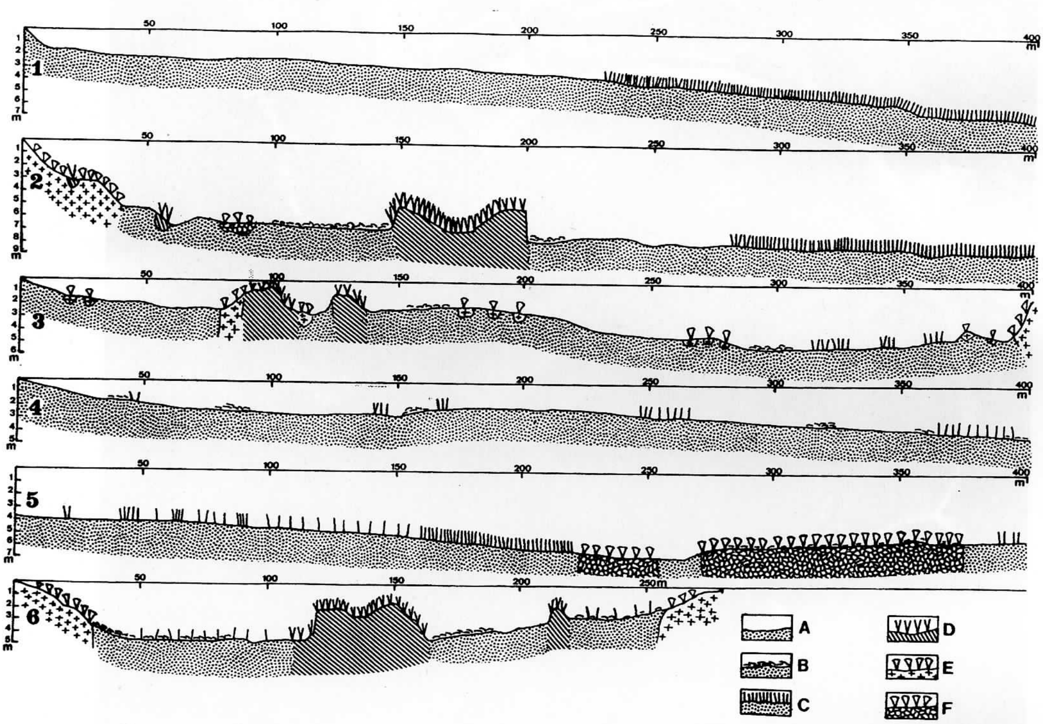

Fig. 3. Details of the six transects. The following standard symbols (MEINESZ *et al.*, 1983) are used to denote different biocoenoses and types of bottom:

A: Sand;

B: Accumulation of dead leaves of *Posidonia oceanica* on sand;

C: *Cymodocea nodosa* on sand;

D: Meadow of *P. oceanica* with "matte" of dead leaves;

E: Photophilous algae on rock;

F: Photophilous algae on stones.

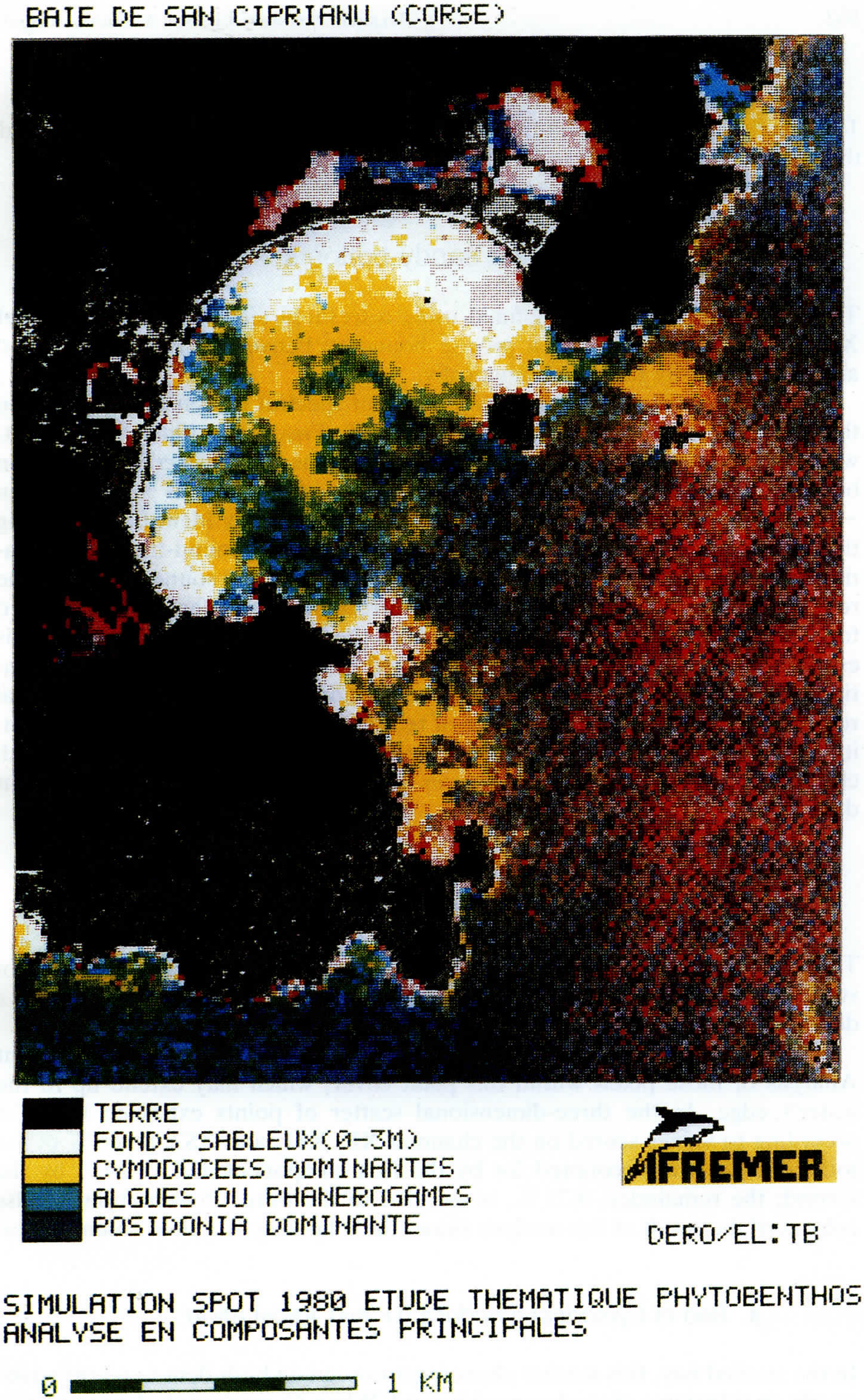

Fig. 4. Final result: processed, simulated SPOT image. (Interpretation: all authors; processing: T. Belsher, IFREMER).

Results

The final treatment (Fig. 4), refined in the light of the ground-truth data allowed the following biocoenoses to be resolved.

1. Littoral fringe and sandy bottoms

The littoral fringe is easily defined using a treshold technique (from channel XS3, 0.79–0.89 µm). Hence a precise boundary between water and exposed areas can be easily traced automatically.

A uniform sandy substrate gives a different spectral response depending on the depth. This well-known (DOAK *et al.,* 1980; PIRAZZOLI, 1982, 1985) effect, which has already been reported for similar bottoms (BELSHER *et al.,* 1985), can be used for fixing isobaths and is particularly precise at depths shallower than −5 m. Sandy bottoms without plant cover are thus easily identified providing that allowance is made for the effect of depth. A single ground-truth identification of this type of bottom, coupled with a suitably accurate sounding, allows the relationship between the different spectral responses and depth to be defined for a particular type of sandy bottom. That the nature of the sandy bottom is essentially perfectly uniform must be verified by well-positioned point observations, and the water must be homogeneous horizontally in terms of spectral response (*e. g.,* turbidity) at the time of remote sensing. For a benthic community chart, the same colour can be given to all sandy bottoms after a full classification of the spectral responses given by these bottoms at different depths.

2. Phytobenthos

The plant cover is visible throughout the underwater part of the bay clear of swell. In the area studied, details of the bottom can be distinguished down to a depth of −12 m.

Several methods of discrimination are possible by Principal Component Analysis of those pixels within this plant cover, which may extend up to the water's edge. In the three-dimensional scatter of points extracted by PCA according to values scored on the channels XP, XS1, and XS2, 86.36 % of the total variance was accounted for by the first component and 12.89 % by the second; the remainder, 0.75 %, is ascribed to the third. Presentation in false colours of the result of this analysis shows the following two plant communities.

a. Bed of *Cymodocea nodosa* (UCRIA) ASCHERSON

In the studied bay, this marine phanerogam occurs in both dense and dispersed stands on substrates of sand or muddy sand. When *Cymodocea* is dense (> 50 % cover), it can be clearly distinguished after processing of the image (Fig. 4).

Moreover, this processing permits detection of dispersed stands of *Cymodocea,* even where these appear very indistinct in the aerial photograph (Fig. 2). For this species the processed image should be recorded between April and September, the season corresponding to its maximum development; during the rest of the year only a small part of the leaves persist (CAYE & MEINESZ, 1986). Care should be taken with calibration using ground-truth surveys, as the speed of colonization in this species can be fast; annual rhizome growth can be as much as 2 m (CAYE & MEINESZ, 1986). Thus the density of cover can vary markedly over time.

b. Meadow of *Posidonia oceanica* (LINNAEUS) DELILE

P. oceanica meadows cover the deeper part of the bay. Their extremely irregular upper limit can for the most part be easily identified using the above processing. However, we noted that photophilic algae growing on rocky substrates, as well as accumulations of dead leaves of *P. oceanica* both give a spectral response similar to that of a *P. oceanica* meadow; this can lead to errors in interpretation. Low-altitude, colour aerial photographs are susceptible to similar errors (BOUDOURESQUE *et al.,* 1985).

Discussion

ORTH & MOORE (1983) have summarized remote sensing techniques using planes or satellites (Landsat) for surveys of submersed vascular plants in very shallow waters (mangroves or estuarine vegetation). In the open Mediterranean we show that, similar to aerial photography, satellite imagery seems to be suitable only for depths between 0 and −12 m.

While the processed data is encouraging for future remote surveying of certain principal Mediterranean biocoenoses such as sandy bottoms and beds of both *Posidonia oceanica* and *Cymodocea nodosa,* some difficulties remain in discriminating between certain types of plant cover. These difficulties could be reduced by techniques of processing designed to compare data obtained by repeated remote surveys. The large areas covered by a single SPOT image (60 km × 60 km) will allow the compilation of charts indispensible to the study and management of the shallow-water littoral zone.

The processing we carried out on the simulated SPOT image and the strategy used for acquisition and processing of ground-truth data are now being used as the base for a study, using real SPOT images, in several regions. These include the Mediterranean (Rade d'Hyères) for seagrass beds, the Pacific (Tahiti-Moorea) for algae of the coral reefs, and Brittany for intertidal and sublittoral algae (Programme PEPS "VEGMA").

The necessity for a large bank of ground-truth data on the identity of benthic biocoenoses is underlined. This may seem to reduce the usefulness of satellite imagery of benthic communities, whose purpose is to rapidly provide data over large areas (60 km × 60 km for SPOT images). Some of the apparently necessary long and expensive field surveys might be avoidable if images were recorded at different times. Both photophilous algae on rocks and accumulations of drifting algae or dead leaves show considerable seasonal fluctuations and might thus be detected.

Summary

A multispectral image of the shallow-water sea bed off Corsica (Mediterranean), was processed so as to simulate one acquired by the satellite, SPOT. It was calibrated against data obtained using traditional surveying techniques, and has allowed the potential of high-resolution satellite imagery of such environments to be evaluated.

Acknowledgements

We thank Messieurs H. NEDELEC (Faculté des Sciences de Luminy), R. PIERSON (Service Maritime de la Direction Départementale de l'Equipement des Alpes-Maritimes), and R. MINICONI (Parc Naturel Régional de la Corse) for help in acquisition of ground-truth data. We are also grateful to Monsieur H. BEN MOUSSA (trainee at IFREMER), Mlle S. SAVY (Faculté des Sciences de Luminy) and all the other staff of IFREMER (DERO/AT and DI/DLS) who helped with the image processing. This study was supported financially by the CNRS (ATP Télédétection spatiale 1985).

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