MAJOR COASTAL ENGINEERING WORKS: MONITORING AND MANAGEMENT OF ENVIRONMENTAL IMPACTS AND RISKS. A CASE STUDY FROM THE CENTRAL MEDITERRANEAN (MALTA).

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Abstract

Coastal tourism and related developments of the past decades have significantly altered parts of the Mediterranean coastline. These include major coastal engineering works and alterations such as marina developments which lead not only to habitat loss but also to risks of degradation of water and sediment quality and of benthic communities. Being the smallest island-state in the region with the highest population density, Malta is an ideal case-study to assess such impacts.The paper presents data from a long-term compliance marine monitoring programmerelated to the development and operation of a major marina in Malta, involving major excavation works to develop a new marina basin able to hold 130 berths, complete with breakwater and other facilities. The monitoring programme(1996 to 2003)aimed at identifying and managing associated risks to the marine environment (including *Posidonea oceanica* meadows).For management purposes, a set of environmental objectives and quality standards were initially set for various water and sediment parameters and then subsequent monitoring of these parameters served as surveillance against risks of environmental deterioration. The paper provides useful information on the dynamics and trends in water and sediment quality resulting from such major coastal engineering works, and on how such trends may be related to associated changes (and possible recovery) of *P. oceanica* meadows.

Keywords: marinas, impacts, water, sediment,benthic, surveillance monitoring.

Introduction

The Mediterranean receives about one third of the world's international tourism and the economic development of many of its coastal regions is significantly dependent on tourism and related activities. Along with increased residential population pressures along its shoreline, these demographic and economic developments are leading to morphological changes as well as to changes in environmental quality in many coastal areas (UNEP/MAP-Plan Bleu, 2009). While this is evident throughout most of the Mediterranean areas, it is nowhere more evident than in Malta, which is the most densely populated island-state in the region. With a total surface area of 316 km^2, a coastline of just 253 km, a resident population of approximately 0.4 million (being increased to 1.2 million by annual tourist arrivals), Malta serves as a microcosm for the whole region, where pressures become more readily apparent over a relatively shorter period of time. Over the past four decades, the Maltese coastline has been transformed by multiple and often conflicting uses such as tourism developments, marinas, coastal fishfarming, stone-cutting quarries and others. Significant coastal engineering works have transformed the coastline. This process is even more accentuated by the fact that almost 50% of the coastline in Malta and Gozo is inaccessible, due to presence of cliffs. Therefore the resultant pressures are concentrated on the remaining coastline.

Marina development has been one major feature of the coastal tourism industry in the Mediterranean. According to UNEP/MAP-Plan Bleu, 2009, Monaco and Gibraltar report the highest density of marinas per km of coast, with an average distance between the ports ranging from 2 to 4 km, while Malta has a marina/port every 30 km. In contrast, Croatia has a marina/port every 77 km, while Cyprus has 1 every 196 km.

By 2009, 6 major marinas or marina complexes were located in Malta and Gozo, offering a total of just over 1500 berths (MMA and MITC,2009). One of these facilities is Portomaso Marina located about 3 km North-West of the Grand Harbour (Figure 1) and which currently holds up to 130 berths of varying sizes. This marina was essentially excavated out of solid rock as part of a redevelopment scheme for a major hotel and for a residential complex. It consists of three interconnected basins covering an approximate total surface area of 20,000 m^2. This development involved major coastal engineering works, including the excavation of 175,000 tonnes of rock material and the construction of a breakwater (including dredging of approximately 30,000 tonnes of material), and of concrete quays along the various basins. All excavated and dredged material was discharged at sea at an officially approved offshore spoil site, through barge transport. Such engineering works started in 1976 and the marina became operational in 2000.

The development was located on the Spinola headland (Figure 1). The whole area (Spinola and Balluta) is densely populated and Spinola Bay as well as Balluta Bay to the south of the development are exposed to intense boating activities and occasional discharges of raw sewage from various coastal overflows. This means that the environmental quality of water and sediments in the area have been exposed to multiple risks of contamination.

A number of potential risks of marine contamination had initially been identified in the environmental impact assessment (EIA) carried out prior to the beginning of the construction phase of the marina. These included increased water turbidity and other changes in the basic water and sediment quality parameters in the area. Baseline monitoring confirmed that water quality in the area was relatively good, except towards the inner bays of Spinola and Balluta. Levels of nutrients and of chlorophyll a, were generally the same as those found in inshore clean waters. Levels of hydrocarbon contaminants and of organotins (antifouling agents, then being used in the maritime industry) in superficial sediments were found to be low.

The shallow water benthic assemblages in the immediate vicinity of the proposed development consisted mainly of photophilic algae and seagrass *Posidonia oceanica*, with another seagrass*Cymodoceanodosa* being predominant in deeper waters. The *P.oceanica* present covered around 30% of the area. These meadows were in a good state as determined through seagrassbioparameters, including shoot density, adult leaf length and density and epiphytic load.

Material and methods

A comprehensive environmental monitoring programme was designed in an effort to prevent or minimize the potential impacts of such a development.As part of such programme, a general environmental quality objective was set for the area, which was to maintain the existing environmental quality so as to protect bathers, marinelife as well as the general water quality required for tourism and recreation (including aesthetic and visual properties of surface waters). With reference to *Posidonia oceanica* meadows, the environmental quality objective was to prevent any degradation of such meadows, beyond the state as assessed prior to the commencement of the project. On the basis of such quality objectives, a number environmental quality standards and thresholds were set for most water and sediment parameters to be monitored. These thresholds are shown in Table 1.

The rationale for the setting of such thresholds had been explained in detail by Axiak *et al*., 1997.Such thresholds were set on the basis of a number of criteria, including: available baseline data on water and sediment quality in the area prior to the start of the works; available data from other inshore waters along Malta and Gozo (including both impacted and clean reference areas); as well as international thresholds (such as in EU Directives) whenever available, relevant and applicable. The set thresholds had to be applied to a limited number of monitoring stations so as to be able to distinguish between impacts arising from the coastal engineering works in question, and other anthropogenic impacts arising from contamination sources in Spinola and Ballutabays. Such thresholds also took into account expected background seasonal fluctuations of the relevant parameters.

During the monitoring programme, water quality parameters were measured at 12 fixed stations as indicated in Figure 1. Temperature, salinity, chlorophyll ***a,*** and water transparency were measured *in situ* by means of electronic probes. Chlorophyll ***a*** was measured using a submersible spectrofluorimeter (Aquatracka III), while water transparency was monitored using a transmissometer, 660nm Alphatracka). Secchi depths were also recorded, using a Secchi disk.

All electronic probes were immediately calibrated prior use. The spectrofluorimeter was calibrated against standard concentrations of chlorophyll ***a*** dissolved in acetone (Sigma). The transmissometer used in these surveys measures beam attenuation at 660nm with an optical path of 25cm. Its calibration involves the measuring of its voltage output at 100% transmission, at

Table 1. Thresholds set for the various environmental parameters.

Parameter	Limit [A]	Stations	Degree of Compliance per survey
Water Transparency at surface and at 5m (Beam Attenuation Coefficient, BAC, 660nm)	0.3 m^{-1}	4,5,7,8	all 4 stations
Water Transparency at surface and at 5m (BAC, 660nm)	0.6 m^{-1}	1,2,3,6,9 and 10	5 out of 6 stations
Water Transparency Secchi depths	8 m	4,5,7,8	all 4 stations
Water Transparency Secchi depths	5 m	1,2,3,6,9 and 10	5 out of 6 stations
Chlorophyll a at surface	5 ug l^{-1}	4,5,7,8	all 4 stations
Chlorophyll *a* at surface	10 ug l^{-1}	1,2,3,6,9 and 10	5 out of 6 stations
Nitrates (+Nitrites) at surface	30 umolN l^{-1}	4,5,7,8	all 4 stations
Nitrates (+Nitrites) at surface	60 umolN l^{-1}	1,2,3,6,9 and 10	5 out of 6 stations
Phosphates at surface	1.5 umolP l^{-1}	4,5,7,8	all 4 stations
Phosphates at surface	3 umolP l^{-1}	1,2,3,6,9 and 10	5 out of 6 stations
Faecal coliforms	100 CFU/100ml	1,2,3,6,9 and 10	5 out of 6 stations
Tributyltin in superficial sediments	100 ngSn/gDW	7 stations	5 out of 7
Petroleum hydrocarbons in superficial sediments	20 ug/gDWCh.Eq.	7 stations	5 out of 7

Note A: Except under unusual meteorological circumstances as specified in Axiak, et al., 1997.

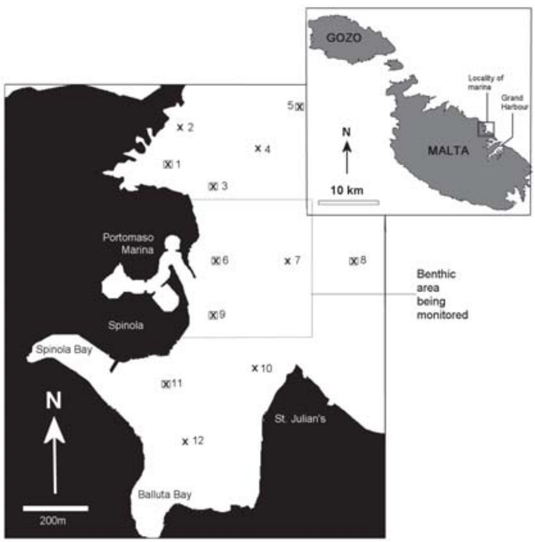

Figure 1. Location of the Portomaso marina, as well as of the monitoring stations for water (x) and sediment (boxes) quality.The monitored benthic area is also shown.

91.3% transmission (pure distilled water), and then at 0% transmission (blocked beam). The water transparency is then measured in terms of a beam attenuation coefficient (BAC).

For nutrient analysis, water samples were collected from various depths by a 3-litre Van Dorn all plastic water sampler. Dissolved nitrates (and nitrites) and phosphatelevels were measured according to Parsons *et al*., (1984). Faecal coliforms and total coliforms where monitored according to WHO membrane filtration standard protocols.Wherever possible, water parameters were measured at surface, at 5m depth and at bottom.

Sediment quality was monitored at seven stations (see Figure 1), where levels of petroleum hydrocarbons and organotins (tributyltin TBT, in particular), as well as granulometric characteristics were analyzed for Superficial sediment samples (top 3 cm) were collected manually by divers.Organotin analysis was carried out as indicated by Vella *et al.,* (1998). Petroleum hydrocarbons analysis was undertaken by solvent extraction and cleaning followed by UV spectrofluorimetry (310nm excitation wavelength and 360 nm emission wavelength) calibrated against chrysene standards (Axiak *et al*., 1993).

All water and sediment quality parameters to be monitored had been identified as being the most relevant during the EIA for the proposed development.

For each survey, sea current speeds and directionwere also monitored at Station 6, using the Lagrange drogue method (through the release of drogues at surface and at 5 m depth).

The extent and state of health of the *Posidoniaoceanica* meadows in the vicinity were also monitored through annual benthic mapping in an area measuring approximately 400 by 400m, using SCUBA diving techniques. Furthermore, samples of *P. oceanica* shoots were periodically collected from four stations (Stations 3, 6, 8 and 9) to enable measurement of standard *P. oceanica*bioparameters, including shoot density, adult leaf length and density,and epiphytic load.

Monitoring was initiated in May 1996 (prior to the start of any coastal engineering works) and terminated in December 2003, when the marina had been operational for 3 years. Over this period of 7 years, water quality was monitored almost every 2 months, while sediment quality was monitored every 4 months.Benthic surveys were undertaken annually, with *P. oceanica*bioparameters being monitored on a seasonal basis.

Results and discussion

The resultant monitoring programme produced an enormous volume of data reported in 16 biannual reports. The present paper may only present an overview of some of the more relevant features and conclusions from such data.

Table 2 shows the degree of compliance with the set environmental thresholds of 8 given parameters, as reported by the regular monitoring programme between 1996 and 2003. It also shows the actual progress of the coastal engineering works on the marina during this period.During this 7-year period, there were 26 cases of exceedance of set thresholds, with the majority (58%) involvingexceedance of the threshold for water turbidity in terms of BAC. Evidently and as expected, this was the main water quality parameter which was mostlyeffected by the whole coastal works. Maximum reduction in water transparency was recorded in the first half of 1999, when the land-locked excavated basin of the marina was opened to the sea and flooded. This resulted in extensive plumes of turbid waters reaching at least up to 1 km away from source. BAC values at Station 8 (500 m away from source) was increased by at least a factor of 2.5 over background values which had been reported prior the start of the project.

This increased water turbidity was also accompanied by increased dissolved nitrate levels which at one time increased by almost a factor of 20 over the normal levels which had been previously reported at Station 8.

Water transparency eventually returned to normal levels though occasional exceedances for BAC were being reported for some stations even by the 3rdyear of the marina becoming operational (Table 2 and Figure 2).

Exceedance of threshold for faecal coliforms was also reported on a number of occasions (making 23% of all reported exceedances). This impact was however difficult to relate to the ongoing engineering works, and was at least partially related to other anthropogenic sources. Exceedance of the threshold for chlorophyll a happened only once, while that for dissolved phosphates was never observed.

Table 2. Degree of compliance with set environmental quality standards (thresholds, as indicated in Table 1) as identified through the environmental monitoring during the construction phase and early operational phase of the marina (1996-2003). ***Shaded box indicates threshold limit for respective parameter being exceeded in a sufficient number of stations (the location of such stations is indicated in box) so that the overall required degree of compliance was not reached. In a number of cases, threshold limits had been exceeded in some stations (as indicated in non-shaded box), but overall degree of compliance was still reached.***

Year	Month	Water Transparency Secchi Depths	Water Transparency B.A.C.	Chlorophyll	Dissolved Nitrates	Dissolved Phosphates	FC	TBT in sediments	PHC in sediments	Engineering Works
1996	5									
	7									
	9									Start of rock cutting and use of barges for disposal of solid waste
	12							1		
1997	3									
	6		1,2				**1,2**			
	7		**7**							Rock cutting and dredging
	8		**8**							
	10		**4,5,7**							
	11									
	12						**1,2**			
1998	2						**1,2,3,9**			
	3						10			
	4						**6,9,10**			
	5		**6,7,8**							
	6		6							
	7	6	6						6,10	
	8									Major rock cutting and excavations
	9									
	10									
	11							3		
1999	1									
	3	6	**6,7**							Opening of marina basin to the outer sea
	3	6	**6,7,9**							
	4		**6,7,9**		**5,6,7,10**		9			
	5		**6,8,10**							
	6		**6,7,8,9,10**				7			
	7									
	8									
	9									
	10			**4**						
	12									
2000	1						**3,6,9,10**			
	2		**4,7,8**							
	3		**4,5**					**1,7**		Marina becomes operational
	4									
	5									
	6		**4,7,8**							
	7									
2001	2									
	3		**8**							
	4									
	4									
	6									
	7									
	8									
	9									
	10		**4**							
	11									
	12									
2002	1									
	2									
	3									
	4									
	5									
	6									
	7									
	8									
	10						10			
	11									
2003	1									
	2									
	3				**3,9,10**					
	4									
	5	5	**7,8**				**3,6**			
	6								**9,11**	

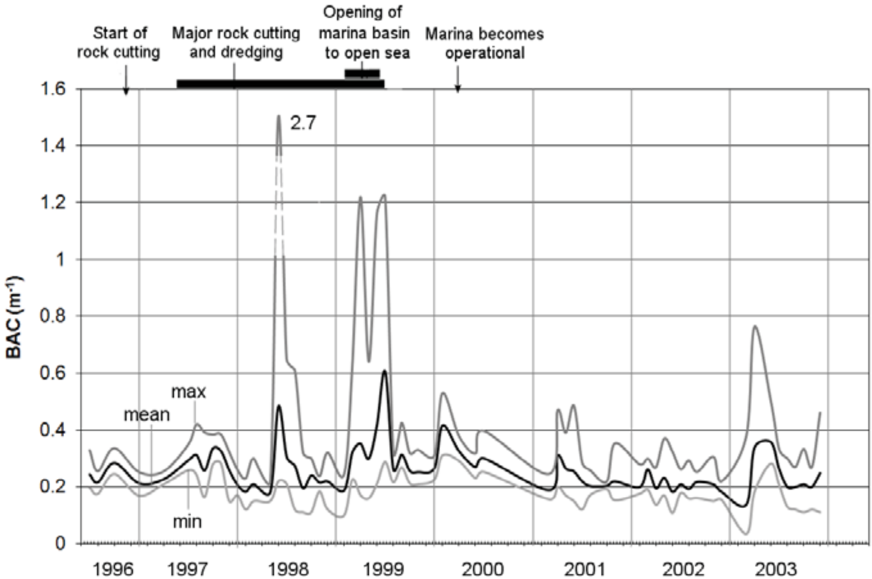

Figure 2. Changes in water transparency in terms of beam attenuation coefficient (BAC) as measured at surface at all stations. Black line indicates the mean BAC value for all stations, the upper grey line indicates the maximum value, while the lower grey line indicated the minimum value as monitored for each survey.

Correlation analysis for all sets of monitored water quality parameters over the 7 year period, produced a number of interesting observations. For example, primary productivity (in terms of levels of chlorophyll a) was mostly determined by levels of dissolved nitrates and not of phosphates. Levels of BAC were not found to be correlated with any seasonally fluctuating parameters such as temperature or salinity, or nutrients, indicating their anthropogenic source(s).

Over this period, sediment quality was not greatly impacted upon, with only one exceedance for TBT threshold and one for petroleum hydrocarbons being reported. Figure 3 shows the changes in the levels of such contaminants in the superficial sediments as monitored throughout the period under review. Evidently as the marina became operational and the maritime traffic in the area increased, the levels of such contaminants increased.

Sediment quality was mostly affected in terms of granulometric profiles. Figure 4 shows the change in the median particle size of superficial sediments as calculated for all the 7 stations over the period 1996-1999. This clearly shows that under the impact of increased sedimentation resulting from the coastal works, the superficial sediments became coarser. Turbidity usually increased with depth, where a cloud of very fine sediment was often being reported (by divers) to be permanently suspended in the water column close to the bottom.

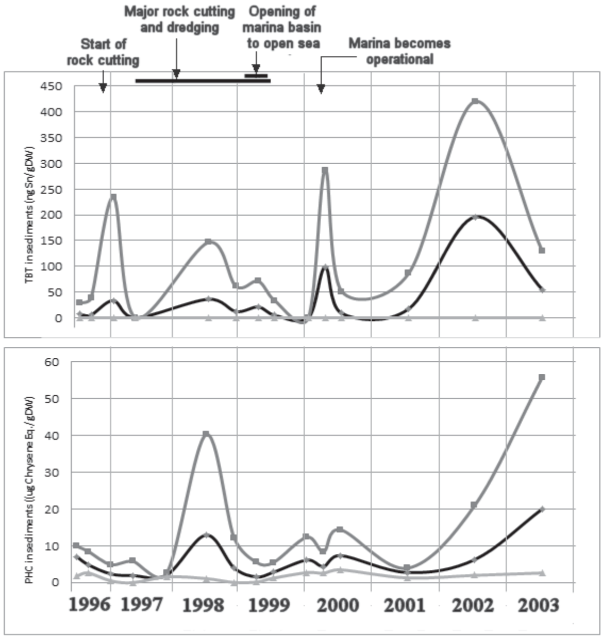

Figure 3. Changes in the levels of tributyltin (TBT) and of petroleum hydrocarbons (PHC) in superficial sediments. Black line indicates the mean value for all stations, the upper grey line indicates the maximum value, while the lower grey line indicates the minimum value as monitored for each survey.

In the meantime, adverse benthic impacts were reported as resulting from alterations in water and sediment quality. First signs of reduced growth and productivity ofseagrass*P. oceanica* was reported in November 1997.This coincided with the first reported exceedances of the thresholds set for water transparency in the area. By 1998, *P. oceanica*meadows at Station 6 were found to be in a largely dilapidated state.Furthermore, appreciable loss of macroalgalassemblages had occurred, mainly in the vicinity of the newly constructed concrete breakwater (Figure 5), as evidenced by the disappearance of the algal forests present before initiation of the works, leaving bare rocky substratum.Similar deterioration of the macroalgalassemblages colonizing the seabed below the shore in the southern parts of the survey area was also evident.Regression of *P. oceanica* was evident at both its lower and upper limits of distribution.

By 1999, massive deposition of mobile sedimentary material was being reported in the area. A large amount of the fine sediment was also being transported offshore and eventually deposited on the photophilic algal assemblages and *P. oceanica* meadows present in the more central parts of the study area, leading to their burial and eventually to decimation. Transport of sediment further offshore, coupled with increased water turbidity also caused death of seagrasses (*C. nodosa* and *P. oceanica*), such that the large area of mixed seagrassbeds originally present in the deeper parts of the study area was broken up into a number of small patches.By the summer of 2000, benthic monitoring indicated a reduction in the amount of sedimentary material present just below the shore close to the breakwater, and partial recovery of the photophilic algae and seagrass beds present in areas having a rocky bottom that was previously buried under the sediment.

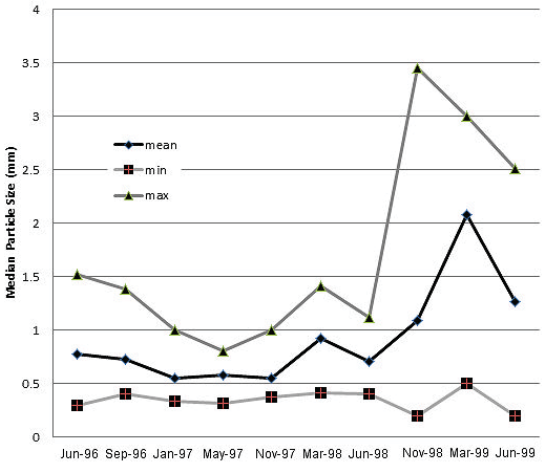

Figure 4. Changes in the mean particle size of superficial sediments for all 7 monitoring stations over the period 1996-1999.

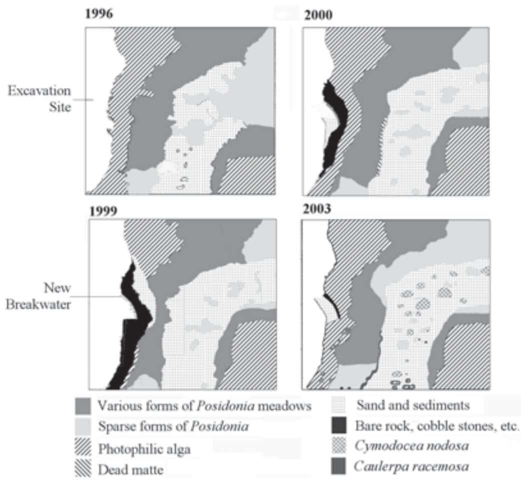

Figure 5. Changes in the benthic communities in the vicinity of the engineering works.

An increase in the number and size of polyspecific patches of seagrass present in the deeper region of the study area was also recorded.By 2001, recovery of *P. oceanica* at the lower limit of the large meadows present on bedrock was being recorded, together with a further increase in the number and size of polyspecific stands of seagrass present in the deeper parts of the study area. However, by this time, the continuous meadow of this seagrass had been degraded to one that was discontinuous and mixed with photophilic algae. By 2002, further small progressive changes and recovery of *P. oceanica* in the study area were being recorded, while further regression of the seagrass was not observed. Furthermore, shoot density values had increased and reached similar values to those recorded in June 1996, before initiation of the construction works.

By 2003, no further regression of *P. oceanica* meadows had occurred. However, there was an evident increase in epiphytic load on *P. oceanica* shootsatthe various stations, which may be related to occasionalexceedances of the thresholds for dissolved nitrates. Furthermore, by this time, there was reported an increase in the abundance and coverage of the alien alga *C. racemosa* throughout the survey area. This alien species was also being reported to have invaded and colonized large areas of the infralittoral and upper circalittoral in many local coastal areas. Its presence was therefore not directly related to the coastal engineering works, though this alga is known to be an opportunistic species and spreads more readily in places where there is anthropogenic disturbance.

Conclusions

This long-term monitoring programmeprimarily served as a management tool which enabled the local environmental and planning authority to regularly assess the degree of compliance with set environmental thresholds by the developer (such compliance being coupled to bank guarantees) and therefore to minimize expected impacts during the construction phase.In the process, it also produced data and insights on the immediate and residual impacts of such project involving major coastal engineering works on ecologically sensitive targets as well as on the extent and manner in which they may recover.

Acknowledgements

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References

Axiak, V., Gauci, J., Grech, P., and Vella, C. (1993). Recent trends in coastal pollution by petroleum hydrocarbons in Malta (Central Mediterranean). Clean Seas93 Conference.

Axiak, V., Vella, A., Borg, A., Micallef, S.A., Lanfranco, E. (1997). Hilton Redevelopment Project - Marine Environmental Monitoring Programme - Second Report: May 1996 – January 1997. Malta University Services Ltd., University of Malta, Msida, Malta.: 1-71.

Malta Maritime Authority, Ministry for Infrastructure, Transport and Communication. (2009). Development of Yachting Facilities in Malta.

Parsons, T. R., Maita, Y., Lalli, C. M. (1984). A manual of chemical and biological methods for seawater analysis.Pergamon Press. Oxford.

UNEP/MAP-Plan Bleu, (2009).State of the Environment and Development in the Mediterranean, UNEP/MAP-Plan Bleu, Athens, 2009.

Vella, A. J., Mintoff, B., Axiak, V., Agius, D., and Cassone, R. (1998). Organotin pollution in Malta coastal zone. Toxicol.andEnv. Chemistry. (67): 491-510.