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Environmental Monitoring at St George's Bay (Malta) in connection with Beach Replenishment Works

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Abstract

Adverse impacts of coastal beach replenishment projects on the marine environment are well documented. As a result, coastal managers have been seeking ways and techniques with which to implement beach replenishment projects without causing adverse changes to marine ecosystems. In May 2004, the Malta Tourism Authority undertook beach replenishment at St George's Bay (St Julians, Malta) in which coarse sediment of terrestrial origin, having a mean grain size of 2 mm, was deposited at the head of the bay to create an artificial beach. An extensive 2-year (January 2004 to December 2005) environmental monitoring programme was commissioned by the MTA to monitor the potential impacts of the replenishment works on the marine environment. The programme included surveys of physico-chemical attributes (beach and seabed profile surveys, granulometric analysis and microscopic examination of sublittoral sediments, and water quality studies), and use of seagrass as a bioindicator of environmental quality. For most of the attributes surveyed, data was collected from stations located within the putatively 'impacted' inlet, and from control stations before initiation of the works and following the beach replenishment works. Data for mean sediment grain size, water quality attributes (salinity, dissolved oxygen, total suspended solids and nutrients) and seagrass morphometric parameters (shoot density, length and biomass of adult leaves, and shoot epiphyte biomass) were analysed using analysis of variance (ANOVA). Overall, the results of the various monitoring components indicated that (i) no major transport of sediment from the beach to the sublittoral had occurred, and (ii) the beach replenishment works did not result in any adverse impacts on the marine environment. Good project planning and management, the relatively sheltered location of the replenished beach, together with appropriate choice of grain size of the sand used for replenishment appear to have contributed to the success of the project.

Keywords: beach replenishment, environmental monitoring, Maltese Islands, *Posidonia oceanica*.

Introduction

Increased anthropogenic use of the coastal zone for recreation and tourism has resulted in a higher demand for beaches. In small countries such as Malta where beaches occupy only 2.5% of the total coastline (Axiak and Sammut, 2002), but where the demand for the amenity is very high, the creation of artificial beaches seems to be an appropriate solution (Hanson *et al*., 2002). However, beach replenishment projects have occasionally resulted in adverse impacts, particularly since sediments used for replenishment may be transported by wave action and currents to sensitive habitats where they affect the biota. For example, the creation of artificial sandy beaches in Toulon, France, partly contributed to the decline of ecological valuable seagrass (*Posidonia oceanica*) habitat in the region (Astier, 1984).

Past attempts at beach replenishment in the Maltese Islands have lacked proper planning, and in some cases have even been carried out illegally. As a result, data on the environmental impacts of local beach replenishment works are lacking altogether. The only local documented case in which the environmental effects of beach replenishment were assessed consists of survey carried out in 1991 at Pretty Bay, Birzebbuga, following deposition of large amounts of fine sediments that had been dredged from a nearby site during the construction of the Malta Freeport. The results of this survey indicated complete decimation of *P. oceanica* seagrass beds that were originally present in Pretty Bay, while the authors also observed an overall lower species richness and abundance of typical biota in their study area (Borg and Schembri, 1993).

In 1998, the Maltese 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, on the northeastern coast of mainland Malta. The project aimed to replenish the beach using imported sediments of terrestrial origin – see Ebejer (2004) for further details. The MTA's application was subjected to an Environmental Impact Assessment (EIA) that included modelling of the fate of added sediment of different grades to the beach under various sea conditions, and assessment of the impact of the replenishment on the marine environment of the bay, including the benthic assemblages and habitats present. In 2000, the Centre for Insular Coastal Dynamics (Foundation for International Studies, University of Malta) commissioned a survey of the benthic biotic assemblages present in the St George's Bay (see Borg and Schembri, 2000), as part of the EIA. On the basis of the EIA results, the MEPA issued an outline permit with conditions guiding the submission and award of a Full Development Permit. One of the conditions of the outline permit was submission of an Ecological Monitoring Plan (EMP), which was mainly aimed at monitoring the potential environmental impacts resulting from the beach replenishment works, with a view to reducing these to a minimum. Furthermore, the EMP allowed for corrective action to be taken, while verifying or otherwise the predictions of the EIA. The EMP required: (a) monitoring of physical and chemical attributes (sediment studies, and water quality); (b) monitoring of the stability of the nourished beach (through aerial imagery, and beach profile and bathymetric surveys), (c) use of biological indicators to monitor the state of the marine environment; and (d) monitoring of the marine benthic assemblages and habitats in the inlet. Being the first time that such beach replenishment works were being undertaken on a relatively large scale, the results of the EMP will also serve to gain experience in local beach replenishment that would be applicable to future replenishment projects at other sites in the Maltese Islands. The Malta Tourism Authority (MTA), on behalf of the local Ministry for Tourism and Culture, entrusted Adi Environmental Consultants Ltd (AECL) with preparation of the EMP that met the requirements of the outline permit issued by the MEPA. In turn, AECL submitted the required EMP which detailed the various physico-chemical and biological components to be undertaken.

The seagrass *Posidonia oceanica* (L.) Delile was chosen as bioindicator for the biological component of the EMP due to its widespread distribution and sensitivity to anthropogenic disturbance (Pergent-Martini *et al*., 2005). In cases where the level of suspended sediments in the water column increases, as may happen following dredging works or when sediments from artificially replenished beaches are transported offshore by wave action and currents, the resulting turbid conditions lead to a reduction in the amount of photosynthetically active radiation (PAR) reaching the seagrass, with subsequent reductions in plant growth rate or possibly even death of the plants (Boudouresque et al., 1994). Nutrient enrichment of the water column may enhance the growth of epiphytes on the seagrass leaf surfaces (Hemminga and Duarte, 2000) and promote phytoplankton blooms, both of which reduce the amount of light reaching the plants, leading to adverse conditions and potential regression of a seagrass bed (Boudouresque et al., 1994).

Beach replenishment works were completed in May 2004, when around 7,000 metric tonnes of coarse sand that had been imported from the Al Jashia quarry in Aqaba (Jordan) were deposited at the head of St George's Bay to create an artificial beach covering an area of circa 4,000 m^2 (Ebejer, 2004). The imported sand is polychromic (mostly reddish brown), and has a mean sediment grain size of 2 mm and a specific gravity of 2.6.

The present paper gives an overview of the results obtained from physico-chemical and biological monitoring undertaken during a two-year period, between January 2004 and December 2005, as part of the EMP for the St George's Bay beach replenishment project.

Material and Methods

Study area

St George's Bay is a narrow inlet located on the northeastern coast of mainland Malta (Figure 1). Being aligned southwest – northeast, the bay is mostly exposed to the north and northeasterly winds. Historical data indicate that a sandy beach was present at the inlet's head, but during the past few decades this was reduced to a small patch of sand at its southern corner. Water depth ranges between < 1 m at the head of the inlet and 20 m at its mouth, while the bottom inside the bay is littered with numerous boat moorings. A sublittoral benthic survey of the inlet carried out in 2000 indicated the presence of four main assemblage types: (i) an assemblage of bare sand; (ii) an assemblage of photophilic algae on hard substrata; (iii) meadows of the seagrass *Posidonia oceanica*; and

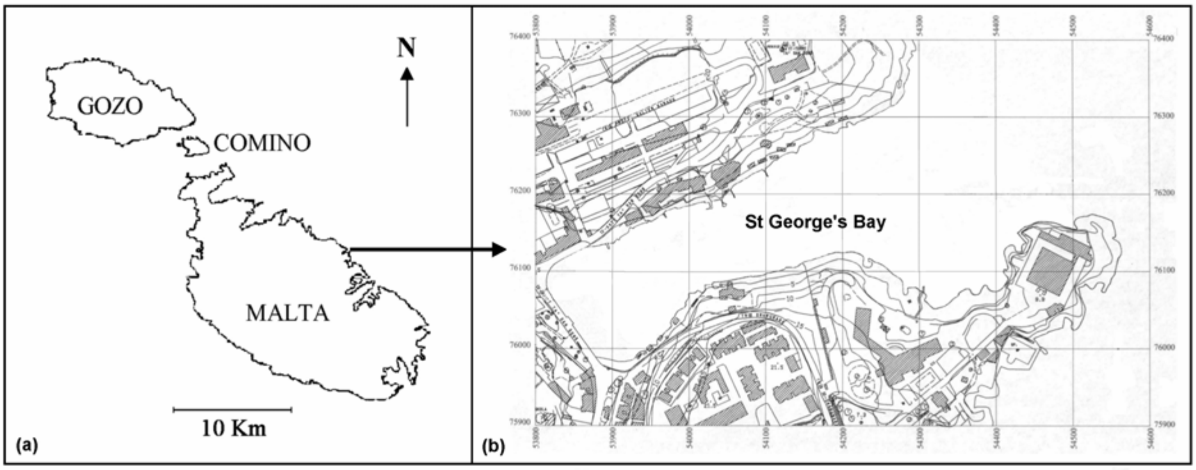

Figure 1. (a) Map showing the location of the study area on the northeastern coast of mainland Malta; (b) the study area (squares making up the UTM grid have a side length of 100 m).

(iv) meadows of the seagrass *Cymodocea nodosa* (Borg and Schembri, 2000).

Physico-chemical attributes

To assess the exposure of the inlet to predominant winds, data for wind speed and direction for 2004 and 2005 were obtained from the Meteorological Station (Station Number 16597) at the Malta International Airport. Beach profile and bathymetric surveys were undertaken in June/July 2004 (prior to the beach replenishment works), September 2004, May 2005 and September 2005. The first survey (June/July 2004) constituted the baseline survey, since it provided data against which future beach profile and bathymetric surveys may be compared. All sessions involved planimetric and altimetric surveys of major features around the study area, including a survey of the seabed from mean sea level to depths varying between 1.45 m and 2.0 m, and bathymetric surveys below mean sea level between depths of 1.0 m and 6.5 m. During the surveys, data was collected along a series of 10 transects aligned perpendicular to the long axis of the inlet. Accurate positioning was achieved with the help of an electronic theodolite. Water depth below mean sea level was measured by SCUBA divers using electronic depth gauges, while horizontal distances on the seabed were measured using tape measures. Data from the surveys was used to plot maps showing depths from -0.5 m to -6.0 m, with contour lines at 0.5 m intervals (Scale 1:1250), and sections showing spot levels measured along each transect.

Monitoring of sediments was undertaken in May 2004 (prior to the beach replenishment works), June 2005, and December 2005. The first survey (May 2004) constituted the baseline survey. During each session, three replicate sediment samples were collected by SCUBA divers from each of five stations located along a transect running through the centre of St George's Bay (Figure 2a). Samples were collected using a 5 cm diameter plastic corer, pushed into the bottom to a depth of 10 cm below the sediment surface. The cores were then transferred into labelled plastic bags and transported to the surface. In the laboratory, the samples were first dried in an oven at 60^{o}C for 24 hours. They were then thoroughly mixed and a 50g sub-sample was weighed out for granulometric analysis. Granulometry was determined according to the method given in Buchanan (1984) using nested 4 mm, 2 mm, 1 mm, 500 μm, 250 μm, 125 μm and 63 μm Endecott test-sieves, agitated on a mechanical sieve-shaker at moderate amplitude. The sediment passing through the 63 μm sieve constitutes the silt/mud fraction, which was not analysed further. All references to grain sizes and respective classification were based on the Wentworth Scale. When granulometric analysis indicated large differences in mean sediment grain size between values recorded from a post-replenishment session and those recorded in the baseline survey, Analysis of Variance (ANOVA; with alpha set at 0.05) was used to determine whether the differences were significant. Microscopical examination of the sediment was carried out by examining 2-4 g sub-samples under a stereo-microscope, using X20 – X80 magnifications.

A total of five monitoring sessions for water quality were held: the first session was undertaken in May 2004 prior to initiation of the beach replenishment project; the second in June 2004 following the works; the third in January 2005; the fourth in June 2005; and the fifth in December 2005. In all five sessions, *in situ* measurements and collection of samples for laboratory analyses were made at each of eight sampling stations; four of which (stations A – D; see Figure 2b) were located in St George's Bay and constituted the putatively ‘impacted’ sites, while the remaining four (stations E – F; see Figure 2b) were located off Bahar ic-Caghaq and Pembroke/White Rocks area and served as controls. Measurements of temperature, salinity, and dissolved oxygen were made at each of the eight monitoring stations using an *in situ* meter. For estimation of chlorophyll a, nitrates, and phosphates, a sample of water was collected in a polycarbonate bottle from 1 m below the surface from each of the eight stations. For bacteriological studies, a 500 ml sample was collected in the same manner from each station, using a sterile glass bottle. To enable estimates of total suspended solids, two 5 L polycarbonate containers were filled with water from 1 m below the surface from each of the 8 stations. All samples were transported to the laboratory within 2 hours of collection. Samples for bacteriological studies were transported in a cooler box at approximately 4° to 10° C. In the laboratory, chlorophyll a, nitrates and phosphates were determined according to the spectrophotometric methods given in Strickland and Parsons (1972) and Parsons et al. (1984). Bacteriological determinations for Faecal Coliforms (FC) and Total Bacterial Counts (TBC) were carried out by filtering the water samples using a membrane filter and inoculating appropriate growth media, followed by incubation and counting of colonies. Total suspended solids were estimated by filtering the water samples using a 0.45 µm Millipore filter, and weighing the residue (to the nearest 0.01 mg) after drying at 75^{o}C for 1 hour (Strickland and Parsons, 1972). Statistical analysis to compare levels of the various physico-chemical data between stations located in St George’s Bay and those recorded from the reference stations was carried out using ANOVA (with alpha set at 0.05).

Biological monitoring

Two monitoring sessions using *Posidonia oceanica* as a biological indicator were undertaken; the first in May 2004 (prior to initiation of the beach replenishment project) and the second in May 2005 following the beach replenishment works. While the first (2004) survey served to provide a baseline against which to compare future monitoring, the aim of the second (2005) survey was to establish whether the beach replenishment works resulted in environmental changes that would be manifested as changes in shoot density and morphology of *P. oceanica*. In both sessions, SCUBA divers were transported to the same eight sampling stations (four putatively impacted and four reference stations) used to monitor water quality (Figure 2b). At each station the divers estimated *P. oceanica* shoot density by counting the number of shoots in five replicate quadrats measuring 35 cm X 35 cm. Ten *P. oceanica* orthotropic shoots were then collected for further analysis. In the laboratory, adult leaves were separated from intermediate and juvenile leaves, as per Giraud’s (1979) technique. For each station, the mean adult leaf length (excluding the sheath) was estimated by measuring the leaves to the nearest mm. The epiphytic load on the adult leaves was determined by scraping off the epiphytes from the adult leaves using a blunt blade and weighing the scraped material after drying at 80 °C for 24 hours. The remaining sheath from the scraped adult leaves was removed and the blades were dried at 80 °C for 24 hours and weighed to determine the mean adult leaf biomass for each station.

Statistical analyses of *P. oceanica* shoot density and morphometric data was carried out using ANOVA (with alpha set at 0.05) based on a Before-After-Control-Impacted (Underwood, 1992; 1997; 2000).

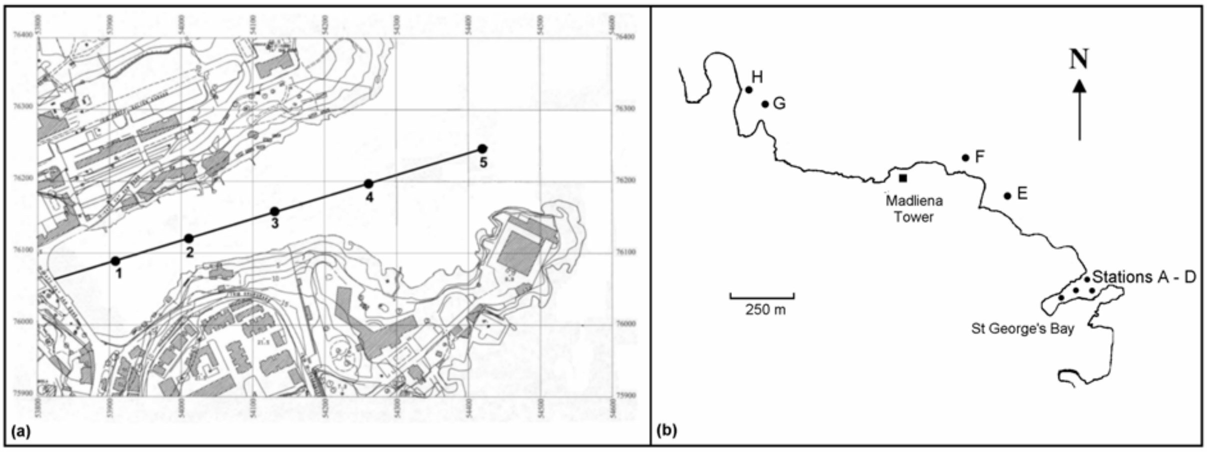

Figure 2. Maps showing the location of: (a) the five sediment sampling stations in St George’s Bay (squares making up the UTM grid have a side length of 100 m); and (b) the eight stations used to monitor water quality and *Posidonia oceanica*.

Results

Analysis of data for wind speed and direction indicated that the predominant winds during the two-year monitoring programme (2004 – 2005) were northwesterly (290-310 sector); these constituted an overall percentage frequency of around 21%. Winds having a direction from sectors 170 to 340, from which St George's Bay is completely sheltered, together constituted a total frequency of 60 % in 2004 and 65% in 2005. Winds having a direction from sectors 350 to160, to which St George's Bay is somewhat exposed, together constituted a total frequency of 31% in 2004 and 33% in 2005. The data also indicated that winds having a speed of 4-6 knots were predominant (around 30%) in both 2004 and 2005, while those having a speed of 22-27 knots had an overall frequency less than 1% in both years. Winds having a speed greater than 27 knots (but less than 34 knots) were only recorded in 2005; these had a frequency of 0.08%. Overall, the percentage frequency of winds having a speed greater than 6 knots and to which St George's Bay is directly exposed was very low.

Overall, the results of the beach profile and bathymetric surveys did not indicate any major transport of sediments (used to replenish the beach) to the sublittoral, following the beach replenishment works. In places, minor differences (of the order of 10 – 30 cm) in the thickness of sediments making up the beach and in the location of its shoreline, together with small differences in the bathymetry of the bay were noted. The results of the first (baseline) session of sediment studies, undertaken in May 2004 prior to the beach replenishment works, indicated a clear pattern of distribution of sediments in the study area, in which different values of mean grain size were recorded between the bay's head and its mouth. The sediment present at the head of the bay had the smallest mean grain size (0.07 mm) and was classified as sandy mud, while sediment present in the central parts of the bay had the largest mean grain size (0.66 mm) and was classified as coarse sand. The sediment present close to the mouth of the bay had a smaller mean grain size (0.20 mm) than that present in the central parts and was classified as fine sand. The results of microscopical examination indicated that the sediments present in the bay were predominantly calcareous and had a high content of biogenic material, which included the skeletal remains of invertebrate fauna, namely sea urchins, molluscs, foraminiferans, brachiopods and bryozoans. Plant fibres originating from seagrass and carbonaceous material that appeared to have an anthropogenic origin were also admixed with the sediments. The sediments were also predominantly monochrome. The results of the second (June 2005) and third (December 2005) sessions, made following the beach replenishment works, indicated a similar pattern of distribution of sediments to that recorded during the previous baseline survey. Furthermore, the results of the two post-replenishment sessions also indicated that the sediments present in the sublittoral were predominantly monochrome and no coarse (> 0.5 mm) polychrome quartz granules that could have originated from the newly replenished beach were observed in any of the samples examined.

The results of the first (baseline) monitoring session for water quality, made in May 2004 prior to the beach replenishment works, indicated that there were no large differences in water column attributes (total suspended solids, temperature, oxygen and salinity) and levels of nutrients (nitrates and phosphates) between stations located inside St George's Bay and reference stations (Figure 3a-f). However, higher values of chlorophyll a were recorded from stations located inside the bay (Figure 3g). The microbiological tests indicated that faecal coliform counts recorded from stations located inside the bay were somewhat higher than those recorded from the control stations (Figure 3h).

Overall, the results of subsequent monitoring sessions for water quality, made following the beach replenishment works, indicated that there were no large differences in levels of the water quality attributes surveyed between stations located in St George's Bay and those recorded form the control stations. In general, where differences in levels of the respective water quality attribute were recorded, ANOVA indicated that these were not significant. Exceptions to this were: (i) levels of nitrates and phosphates; and (ii) faecal coliform counts recorded during the fourth (June 2005) session, which were significantly higher ($p < 0.05$ and $p < 0.001$ respectively) at stations located within the bay compared to those recorded from the control stations.

The results of *P. oceanica* monitoring from the pre-replenishment (May 2004) session indicated that values of shoot density, adult leaf biomass and adult leaf length were all lower inside St George's Bay than at the control sites, while the reverse was true for values of leaf epiphyte biomass, which were higher inside the bay. Overall, the results of ANOVA carried out on data from the 2005 monitoring session (undertaken following the beach replenishment works) and the previous 2004 (pre-replenishment) session did not indicate significant changes in any of the four morphometric attributes monitored following the beach replenishment works (Figure 4).

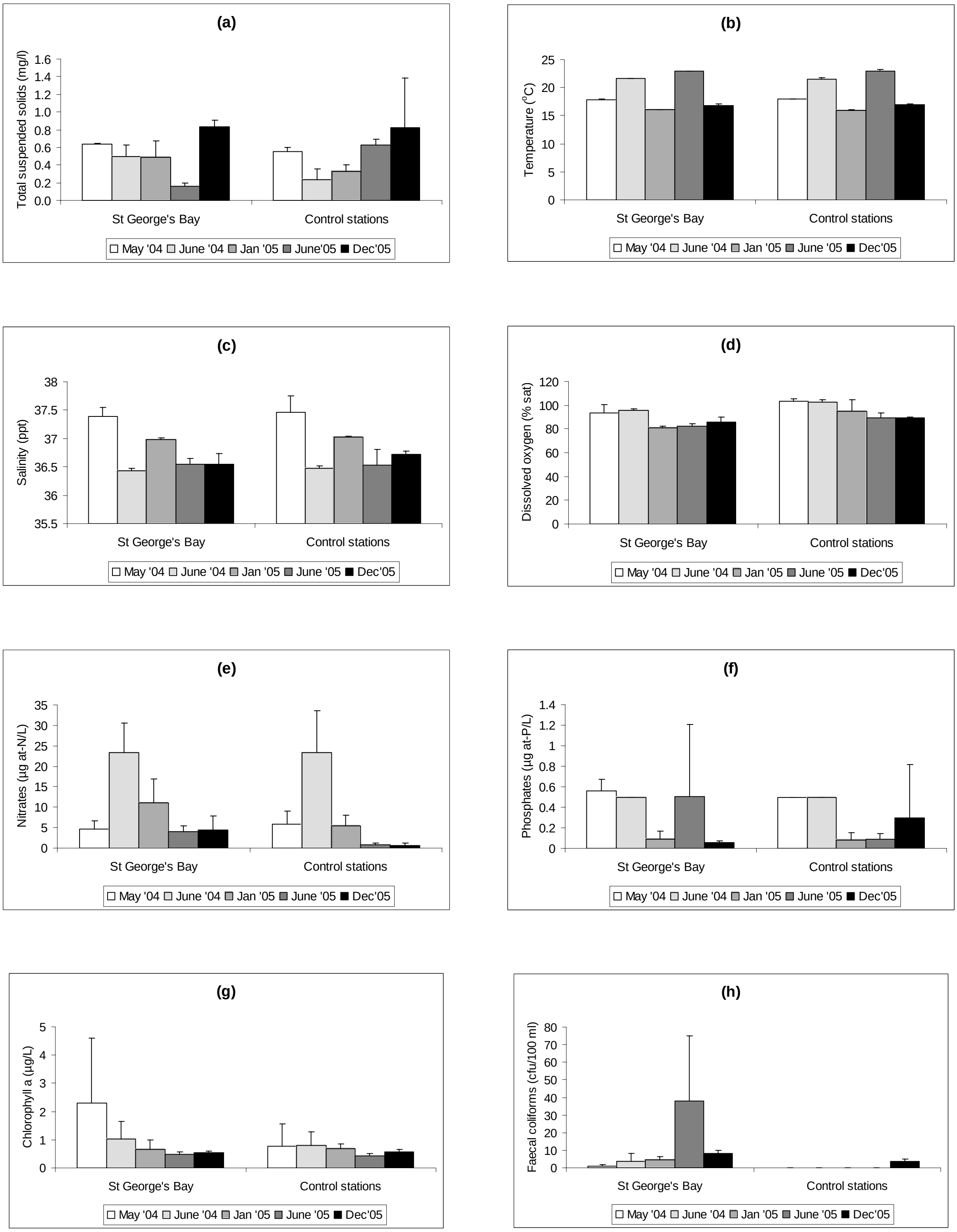

Figure 3: Mean values of: (a) total suspended solids, (b) temperature, and (c) salinity; levels of (d) dissolved oxygen, (e) nitrates, (f) phosphates and (g) chlorophyll a; and (h) faecal coliform counts recorded from stations located within St George's bay and control stations between May 2004 and December 2005. Error bars represent 1SD.

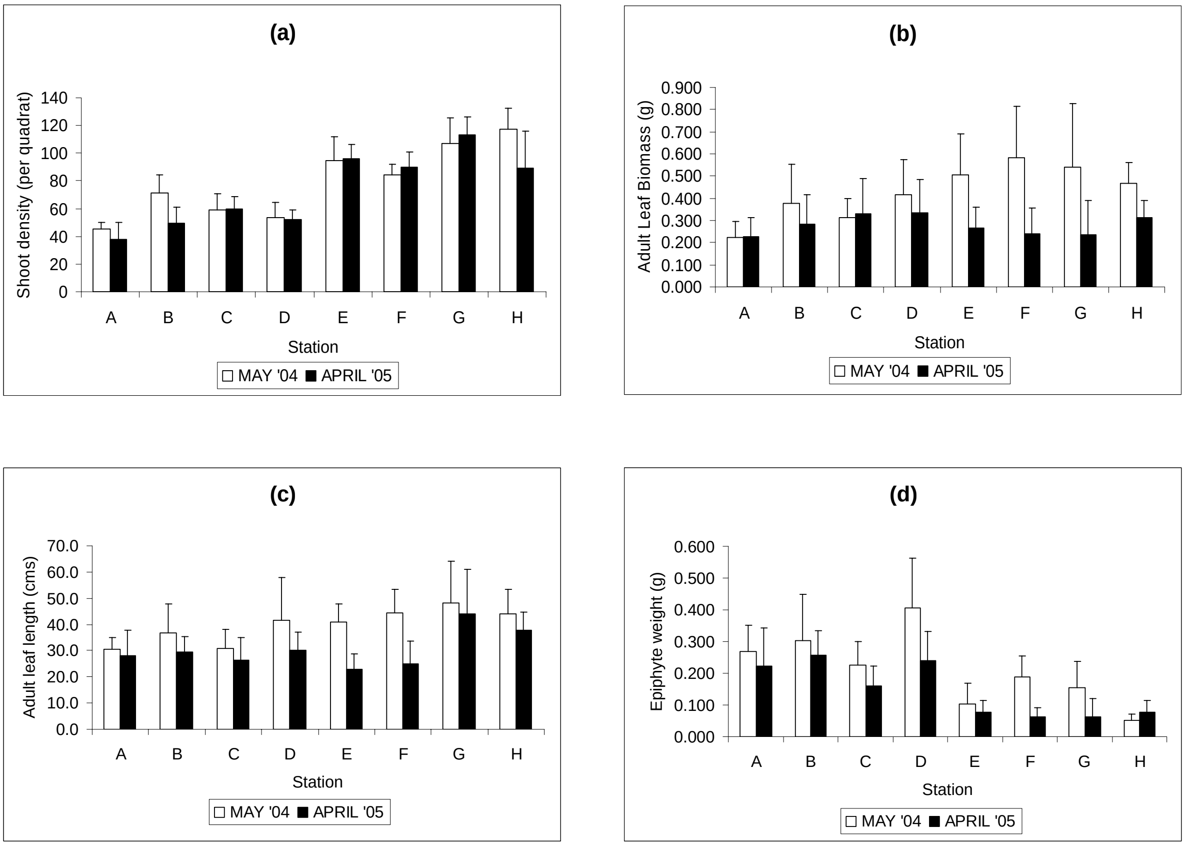

Figure 4: Mean Values of: (a) shoot density; (b) adult leaf biomass; (c) adult leaf length; and (d) epiphyte weight (adult leaves) recorded from the eight *Posidonia* sampling stations in May 2004 & April 2005. Stations A – D are located in St George's Bay and constitute the putatively 'impacted stations', while stations E – H are controls. Error bars represent 1SD.

Discussion

The physico-chemical and biological characteristics of St George's Bay are typical of ones recorded from local bays and inlets present on the northeastern coast of the Maltese Islands (Axiak, 2004; Borg et al., 1997). The observations from the sediment studies are consistent with the physical characteristics of marine sediments found locally on beaches and in the shallow infralittoral. Values of surface temperature and salinity recorded from the monitoring stations were typical of local inshore waters, as were levels of dissolved oxygen and total suspended solids. Analysis of data for wind speed and direction indicated that the inlet is relatively sheltered from predominant winds. Although the data is from only two years, it is representative of the general situation concerning wind speed and direction for the Maltese Islands (Chetcuti et al., 1992).

The results from the beach profile and bathymetric surveys indicated that no major transport of sediments (used to replenish the beach) to the sublittoral had occurred following the beach replenishment works. Small changes in the height of sand making up the beach and in the bathymetry of the bay were detected, however, such changes are to be expected considering that coastal bays and inlets are characterized by dynamic physical processes, including ones related to the hydrodynamic regime, deposition of sand by wave action, and transport of sediments with terrestrial runoff.

Monitoring of water quality indicated that levels of nutrients and Chlorophyll a and counts of faecal coliforms and total bacteria were at times higher at stations located within St George's Bay compared to the control stations. However, given that these differences were recorded from the May 2004 session held prior to the beach replenishment works and had also been detected in previous years by other workers (e.g. Axiak, 2004), they cannot be attributed to the beach replenishment project. The source of nutrient enrichment and bacterial contamination appears to be an effluent located in the southern parts of the bay close to its head (authors, unpublished data).

The results of seagrass monitoring sessions indicated that *P. oceanica* present in St George's bay is somewhat stressed, compared to that present at the control sites. The lower *P. oceanica* shoot density recorded inside the bay has probably resulted from anthropogenic disturbance, including anchoring and deployment of moorings (Hastings *et al.*, 1995; Francour *et al.*, 1999). The differences in shoot morphometric features (adult leaf biomass, adult leaf length and leaf epiphyte biomass) between *P. oceanica* present inside the bay and that located at the control sites have probably resulted from differences in physico-chemical characteristics of the water column (Hemminga and Duarte, 2000) between stations located inside the bay and the 'control' stations outside, as indicated by the results of the water quality sessions.

Conclusion

Overall, the results from the present study carried out over a two-year period indicate that the beach replenishment project at St George's bay was successful, since: (i) the sand used to replenish the beach was retained at the head of the bay, and (ii) no adverse environmental effects were detected. We attribute the success of the project to (a) good planning and management (see Ebejer, 2004 for details), (b) choice of an appropriate grain size of the sand used to replenish the beach, and (c) the physical setting of the inlet, which is characterised by relatively sheltered conditions as corroborated by the data for wind speed and direction. Future monitoring sessions will give an indication of any changes in the physical characteristics of the artificial beach, and whether the St George's beach replenishment project will have any adverse effects on the marine environment of the area. In the meantime, the monitoring design used in the present study can be extended to environmental monitoring programmes held in conjunction with future beach replenishment projects that may be implemented at other sites in the Maltese Islands.

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