Underwater Imagery, a Measuring Tool to Extend the Spatio-Temporal Understanding of Benthic Organisms Dynamics: Case Study of *Codium elisabethae* in the Azores.

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1. INTRODUCTION

Benthic habitat mapping studies have been increasingly exploiting the use of underwater images to collect information on substrate nature and biological coverage. Concurrently, research has been ongoing to develop methods that use the imagery collected to extract quantitative measurements and use them for regular monitoring studies of biological resources distributed over large areas. This study provides the first multi-annual monitoring information on the dynamics of a benthic macroalgae population derived from underwater imagery collected by scuba divers in the marine Natura 2000 Site of Community Importance of Monte da Guia (Faial isl., Azores, NE Atlantic). *Codium elisabethae* - a long-living green alga that represents a potential good indicator of coastal environmental change - was chosen for the study. It is well represented in the study area and its abundance distribution was described at the scale of Faial island neighbouring passage in Tempera (2008). Here, two study sites were investigated: Caldeirinhas site, a sheltered no-go reserve exhibiting a dense population, and Ponta Furada site experiencing more exposed conditions and holding a sparser population (Fig. 1). The analyses focus on using the underwater imagery to quantify seasonal fluctuations of density, percentage cover, biomass, growth rate and primary production of the species.

2. IMAGERY SURVEYS

Study sites were chosen as rectangles with 8m length by 4 m width. Permanent seabed marks were installed on vertices of a 2 m quadrangular grid to allow for image geo-correction during photo mosaicking. Video imagery collection was conducted using a semi-professionnal digital camera DCR-VX1000E (3 CCD sensor, 0.4 megapixel) mounted on a diving scooter. The possibility to describe *Codium elisabethae* populations from video imagery transect was initialy demonstrated, first using manual recognition (Salgado, 2002) and then using automated methods (Sirjacobs, 2002). The continuation of field surveys permitted comparing the quality of mosaics produced from video footage with photomosaics produced from stills taken with a commercial Sony DSC-P9 digital camera (mono CCD sensor, 4 megapixels). No artificial lighting was used and optimal quality of mosaics was obtained using still photos taken at a 4 m distance. Regular imagery monitoring surveys started in the end of August 2003 and lasted until November 2005.

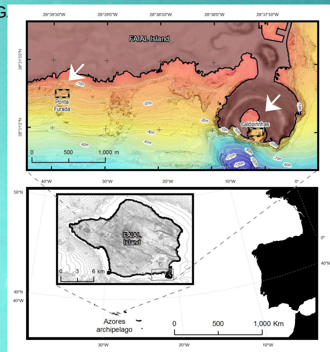

Figure 1- Location of the study sites Ponta Furada and Caldeirinhas within the "Monte da Guia" Site of Community Importance (southwestern Faial Island, Azores).

3. PROCESSING

Figure 2 gives an illustration of image acquisition (A), followed by the first steps of image processing chain : image rectification and mosaicking (B), computer assisted detection on blue and green band eqalized subsets of images with pixel resolution of 0.2 cm (C), and reconstructed population spatial distribution as illustrated illustrates such results for both sites (D). The program provides then automatically various instantaneous informations about the *C. elisabethae* population structures: number of individuals, size histogram, substate percentage cover, and even biomass as computed from size related relation established in laboratory.

MOSAICKING Our specific goal was to define a mosaicking methodology allowing to extract organisms metrics from geometrically corrected images. For both video and still image sequences, various methodologies were investigated from commercial stitching packages to individual matlab codes. Video mosaicking was conducted using the Adelie Mosaic package (©Ifremer) and with the Mosaico.m Matlab software (IST–Lisbon, Prof. J.P. Costeira). For our application, Mosaico.m provided better results than Adelie but variations in light conditions and camera roll and pitch resulted in distortions and discontinuities in the final mosaics, as illustrated on similar zone by figure 2B (top: video mosaic, down: still imagery mosaic). Advantages of still imagery mosaicking were (i) enhanced resolution of the seabed, (ii) reduced number of images, (iii) better focus control. After testing Canon Photostitch (© Canon) and ArcView GIS to build photo mosaics, a Matlab program was written to produce efficiently well referenced and geometrically corrected mosaics according to reference marks positions and to local topography.

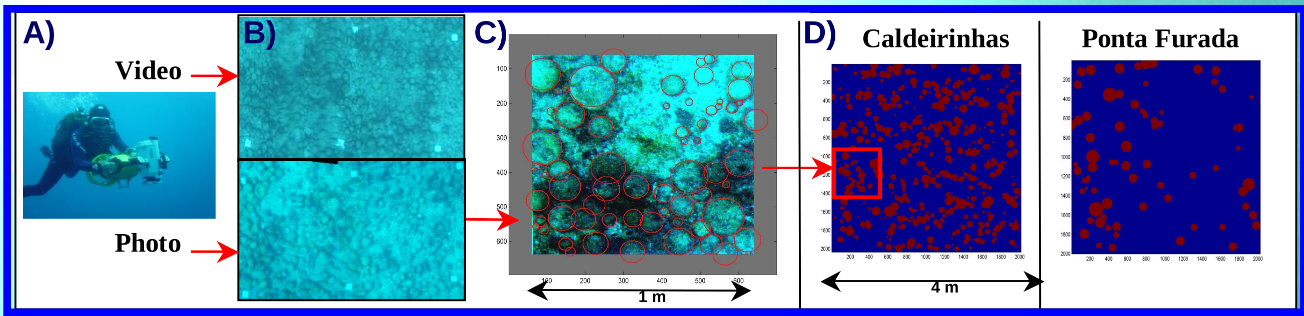

Figure 2 – Steps of image processing for instantaneous information (static) : image acquisition (A), image mosaicking (B), computer assisted detection (C), reconstruction of population spatial distribution as illustrated for both sites (D).

VALIDATION 20 repetitions of situ measurements in 1m² quadrats were used to evaluate the consistency of the population structure produced by *in -situ* and imagery-based methods. Chi-square contingency table analysis (Zar J.H., 1999; Roscoe and Byars, 1971) was used on data aggregated 1 cm class size histograms obtained, and confirmed the validity of a centimeter precision estimation of population structure for individuals larger than 5 cm (Figure 3).

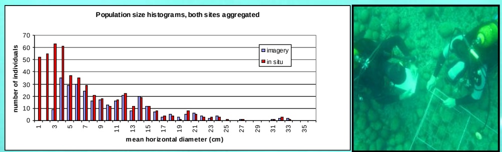

Figure 3 – Comparative size histogram aggregated over time and sites (left) as obtained from imagery and in-situ countings in validation quadrates (right)).

CALCULATION OF POPULATION DYNAMICS PARAMETERS FROM IMAGE CHANGE DETECTION

Similar mosaicking and detection analyses were executed at different periods producing evolution of the population size structure (as an in situ counting would provide) but showed also the establishment, growth and disappearance of specific individuals (Fig. 4). Algorithms synthetised the temporal evolution of number of individuals, density, substrate percentage cover and mean diameter, and created images of "differences between two periods", allowing easy visualisation of change. A second processing phase exploited images to test for change of individuals and classify them as new, vanished, or growing. This provided an automated quantification of growth rate of individuals according to size, period and site studied from the series of images. Similarly, mortality or "recruitment" of individuals could be produced.

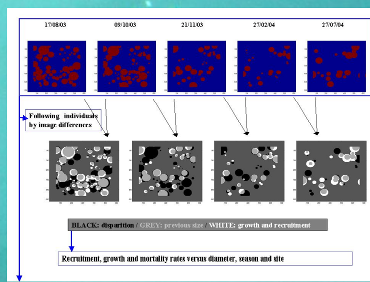

Figure 4 - Illustration of the evolution at individuals level (1 m², Caldeirinhas).

4. RESULTS: ECOLOGY, POPULATION DYNAMICS, AND PRIMARY PRODUCTION

2 years of monitoring of *Codium e.* population dynamics is synthetized (Fig. 5) :
High Biomass (Caldeirinhas : 730 g dry wt.m⁻²; Ponta Furada, 213 g dry wt.m⁻²) compared to (Vidondo and Duarte, 1998) and for *C. elisabethae* (Neto, 1997), pronounced seasonal cycle;
Important population reduction over the 2 years monitoring, mainly for the site of Ponta Furada diplaying clear ageing of the population with mean diameter increase.
High Primary Production (till 15 kg/(m².month) in fresh biomass)

High Growth rate with clear seasonal signal could be precisely measured from image change detection (Fig. 6), maxima values observed are for intermediate class size (8-10 cm) and ranged from 0,3 cm/month (winter) till 2,5 cm/month (summer).

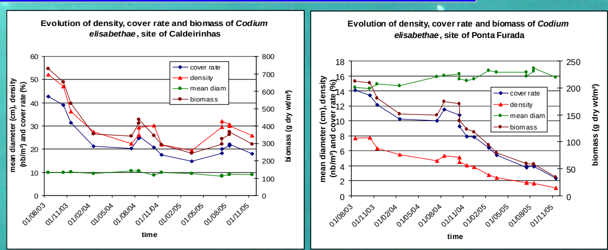

Figure 5 - Evolution of density, cover rate and biomass of Codium elisabethae population, sites of Caldeirinhas and Ponta Furada

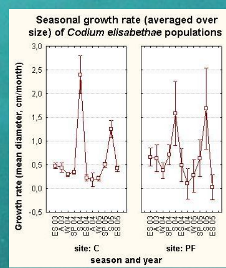

Figure 6 – Seasonal growth rate averaged over size for each site (ES = End Summer (September - mid October); A = Autumn (mid October - end December); W = Winter (January, February, March); SP = Spring (April, May, June); S = Summer (July-August).

5. CONCLUSIONS

1) First long-term monitoring of macroalgae population structure and dynamic by underwater imagery

2) Validity of a centimeter precision estimation of global population structure (organisms > size of 5 cm diam.)

3) Codium elisabethae: demonstration of clear seasonal and interannual variations of biomass and growth rate
! Important reduction of populations over the monitoring period !

4) Advantages of the analysis of seabed visible mosaics for benthic organisms studies:
a) precise adressing of spatio-temporal variability of organisms at individual scale → growth, patchiness
b) very efficient in term of scuba diving time investment
(33 imagery dives = 440 in situ counting dives)
→ increase extent and frequency of studies, as robustness of conclusions;

Acknowledgments

This work is conducted within the frame of the MAROV project (grant PDCTM/P/MAR/15249/1999). Damien Sirjacobs was funded by a PhD grant from Fund for Research in Industry and Agriculture (Belgium). Fernando Tempera was funded by a PhD grant from Fundação para a Ciência e a Tecnologia – Portugal (ref. SFRH/BD/12885/2003)

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