

Aerial Remote Sensing and Spatial Analysis of Marine Benthic Habitats in St George's Bay (Malta)

Charles Galdies⁽¹⁾, Joseph A. Borg⁽²⁾

⁽¹⁾ *International Ocean Institute, P.O. Box 3, Gzira GZR01, Malta.*

Email: cgaldies@yahoo.co.uk

⁽²⁾ *Ecoserv, 12 Sir Arthur Borton St., Mosta MST14, Malta.*

Email: jaborg@ecoserv.com.mt

Abstract

The spatial distribution of marine benthic assemblages and habitats present in St George's Bay (St Julians, Malta) was mapped using aerial photography and GIS techniques as part of an environmental monitoring programme to assess the potential impacts of beach replenishment works carried out in the bay. Maps showing the distribution of benthic habitats in the study area were produced in May 2004 (prior to initiation of the beach replenishment works), and in April 2005 (one year following the beach replenishment works). On both occasions, data from the maps was ground-truthed by SCUBA divers, who also collected data on the occurrence of characteristic plant and animal species from each habitat type. The results from the remote techniques and diving surveys indicated the presence of four main benthic assemblage types in the study area: (i) an assemblage of bare sand; (ii) an assemblage of photophilic algae on hard substrata; (iii) *Posidonia oceanica* meadows; and (iii) *Cymodocea nodosa* meadows. Comparison of the map produced in 2004 (pre-replenishment) with the one produced in 2005 (post-replenishment) indicated that, following the beach replenishment works, the main changes in the distribution of benthic assemblages and habitats in the study area consisted of: (i) a decrease in coverage of assemblages of bare sand; and (ii) a corresponding increase in coverage of supralittoral sand habitat. Overall, the results from the first year of environmental monitoring showed that the beach replenishment works did not have any adverse impacts on the marine benthic assemblages and habitats of the area. The results are discussed in the light of use of aerial photography and GIS techniques for the first time locally to monitor potential adverse impacts from coastal development works on marine benthic habitats.

Keywords: remote sensing, spatial analysis, benthic assemblages

Introduction

In 1998, the Ministry for Tourism and Culture applied to the Malta Environment and Planning Authority (MEPA) for a development permit to replenish the sandy beach at St George's Bay, St Julian's. This application was subjected to an Environmental Impact Assessment (EIA) that included, among other components, an assessment of the impact of the replenishment works on the marine benthic environment of the bay. On the basis of the EIA results, MEPA issued an outline permit with conditions guiding the submission and award of a Full Development Permit (FDP).

One of the conditions of the outline permit was to submit, together with the FDP, an Ecological Monitoring Plan (EMP) for approval by MEPA in order to monitor the environmental impacts arising

as a result of the beach replenishment works, with a view to reducing these to a minimum. The EMP includes: (a) the monitoring of physico-chemical and biological attributes; (b) monitoring of the stability of the nourished beach; (c) detection of potential environmental degradation of the marine environment; and (d) aerial photography, bathymetric surveys, assessment of benthic communities. The EMP proposes that a set of environmental indicators for water quality and for the seagrass *Posidonia oceanica*, mainly based on measurement of seagrass bioparameters, be established for this purpose.

Aerial remote sensing and spatial analysis using GIS was used to address one of the above issues, namely the occurrence and spatial distribution of different

benthic habitats in the bay, including seagrass meadows, rocky substrata supporting macro-algal beds, and drift macrophyte accumulations (e.g. [Meinesz et al., 1988](#)). This study details the application of aerial remote sensing and GIS analysis as a primary surveying technique and an excellent medium for spatial data analysis for benthic habitat mapping, in combination with an underwater *in situ* survey and ground-truthing. This is the first time that such a combination of techniques has been used locally as part of an environmental monitoring programme, specifically to assess the potential impacts of beach replenishment works on marine benthic habitats.

Material and Methods

Overhead digital aerial imagery

A set of overhead aerial photographs of St George's Bay were taken on 28th April 2005 using a light aircraft (Cessna) flying at an altitude of 2000 feet. The aerial images that together covered the area of interest were selected and scanned at high resolution (800 dpi, 24-bit colour) from the negative prints. The imagery was selected on the basis of colour contrast, representation and suitability for benthic mapping. Differences in colour and shade of different habitats makes them easily identifiable from aerial photographs ([Kirkman, 1996](#)), especially given the clear transparent coastal waters of the Maltese Islands.

In order to use the acquired aerial imagery to interpret the spatial distribution of marine benthic assemblages, the topographical effects of the area of interest were accounted through the process of geo-registration. For the present purpose, digital base maps (having a scale of 1: 2,500) acquired from the MEPA, were used to derive all the spatial information to rectify the aerial photos.

To minimize photographic distortion, only central portions were considered and imported in the PC program ERMAPPER. Algorithms were produced to geo-rectify each image ([Green et al., 2000](#); [Lillesand & Kiefer, 2000](#)). The Geodetic Datum used for the rectification was ED50 and map projection was SUTM33, Easting and Northing. A selected number of ground control points (X, Y) were extracted from the digital basemap, and assigned to the corresponding features on the aerial imagery. X and Y control point values extracted from the GIS digital map were standardised and inserted in the rectification matrix of every image. Addition of new control points and polynomial rectification was continued until the best fit against the digital base map was achieved. The rectification sampling was nearest neighbour and the sampling was scaled up to

10 by 10 cm. Geo-rectified images were then mosaiced together and exported in TIFF format.

Ground truthing of the spatial distribution of benthic assemblages (diving survey)

In April 2004, prior to the initiation of the sand replenishment works at St George's Bay (St Julians, Malta), a diving survey was undertaken in the study area. SCUBA divers laid transect lines, graduated at 5 m intervals, along the bottom at compass bearings perpendicular to the shore ('shore-normal transects') starting from the pre-determined points on the shore. Divers then swam along the transects and recorded the occurrence, type and area of bottom covered by the different benthic assemblages (e.g. [Borg et al., 1997](#)). Although the benthic assemblages and most of the species were identified *in situ*, specimens of species that could not be identified in the field were collected for identification in the laboratory. Characterisation of the benthic assemblages was based on indicator species and following the scheme of Pérès (1967; 1982).

A similar survey, using the same diving techniques and transect locations was carried out in April of 2005, a year after the bay was replenished with sand. Data collected during the diving surveys were used to ground truth the data on the spatial distribution of marine benthic assemblages obtained from aerial imagery imagery (see [Orth & Moore, 1983](#); [Kirkman, 1996](#)) and GIS analyses, as described below.

Spatial distribution of the main benthic assemblages derived from the aerial imagery and GIS

To enable quantitative comparison of coverage of the main benthic assemblages recorded from the baseline (2004) session with that obtained from the (2005) session, analyses of the aerial imagery obtained from the two sessions was carried out following the geo-registration procedure.

Because of the varying spectral signatures between the geo-rectified photos, unsupervised classification was performed on separate photos photos ([Green et al., 2000](#); [Lillesand & Kiefer, 2000](#)). Unsupervised classification was used so that the different biotic assemblages and benthic habitats could be appropriately interpreted ([Micallef and Galdies, 2003](#)). This classification procedure was refined to enable detection and separate the major classes for input into the Geographical Information System (GIS). The best setting for unsupervised classification took into account the generation of ten major classes with a confidence limit of greater than 98%, maximum standard deviation of 4.5 and a minimum distance between class means of 3.2. This

setting allowed a clear and distinct separation between *Posidonia oceanica* and *Cymodocea nodosa* seagrass meadows, which were represented by similar classes (resulting from similar colour representation in the aerial images). Careful consideration was also given to allow this procedure to discriminate between *C. nodosa* and the subtle colour change in the transition between *P. oceanica* and sand. To simplify analysis and interpretation, no distinction was made between *P. oceanica* meadows growing on bedrock and those growing on a soft sediment substratum.

The major classes generated were then edited and irrelevant ones were discarded. Relevant classes included the following habitat types:

- i) supralittoral sand;
- ii) accumulations of seagrass leaf litter;
- iii) bare sand intermixed with small outcrops of exposed bedrock, patches of *C. nodosa*, photophilic algae on stones, and accumulations of seagrass leaf litter;
- iv) *P. oceanica* meadows;
- v) photophilic algae intermixed with small patches of *P. oceanica*, including patches of bare bedrock;
- vi) *C. nodosa* meadows.

The above raster-based classes were extracted from all geo-rectified photos and converted into vector form. They were then imported into Mapinfo for GIS analysis (Galdies, 2002). Once in GIS format, the validity of the vector polygons corresponding to

each class was assessed, filtered and clumped together into single thematic layers. Each thematic layer was labelled and the coverage of each main habitat type was determined.

Results

The main output of the aerial photography is the composite image shown in Figure 1. The image clearly shows the newly created beach adjacent to the road and the distribution of different benthic assemblages between the sandy shore and the mouth of the bay, following the replenishment works. Areas that appear turquoise in the inner and central parts of the bay represent a sandy seabed, while areas that appear dark blue represent accumulations of drift seagrass leaf litter (the dark blue area in the innermost parts of the bay) and meadows of *P. oceanica* (present in the central and outer parts of the bay). Stands of *C. nodosa* sandwiched between the *P. oceanica* meadows and the bare sand towards the head of the bay appear green-brown. Areas of rocky bottom supporting assemblages of photophilic algae appear as a blue-green fringe between the shore and the *P. oceanica* meadows along the bay's headlands.

The setting of the unsupervised classification method to differentiate between spectrally close classes, such as *P. oceanica* and *C. nodosa* proved to be effective. Figure 2 a,b represent an example of the raster imagery obtained following the fine-tuned image processing.

Image Info:

Geodetic Datum: ED50
Map Projection: SUTM33
Zero rotation

Pixel size:

Cell width: 0.1m
Cell height: 0.1m

3 Bands (Red,Green,Blue)

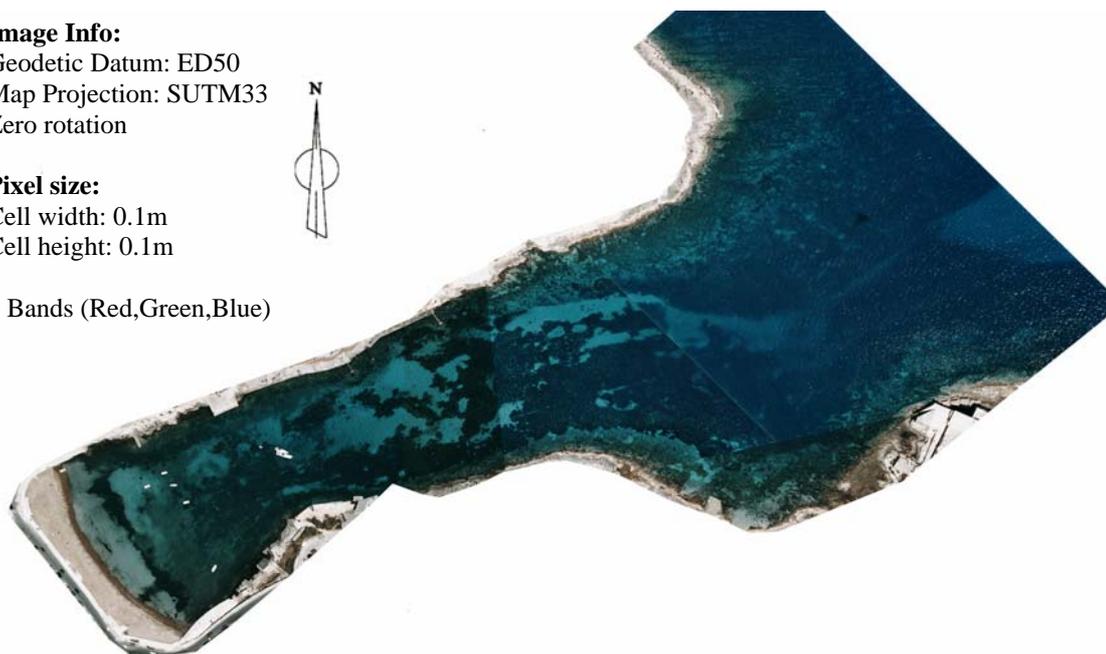


Figure 1: Aerial photograph of St George's Bay taken during the April 2005 survey (mosaic image produced from 5 aerial photographs).

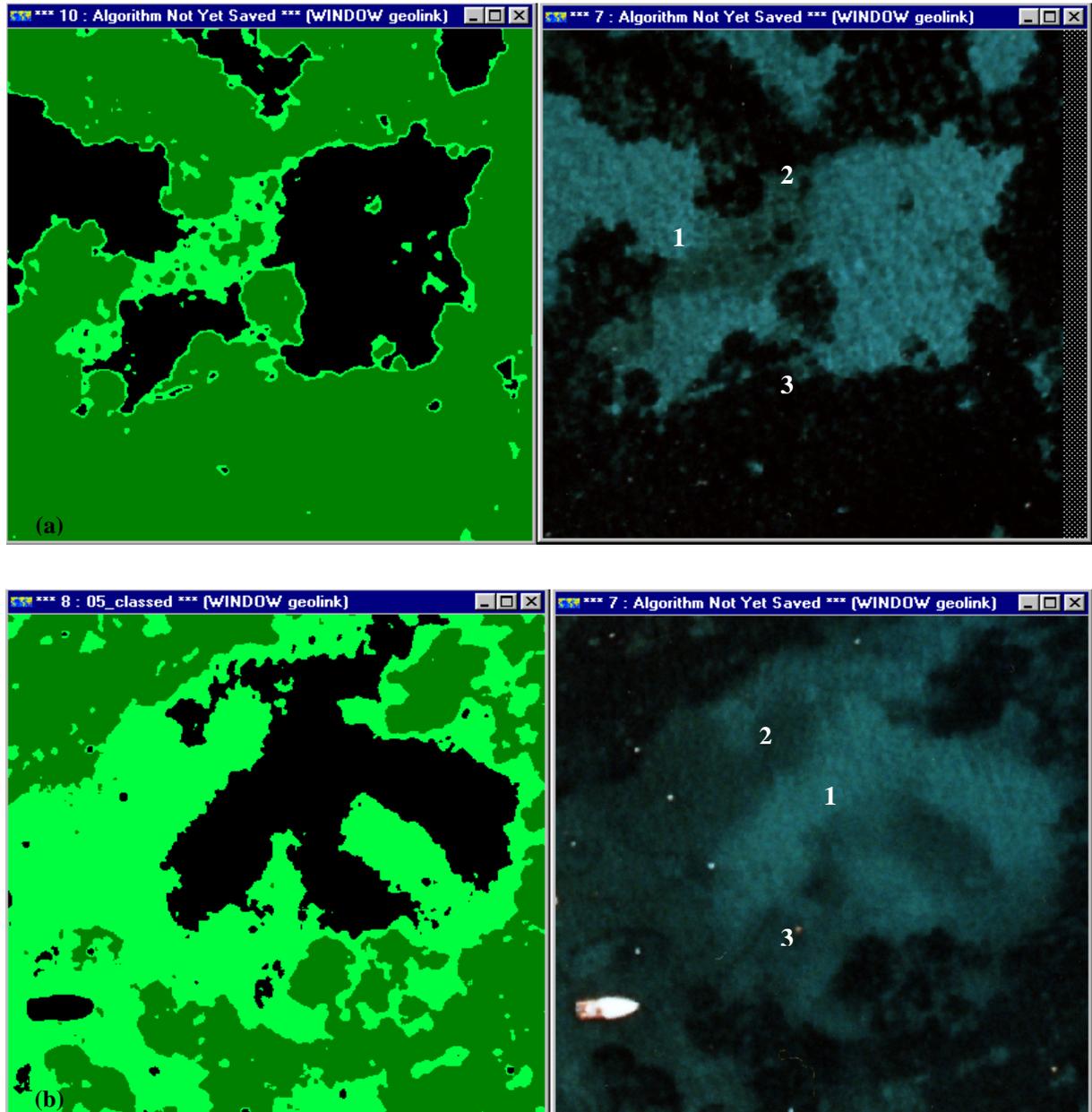


Figure 2. a-b: Classified images (left) that differentiated *C. nodosa* [1] from patches of bare sand [2] and *P. oceanica* meadows [3], as identified from the aerial images (right).

Figure 3 shows the distribution of the main sublittoral benthic assemblages in the study area as obtained from the aerial photographs, GIS analysis and the diving survey in 2005. Four main assemblage types were recorded from the study area:

- i) Assemblage of bare sand
- ii) Assemblage of photophilic assemblages on hard substrata
- iii) *Posidonia oceanica* meadows
- iv) *Cymodocea nodosa* meadows

These constitute the same assemblages that were recorded from the same bay during the previous

A comparison of the map (produced from the GIS

2004 survey and the one carried out earlier by Borg and Schembri (2000) as part of the EIA for the St George's Bay beach replenishment project. A large strip of accumulated drift macrophyte litter (mainly originating from *P. oceanica*) was also present in the inner parts of the bay on the assemblage of bare sand (see Figure 1). However, being a very transient habitat, which can shift at any time from one part of the bay to another, or to deeper waters, drift macrophyte litter was not included as a separate habitat type in the GIS analysis and is therefore not shown in Figure 3. In the GIS analysis, the area occupied by accumulated drift seagrass litter was included with that for bare sand.

analysis) shown in Figure 3 (2005 survey) with the

one (also produced from the GIS analysis) in Figure 4 (2004 survey) indicates that, overall, the main change in the distribution of the benthic assemblage types in the study area consists of a decrease in coverage of the assemblage of bare sand, and a corresponding increase in coverage of supralittoral sand habitat following the beach replenishment works.

Table 1 shows the final statistical derivation of coverage values based on the classified image composites, following comparison between GIS results of the 2004 and 2005 surveys. Note that direct comparison between the 2004 and 2005 classified images can only be considered if the pixel data attributes are derived under exactly the same spectral (e.g. illumination, sun angle and RGB contrast) and geophysical (e.g. height and angle) factors. Therefore, it is best to consider the statistical derivation of the thematic coverage as a relative one. Overall, the results of determination of coverage estimates for the main benthic assemblage types from the GIS analyses corroborate the observations made by direct visual examination of the composite aerial images obtained from the two different surveys (2004 and 2005); the main difference in coverage recorded from the present (2005) survey consists of a decrease in total surface area occupied by the assemblage of bare sand, and a corresponding increase in coverage of supralittoral sand habitat following the beach replenishment works.

Data from the sublittoral diving survey held in 2005 showed that the species composition of benthic

assemblages was similar to that reported from the previous survey made in 2004. In the inner parts of the study area the dominant macroalgae in this assemblage type mainly comprised *Dictyota* spp. In places, sparse stands of the alien alga *Caulerpa racemosa* were present intermixed with *Dictyota* spp. As recorded during the 2004 survey, several species of macroalgae and macrofauna that thrive better in nutrient-rich waters, namely the algae *Cladophora prolifera* and *Ulva rigida*, the hydroid *Aglaophenia* sp., the gastropod *Murex trunculus*, holothurians *Holothuria* spp., some sponges (Porifera) and several species of ascidians were abundant throughout the area surveyed. However, dense stands of the alga *Ulva* (= *Enteromorpha*) *linza* were recorded on the rocky substratum of the mediolittoral and upper infralittoral zones in the southern parts of the study area, just off the beach in the vicinity of the newly constructed culvert, which is conveying effluent from a desalination plant.

Overall, the state of health of the seagrass (*P. oceanica* and *C. nodosa*) meadows present in the study area appeared to have remained unchanged since the previous (2004). Although in most places, meadows of *P. oceanica* and *C. nodosa* appeared to be relatively stressed (compared to meadows of the same seagrass found in cleaner waters), some parts of the study area supported seagrass beds that had long leaves and a rich associated macrofauna (e.g. the noble fan-shell *Pinna nobilis*). Meadows of *C. nodosa* were intermixed with stands of the alga *C. racemosa* in several places.

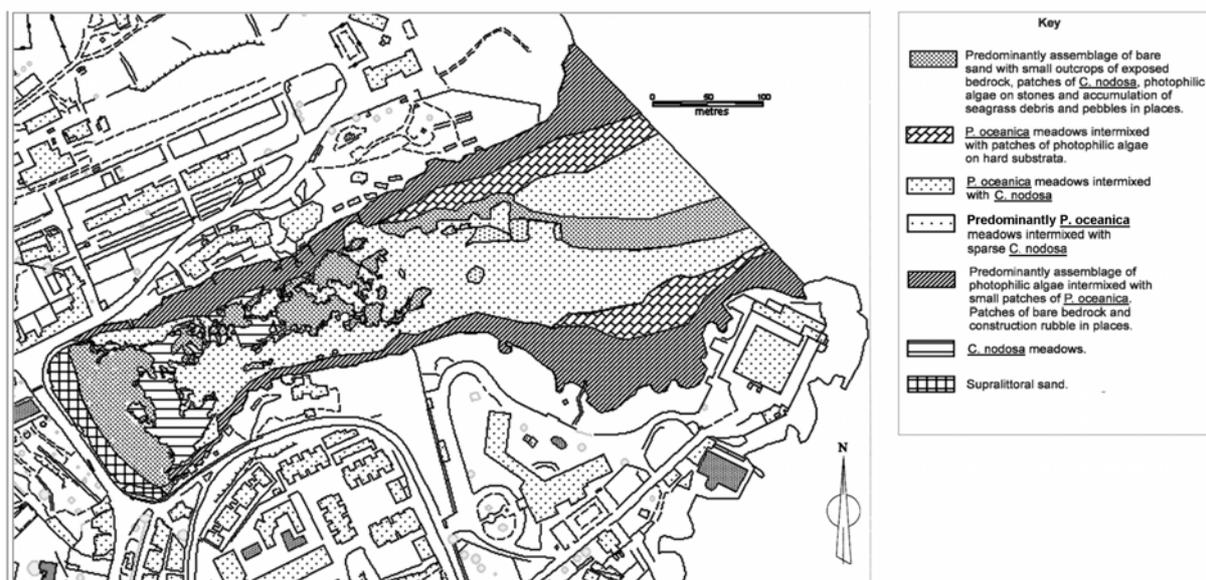


Figure 3: Map produced from GIS analysis of aerial imagery taken during the 2005 survey showing the distribution of main benthic assemblages in the study area.

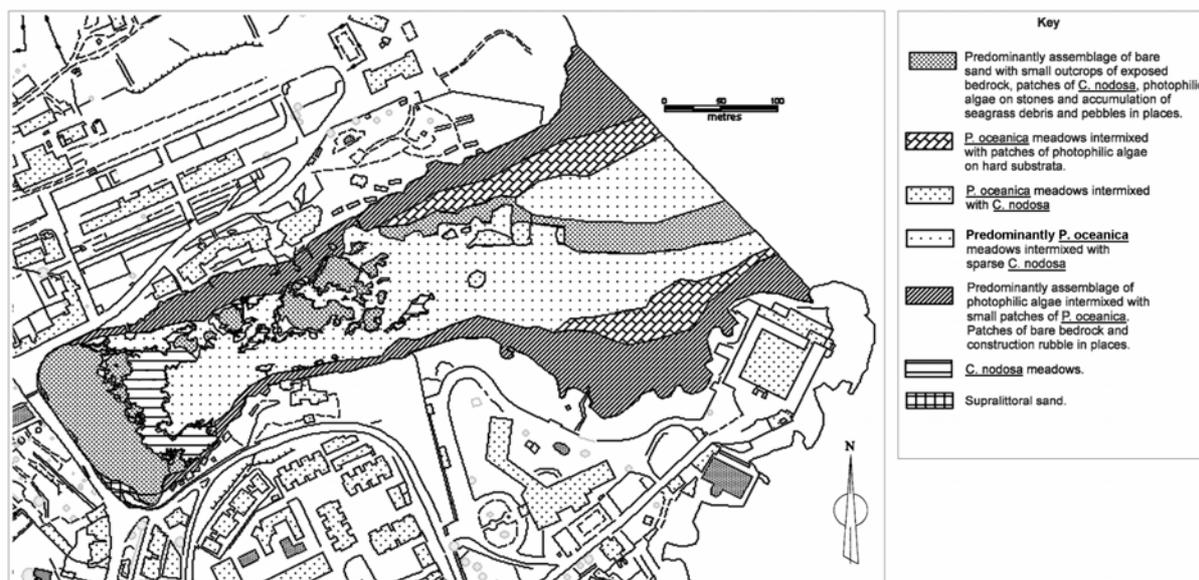


Figure 4: Map produced from GIS analysis of aerial imagery taken during the 2004 survey showing the distribution of main benthic assemblages recorded from the study area.

Benthic assemblage type	Image composite 2004	Image composite 2005
Supralittoral sand	470	2,877
Predominantly assemblage of bare sand but with small outcrops of exposed bedrock, patches of <i>C. nodosa</i> , photophilic algae on stones, and accumulation of seagrass debris	20,050	17,360
Predominantly <i>P. oceanica</i> meadows intermixed with patches of photophilic algae on hard substrata	10,121	10,386
Predominantly <i>P. oceanica</i> meadows intermixed with sparse <i>C. nodosa</i>	42,559	40,316
<i>P. oceanica</i> meadows intermixed with sparse <i>C. nodosa</i>	942	1,252
Predominantly assemblage of photophilic algae intermixed with small patches of <i>P. oceanica</i> in places.	27,220	27,320
<i>C. nodosa</i> meadows	4,628	6,437

Table 1: Coverage of the different assemblage types (area in m²) derived from the GIS statistical analysis of aerial imagery composites produced from the previous (2004) survey and the present (2005) survey.

The assemblage of bare sand also appeared to have similar characteristics to those recorded from the previous (2004) survey; the epifauna associated with this assemblage type was impoverished, but a rich infauna was present as evidenced by the numerous openings to burrows present on the surface, including ones made by *Upogebia* sp.. Close to the replenished beach, there was no visual evidence that sand used for replenishment had been transported to the upper infralittoral adjacent the beach.

Conclusions

The results of the EMP have served to gain experience in local beach replenishment that would be applicable to future replenishment projects that may be carried out at other sites.

As in the previous (2004) baseline survey, the overhead aerial photographs taken as part of the present study clearly show the spatial distribution of benthic assemblages present in the sublittoral zone of St George's Bay, together with the extent of

newly created beach following the replenishment works.

A comparison between the two benthic maps (for 2004 and 2005) produced from the GIS procedure indicated that, overall, the main change in the distribution of the benthic assemblage types in the study area following the beach replenishment works consists of a decrease in coverage of the assemblage of bare sand, and a corresponding increase in coverage of supralittoral sand habitat. This observation was confirmed by the results of statistical derivation of coverage values for the main different benthic assemblage types obtained from GIS analysis of the classified image composites for the two sessions (2004 and 2005).

The results of the diving survey made in 2005 corroborated the data obtained from aerial imagery and confirmed the occurrence of the same main benthic assemblages that were reported in the previous survey (held in 2004) and earlier studies (Borg and Schembri, 2000): (i) an assemblage of photophilic assemblages on hard substrata; (ii) *Posidonia oceanica* meadows; (iii) *Cymodocea nodosa* meadows, and (iv) an assemblage of bare sand. Overall, no large changes in the spatial extent of the main assemblage types were recorded during the 2005 session from the study area following the beach replenishment works made in late spring 2004.

The state of health of the benthic assemblages, including of the seagrass beds, present in the study area appears to have remained unchanged following the beach replenishment works. However, nutrient enrichment in the southern, inner parts of the study area may have led to the observed colonisation of the mediolittoral and upper infralittoral zone by dense stands of the alga *Ulva* (= *Enteromorpha linza*), an opportunistic alga that typically colonises hard substrata in polluted waters. The source of nutrient enrichment leading to the observed profuse growth of this alga is not known with certainty, but it may very well be associated with the effluent being discharged into the sea through a culvert constructed close to where the *Ulva* (= *Enteromorpha linza*) stands occur.

Future monitoring surveys should indicate whether any further changes in the state of health of the benthic assemblages, and their spatial distribution in St George's Bay, have occurred with time.

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