Malta Environment and Planning Authority
‘*Environmental Initiatives in Partnership*’ programme.

ARTIFICIAL REEFS PROJECT

FINAL REPORT OF SCIENTIFIC STUDIES (2004 – 2006)

Marine Ecology Research Group

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Summary

A study was undertaken to assess the environmental impact of four artificial reef units on the soft sediment marine benthic assemblages and fish fauna in their vicinity, and to evaluate the reefs' potential as a habitat. Another aim of the study was to assess whether the two different materials used to construct the reefs – native Globigerina limestone and a concrete mixture that incorporated Globigerina debris – had different effects on the benthic biota and fish fauna.

To assess the impact of the artificial reefs on the soft sediment benthic fauna, five replicate sediment cores (diameter: 10 cm) were collected from each of five stations positioned at incremental distances (1, 2, 5, 10, 20 and 50 m) along each of two transects located on opposite sides (west and east) of each of two artificial reef locations. Five replicate samples were also collected from each of two control sites that had similar seabed characteristics as the reef sites. Additionally, three sediment cores were collected from the reef and reference stations to measure the mean grain-size and percentage organic carbon content of the sediments. Samples for benthic faunal analysis and physico-chemical attributes were collected from the designated reef sites during winter 2003/2004 before deployment of the artificial reefs, and during winter/spring 2005 following deployment of the reefs.

To assess the impact of the artificial reefs on the fish fauna in their vicinity, fish censuses were made at each of: (i) the four artificial reef sites, (ii) two rocky substratum control sites and, (iii) two sandy substratum control sites. Censuses were made along each of two transects that extended for a length of 80 m on opposite sides (west and east) of each reef location; one transect was located on the western side and the other on its eastern side. The fish censuses were made in: October 2003 and April-June 2004 before deployment of the artificial reefs, and in May-June 2005 and August-September 2005 following deployment of the reefs.

Data on mean sediment grain size and organic carbon content of the sediments, and on total number of species, species abundance and total abundance of benthic biota and fish fauna, were analysed using multifactor ANOVA to test for differences in these attributes between different reef sites and between the pre- and post- reef deployment sessions. Species-abundance matrices for the benthic biota and fish fauna data were analysed using multivariate techniques (multidimensional scaling and cluster analysis).

The results of the sediments and sediment biota study component indicated that the two reef structures studied had an influence on the adjacent benthic assemblages; however, this impact was localised to the area in the immediate vicinity of the reefs. The results also indicated some differences in the recorded impacts, which were attributed to differences in the physico-chemical characteristics of the seabed between the reef sites, rather than to differences in the material used to construct the two reefs. A significant change in the benthic assemblage structure was also detected during the post-deployment sessions at one of the sand controls, indicating natural spatial and temporal variations in physico-chemical and biological characteristics of the marine environment in the general area where the reefs are located.

The results for the fish fauna study component indicated that the fish assemblages inhabiting the sandy bottom in the area where the artificial reefs were deployed were significantly affected by the presence of the reefs. The observed changes mainly consisted of a decrease in the abundance of fish that are typical of sandy bottoms with a concurrent increase in species richness and abundance for fish that are typical of rocky bottom habitats. However, the observed changes were mainly restricted to the immediate vicinity of the artificial reef structures. An increase in

total fish abundance was also recorded at the rock control sites during the post-deployment survey, which, however, was attributed to natural temporal changes. Overall, the results of the fish study component indicated that the artificial reefs attracted fishes from rocky bottom habitats located at a distance from the reefs, while also serving as nursery sites and to enhance production.

The results for both study components (sediments and sediment biota and fish fauna) also indicated that the two different materials used to construct the experimental artificial reefs did not result in different effects on the benthic biota and on the fish fauna in their vicinity.

While the results from the present study give an indication of the ecological processes occurring at the artificial reefs, these findings should be considered as preliminary, especially since the period over which the investigations were made is somewhat short. However, the results obtained show that, overall, artificial reefs have the potential of serving as a habitat for a large variety of fish and other biota, but careful planning of aspects of their design, deployment and management are crucial for a successful positive outcome of any artificial reef programme. Additionally, artificial reefs and the biota they support may serve as an underwater attraction for SCUBA divers.

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1. INTRODUCTION

1.1 The Artificial Reefs Project

The Artificial Reefs Project is a joint project between the Malta Environment and Planning Authority (MEPA[1]) and the Marine Ecology Research Group at the Department of Biology of the University of Malta, undertaken within the framework of MEPA's *'Environmental Initiatives in Partnership'* programme. The main aim of the project is to create a habitat in the form of an 'artificial reef' to provide an alternative benthic habitat off St Julians Bay to compensate for large adverse alterations of the benthic environment in the area that resulted from coastal development works at Spinola in connection with the construction of a marina and hotel. The resulting alterations to the benthic environment included degradation and loss of *Posidonia oceanica* meadows in places. As with many seagrass species, *P. oceanica* forms meadows that are considered to be highly 'structured habitats' because of their varied meadow morphology, peculiar mode of growth, interaction with physical environmental factors, and bed architectural characteristics. *P. oceanica* beds are arguably the single most important shallow water habitat in the Mediterranean; they are highly productive, support a large species diversity and serve as feeding grounds and nurseries for many invertebrates and fishes, and as a refuge against predation for numerous species.

Since it is very difficult to reconstruct the original habitat following loss, the next best thing is to provide a 'matrix' that can be colonised by a large a variety of benthic marine species. The richest infralittoral matrices, apart from seagrass beds, are shoals (so called rocky 'reefs'). It was therefore proposed to create such a habitat in the form of an 'artificial reef' to provide an alternative benthic habitat in the area that would compensate for the degradation and loss of *P. oceanica* meadows off Spinola. The project would entail the creation of scientifically planned, constructed and monitored artificial reef units for the assessment of the environmental impacts of such reefs on the marine environment and for monitoring colonisation of the artificial reefs by marine life. From the outset, this experimental project aimed to construct purposely-designed reef modules based on the extensive experience of other Mediterranean countries.

1.2 Artificial reefs

Artificial reefs are man-made structures deployed in the marine environment to serve as shelter, a source of food and as breeding grounds for fish and other organisms in the absence of a natural hard substratum (Miclat & Miclat, 1989). The European Artificial Reef Research Network (EARRN[2]) defines an artificial reef as 'a submerged structure placed on the substratum deliberately, to mimic some characteristics of a natural reef'. This is the definition used for the purpose of the present project.

Artificial reefs have been deployed in different parts of the world for different reasons, including to:

- protect coastal environments from illegal trawling;
- protect the seabed and coast from erosion;

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[1] MEPA is the statutory body set up to regulate land and sea use, the environment and development in the Maltese islands.

[2] The EARRN was formed in May 1995 to promote increased awareness of, and collaboration between, current artificial reef programmes throughout Europe, both marine and freshwater.

- protect marine habitats; (e.g. near-shore seagrass beds)
- attract, concentrate and provide shelter for species of economic importance;
- increase substrata for colonization (e.g. mollusc aquaculture and algal culture);
- provide refuges, breeding and nursery areas for marine organisms;
- serve as a diving attraction

(Jensen, 2002).

Artificial reefs were first used by the Japanese around the middle of the 17th century but have now been deployed in many countries, some of which have established extensive reef research programmes. In the Mediterranean the most important centres of reef use and experimentation are found in Italy, Spain, France, Monaco and Israel. Artificial reefs have been constructed from various materials, often relating to the type of construction material available in the country. They have been made from bamboo, palm fronds, cement/concrete blocks, rubble, PVC pipes, steel pipes, disused automobile tyres, scrapped vehicles, and steel ships and barges (Miclat & Miclat, 1989), however, the overwhelming majority of Mediterranean reefs are constructed of concrete (some reinforced and some not) (Collins & Jensen, 1997; Relini, 2000).

Once an artificial reef is deployed, a process of colonisation commences. The success of this colonisation depends very much on the type of material used and the location of deployment, including distance to the nearest natural reefs, and on the water quality and the current regimes. Colonisation of the reef surface starts with settlement of microorganisms and algae, which are then followed by other marine species. An artificial reef will attract species from similar habitats located nearby (in the case of artificial hard substrata, the natural habitats will be those present on rocky or coarse bottoms) and will be colonised by the propagules that originate from the latter (Falace & Bressan, 2000). Other adjacent habitats such as seagrass meadows can also act as recruitment sources for reef colonisers.

Once colonisation is complete, a number of fish will become associated with an artificial reef. One of the biggest controversies surrounding the topic of artificial reefs concerns whether such structures actually increase fish production or whether they merely redistribute fish by attraction from surrounding areas (Bohnsack, 1989; Santos *et al.*, 1997).

Apart from the effects of artificial reef structures on the biota which colonise them, there are two other main aspects concerning interactions between the structures (and biota they may support) and biota and habitats present in their vicinity. These are:

(i) Interactions between the reefs and the benthic habitats present in their vicinity, in the present case soft sediment habitats;
(ii) Effects of the reefs on the demersal and pelagic faunal assemblages, notably fish fauna, present in their surroundings.

To place things into perspective, brief overviews of each of these two aspects are given below.

1.2.1 Effects of the reefs on benthic habitats present in their vicinity

Artificial reefs can potentially affect adjacent soft-bottom assemblages by altering the species abundance and distribution, and the assemblage structure. Although soft sediment bottoms appear bare, they support a multitude of infaunal organisms, including polychaetes, crustaceans, molluscs and echinoderms, many of which serve as food for commercial fish species, while they are essential for ecosystem function in general (Snelgrove, 1999). Besides infaunal assemblages, such habitats also support species-poor epifaunal assemblages. A change in the abundance of one or a few species living in such a habitat can result in large overall changes; a change in species abundance may be brought about by changes in an environmental factor caused by human activities, such as deployment of artificial structures (Ambrose & Anderson, 1990). It is therefore very important to establish baselines when assessing potential impacts of human activities, to understand the resulting degree of change that can potentially occur.

Many studies have dealt with the fish assemblages associated with artificial structures (e.g. Cliff, 1983; Stephan & Lindquist, 1989; Chou *et al*., 1991; Charbonell *et al*., 2000; Rilov & Benayahu, 2000), and others considered the epibiota that live on them (for example, Wendt *et al*., 1989; Connell, 2000; Relini *et al*., 2000; Collins *et al*., 2002; Qvarfordt *et al*., 2006), but little attention has been paid to the effects which artificial reefs may have on the biotic assemblages of the sedimentary bottoms on which such structures are usually placed, in spite of the fact that a reef kills organisms buried underneath it and that changes to the physical and biotic environment caused by the reef can also affect the sediment-inhabiting assemblages (Ambrose & Anderson, 1990). In the meantime, as an increasing number of man-made structures such as artificial reefs, oil platforms, breakwaters, jetties, bridge supports, outfall pipelines and offshore wind-farms are being placed on or over coastal marine sediments, the need to assess their effects on sediment-inhabiting assemblages becomes more evident.

Artificial reefs may induce a number of physical and/or biological changes on adjacent soft-bottom habitats, which in turn can alter species abundances, distribution patterns, and habitat structure. For example they may:

- Alter the hydrodynamic regime (i.e. affect current speed and direction, and waves);
- Alter the physical characteristics of the substratum by changes in sediment erosion, changes in sedimentation rates and changes in grain-size distribution;
- Alter the organic matter content through the metabolic activity of both benthic and nektonic reef assemblages and the accumulation of detrital organic matter;
- Modify the distribution and/or composition of the available food sources; and
- Alter the biological interactions between different parts of the food web.

These effects may vary greatly between different localities due to differences in the physical characteristics of soft-substrate habitats, differences in the ability of organisms to adjust to changes in their habitat characteristics, and complex interactions between organisms (Dahlgren *et al*., 1999). Moreover, a particular effect may prevail over the others, or the different forcing factors may act together to result in complex responses of the infaunal assemblages (Donovaro *et al*., 2002).

Sedimentary habitats are primarily controlled by the hydrographic regime and the availability of sediment. The type of sediment present in any location, its stability, grain size, dynamics and other physico-chemical characteristics are dependent on current strength and direction, seasonal changes in the current regime, storms, wave action (especially in the intertidal and shallow subtidal), and the resultant equilibrium between accretion and erosion. Any structure that affects water flow or wave action is likely to change the sediment dynamics locally, and potentially, over a wide area.

Soft sediment assemblages are themselves dependent on the stability of the sediment, its grain size and hence porosity, organic content and nutrient cycling, and on oxygen content and redox potential. Therefore, any activity or structure that changes the hydrodynamic regime is likely to affect the benthic assemblages present. For example, currents driven by tides, wind, waves and density gradients are among the most important factors affecting reef stability and reef performance (Sheng, 2000).

Additionally, changes in local currents caused by the presence of an artificial reef may lead to scouring in some places, while other sites act as recipients for deposits. These processes potentially affect the stability of the reefs and their functionality (Cripps & Aabel, 2002). Scouring can lead to the formation of scour holes especially at reef edges and may be a major reason for reefs subsiding (Shyue & Yang, 2002). The extent of scouring depends on reef shape, size and location relative to the bottom, on the nature of the primary flow, and on the sediment parameters. Sediment motion is inevitable where the speed of water particles due to current exceeds the threshold velocity of given sediment sizes.

The presence of a large reef structure in a coastal area with strong currents may create a downward flow adjacent to the upstream side of the reef structure. As the downward current approaches the bottom, a horseshoe vortex is formed and this may cause re-suspension or scouring of sediments around the reef bottom. The re-suspended sediments are partly transported to the upper water column and partly transported to the lee side of the reef, where the currents are weaker, and become deposited there (Sheng, 2000). Deposited sediments may directly clog the feeding or respiratory apparatus of suspension feeders. Scouring and re-suspension in high-energy areas cause erosion of the sand and deposition of this sand in low-energy areas; as a result, the grain-size distribution is affected (Wilding & Sayer, 2002). As the finer sand particles are transported from a high-energy area to a low-energy area, the deposited material will consist of finer sediment while the sediment left in the high-energy area will be coarser in nature. The effects of scouring are largely confined to the immediate vicinity of the reef, and thus changes in the grain size distribution are expected to be limited to the area close to the reef.

Since benthic macrofaunal assemblages respond to differences in physical characteristics of the sediments, and grain-size is considered to be one of the most important factors influencing these assemblages (Barros *et al*., 2004), a change in the grain-size distribution around a reef is expected to cause a change in the infaunal assemblages present in its vicinity.

Artificial reefs may alter and modify sediments through the addition of shell fragments derived from organisms growing on the reef (Davis *et al*., 1982; Ambrose & Anderson, 1990; Barros *et al*., 2004). This 'faunal litterfall' alters the physical characteristics of the seabed by creating hard substrate habitats and altering bottom topography (Bomkamp *et al*., 2004). Furthermore, alteration of soft-bottom habitats may also result from entrapment of drift algae and other organic material which, along with the activities and death of reef associated organisms, can result in organic build-up in the sediment (Davis *et al*., 1982; Fabi *et al*., 2002). The organic matter falling to the seafloor from the reef then provides a food subsidy to benthic consumers (Bomkamp *et al*., 2004). The trapping and subsequent decomposition of organic matter in the form of macro-algal detritus in areas around reef modules where current velocities are reduced can lead to changes in sediment oxygenation and the development of sediment hypoxia. Reduction in oxygen availability can have a profound impact on the existing infauna (Wilding & Sayer, 2002).

Investigations of community structure at discontinuities between different marine habitat types have often revealed patterns suggesting interactions between the adjacent habitats. The term 'halo' has been used to describe these 'edge effects', which have often been attributed to foraging by mobile fauna from a 'shelter habitat' out into a 'food habitat' (Langlois *et al*., 2006).

‘Infaunal halos’ have been observed in soft-sediment communities adjacent to subtidal natural reefs (Posey & Ambrose, 1994; Dahlgren *et al*., 1999; Barros *et al*., 2001; Langlois *et al*., 2005) and artificial reefs (Davis *et al*., 1982; Ambrose & Anderson, 1990). However there is disagreement on the mechanisms behind these patterns (Barros, 2005).

‘Haloes’ of decreasing abundance with increasing distance from the reef edge have been described for some organisms (Ambrose & Anderson, 1990; Dahlgren *et al*., 1999; Langlois *et al*., 2005), but more frequently ‘haloes’ of increasing infaunal abundance with increasing distance have been documented (Davis *et al*., 1982; Ambrose & Anderson, 1990; Posey & Ambrose, 1994; Barros *et al*., 2001; Langlois *et al*., 2005).

The existence of ‘infaunal halos’ has been often attributed to predation by reef-associated fish (Davis *et al*., 1982; Posey & Ambrose, 1994; Langlois *et al*., 2005), without quantifying the contribution of other processes. Although predation is capable of producing ‘infaunal halos’, other processes can be important (Dahlgren *et al*., 1999), including enrichment by reef productivity, bioturbation (Dahlgren *et al*., 1999), physical disturbance (Barros *et al*., 2001), gradients in physical properties (Ambrose & Anderson, 1990; Barros *et al*., 2004), or a combination of several factors acting together (Barros, 2005).

Predation is recognized as an important process in ecological systems (Barros, 2005). Many reef-associated fish and invertebrate predators use the reef structure and ledges primarily as a refuge, but forage for food on the surrounding sand-bottoms (Nelson *et al*., 1988; Posey & Ambrose, 1994). In fact, predation has been found to be a major factor affecting benthic populations in soft-sediments, and many reef-associated fish and crustaceans forage extensively over adjacent sandy bottoms areas and can alter the faunal assemblages by feeding on infauna (Davis *et al*., 1982). The model suggesting that reef-associated predators are responsible for halos is supported also by studies of gut contents of fish on temperate reefs (Lindquist *et al*., 1994).

1.2.2 Effects of the reefs on the demersal and pelagic faunal assemblages, especially fish fauna

Artificial reefs have been shown to enhance fish biomass, abundance and species richness. Most studies describe an overall increase in ichthyofaunal populations but consensus on the mechanisms controlling this has not yet been reached. In this respect, the current debate concerns whether artificial reefs contribute to biological production or simply attract fish, facilitating their harvest (e.g. through fishing). The notion that an artificial reef amplifies harvest or serves as a ‘biological sink’ does not consider the overall environmental effects, as many studies have focussed on marine fisheries, but not other aspects of the marine ecosystem. Regardless, many artificial reefs have been created for the purpose of establishing easily located and productive fishing areas but this has been underscored by uncertainty on the part of managers to support artificial reef construction, originating from the controversy surrounding attraction versus production.

Bohnsack & Sutherland (1985) discuss that an artificial reef functions by either aggregating individuals or by secondary biomass production due to a number of different mechanisms. Behavioural studies suggest many mechanisms to explain fish attraction to artificial reefs. Thigmotaxic behaviour presumably evolved because of some selective advantage (faster growth, increased survival). One concern is that artificial reefs may provide cues beyond the evolutionary experience of fish and elicit responses that are not necessarily adaptive. An analogous example is attraction to warm water: fish movement to warm water is adaptive (since temperature influences growth) but when man-made sources of warm water are present (e.g. power plant effluent) this might trigger undesired mechanisms in fish physiology (e.g. spawning in the wrong season).

Artificial reefs provide additional food and increased feeding efficiency. Large reef structures located in the direction of the water flow can create locally significant vertical upwelled currents. This local upwelling can lead to the transport of sediments and nutrients from the bottom water column to the surface water causing aggregation of fish at the reef site. The interaction of the structure with the prevailing current also alters water flows resulting in the formation of a wake zone with local eddies downstream of the reef. This may attract certain species by providing shelter, a resting area, a feeding ground and a spawning area. On the other hand, eddies and vortices outside the wake region contain higher turbulence that may attract other fish species.

As the added substratum provides additional surface area for growth of primary producers, some species will start feeding and producing new biomass at the reef site. Relini *et al.* (2002) assessed trophic relationships between fish and artificial reefs by studying the stomach content of species commonly associated with artificial reefs; in the case of *Serranus cabrilla* they found that 61% of the food originated from the artificial reef structures.

Artificial reefs provide shelter from predators and greater habitat availability for recruits (Bohnsack, 1989). Deployment of artificial reefs results in the introduction of new surfaces for settling larvae which, in the absence of suitable substrata, would not be possible (Bombace *et al.*, 1990). Larval studies indicate an increased production at artificial reef sites (Stephens & Pondella, 2002), however, the majority of the reproductive output is exported.

Indirectly, fish moving to artificial reefs create vacated space in natural environments which will then be filled by new production. Thus the artificial reefs help in maintaining natural reef communities below the carrying capacity. The attraction hypothesis predicts a worst case scenario in which an initial increased catch is followed by a decline to levels below what existed previously before deployment of the artificial reefs. Such a fall is a result of the increased catchability and concentration of ichthyofauna at new reef fishing grounds.

The production and aggregation scenarios should be considered as two extremes in a continuum of biological development on artificial reefs (Bohnsack, 1989). Most fish populations probably respond to an artificial reef somewhere between the two extremes. Therefore, the success of an artificial reef structure is also species specific since different fish species are influenced differently (Relini *et al.*, 2002). Predictive models on such aspects will be better once researchers understand better the actual requirements of the various species at each phase of their life (Ceccaldi, 2002).

Bombace (1989) indicates that the location where the reef is deployed will ultimately affect recruitment patterns. Fish attraction is more significant in locations with natural reef habitats, while production adds to biomass on the artificial reef in areas located at a distance from natural reefs. The mechanisms for reef colonisation are also species specific: habitat-limited, demersal and territorial species associated with hard substrata account for localised production at artificial reefs, while pelagic, mobile, partially reef-dependent and opportunistic reef species contribute more to aggregation around deployed structures.

Different habitat variables, such as structural complexity (Gratwicke & Speight, 2005; Kellison & Sedberry, 1998; Wilhelmsson *et al.*, 2006), reef age (Spanier *et al.*, 1990), substratum composition and habitat heterogeneity (Charbonnel *et al.*, 2002; Chabanet *et al.*, 1997), have all been shown to be important in regulating demersal fish assemblages on artificial reefs. Habitat variables can be replicated by appropriate design of artificial reefs, since it gives researchers the ability to design reefs for specific purposes and to target growth of particular organisms on the deployed structures (Ramos-Espla *et al.*, 2000; Seaman, 2000). In particular, aspects of the reef structure are known to strongly influence fish catch volume (Kim *et al.*, 1994). Reef rugosity and complexity influence fish community structure. Leung & Wilson (2002) recorded a higher fish diversity and abundance on artificial reefs compared to nearby rocky habitats; this was attributed to a higher degree of complexity of the artificial reef structure. Fish are attracted to the basic reef structure for shelter, foraging, and reproduction. The numerous crevices, holes, and undercut ledges within the artificial reef structure provide refuge from larger predatory fish. It also provides a barrier to currents and a substratum for attachment of eggs. Spanier (1990) emphasizes the importance of small but numerous separate holes. The design of the holes (size and orientation) depends on the targeted colonising organisms and spaces created by the reef blocks are also utilized differently depending on their vertical distance from the substratum. For example, it was found that groupers preferred horizontal holes near the bottom of reef blocks (Spanier, 1990). For a 'general-purpose' recruitment artificial reef, an array of hole diameters is used, as these can be utilised differently by different species. Micropores which arise from the characteristics of the reef construction material are important for rhizoid attachment of algae; macropores are essential for sheltering small invertebrates; and megaspaces are utilised by fish and the larger invertebrate fauna for sheltering in.

Aspects of the reef architecture are also important. Haphazard deployment of reef material provided a significantly poorer enhancement of fish populations relative to reefs constructed of designed modules and assembled into a specific configuration (Brock & Norris, 1989). In a review by Borntrager (1992), the volume of deployed material was found to have an effect on the ichthyofauna. Larger reefs were described as having higher abundances and species richness. However, community parameters did not increase linearly with reef volume. Small reefs had a higher species richness per unit volume than medium sized and large reefs. Size-independent aspects of artificial reefs, such as shape, are therefore likely to be more important than size in determining ideal reef design.

1.3 Artificial reefs in Maltese coastal waters

To date, no policies exist on the construction of artificial reefs in local waters, while the present project is the first of its type. However, several obsolete vessels have been scuttled in offshore areas to serve as diving attractions. The current total number of such reefs, more commonly referred to as 'wrecks', present in Maltese coastal waters stands at nine[3]. As these wrecks were not planned as artificial reefs, little or no scientific monitoring has been undertaken, with the result that the environmental impacts of such structures, whether positive or negative, is not well known. Likewise, data on the colonisation of artificial reefs by marine benthic organisms and fish is limited to sparse qualitative data collected during brief monitoring surveys of some of the wrecks and to casual observations.

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[3] The *'Rozi'* tugboat in Cirkewwa, the *'Um el Faroud'* tanker at Wied iz-Zurrieq, the *'St Michael'* and the *'Number 10'* tugboats at Marsascala bay, the *'Imperial Eagle'* ferry boat located off Qawra Point, the MV *'Xlendi'* ferry boat off Ix-Xatt l-Ahmar in Gozo (Magro, 2002), the MV '*Karwela*' and MV '*Cominoland*' also off Ix-Xatt l-Ahmar (Scerri, 2007), and most recently (August 2007) another vessel the '*P29*' patrol boat, scuttled at Cirkewwa.

Applications lodged with the MEPA for scuttling wrecks in Maltese offshore areas specify that the structures will be deployed on 'bare sand'[4] habitat, since it is argued that this habitat type has a lower ecological sensitivity and value compared to others (e.g. seagrass meadows) that occupy large areas of the seabed in local coastal waters. However, although it is true that the infauna inhabiting 'bare sand' have a high resilience to moderate disturbance, no studies on the impact of artificial structures on the benthic assemblages associated with such a habitats are available. In the meantime, plans are in place for scuttling additional wrecks in local coastal areas, which increases the need for gathering scientific data on artificial reef colonisation; an artificial reef policy can only be validly formulated on the basis of such information.

In the Maltese Islands, all existing scuttled vessels are made of metal. Although cleaned before scuttling, most wrecks still have a layer of paint (which may include anti-fouling agents) that may restrict growth of algae and other organisms, such that the number of organisms settling on top of other organisms (i.e. using a secondary substratum) is generally higher than those settling directly on the vessel. Moreover, as the paint peels off with time and superficial layers of rust fall off, any colonising biota is shed with the paint and rust, which results in an overall unstable system (Magro, 2002).

A better option, in terms of material used for the construction of artificial reefs, is to use locally generated inert waste that is readily available at a relatively low cost (Collins & Jensen, 1997). In Malta, the amount of demolition, excavation and construction waste is increasing by an average of 3% per annum. In 1995 alone, it was estimated that Malta produced around 1,230,000 tonnes of construction and demolition waste. This creates a huge waste disposal problem (WasteServ Malta Ltd., 2004). Such waste is partly being disposed of in various non-operational quarries across the islands. Between May 2003 and August 2005, over 3.57 million tonnes of construction waste were dumped in non-operational quarries. However, infilling non-operational quarries with such waste does not provide a long-term solution to the problem. Given the situation, it would seem appropriate to consider the possibility of utilising the inert[5] component of such material for the construction of offshore artificial reefs to enhance benthic habitats and fishery stocks, and potentially serve as an underwater attraction. The bulk of inert material that is currently disposed along with other waste types mainly consists of Globigerina Limestone, which is also ubiquitous underwater in many parts of the Maltese Islands, and is known to support a high diversity of benthic biota and habitats.

1.4 Project details and design

The Artificial Reef Project entailed construction of artificial reef units using a concrete mixture that utilises inert Globigerina waste and fibre-mesh reinforcement. Based on the design shown in Figure 1, it was estimated that each Globigerina-based concrete reef would use up around 423 tonnes of inert Globigerina Limestone waste.

In view of the importance of substratum for colonisation by biota, a main aim of the Artificial Reef Project is to assess the potential of reefs made of Globigerina-based concrete to be

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[4] 'Bare sand' habitats are soft-sediment habitats characterized by an impoverished epifauna but a rich infauna (see for example, Grech Santucci, 2005).

[5] Inert materials are here regarded as those which do not cause pollution through leaching, physical or chemical weathering and/or biological activity

colonised by marine life, as compared to artificial reefs made of native Globigerina Limestone. Monitoring colonisation by epibiotic assemblages provides a test of the suitability of the material (i.e. Globigerina-based concrete), based on the argument that if there are any effects, even if minor, then these will be revealed by the process of species settlement and the development of the epibiotic assemblage (Collins & Jensen, 1997). The results from such a comparison would allow determination of whether Globigerina-based concrete is environmentally acceptable as a reef construction material. If the results obtained indicated a positive colonisation effect, it would be acceptable in future to construct artificial reefs using building waste, thereby allowing re-use of an inert waste stream that is currently dumped.

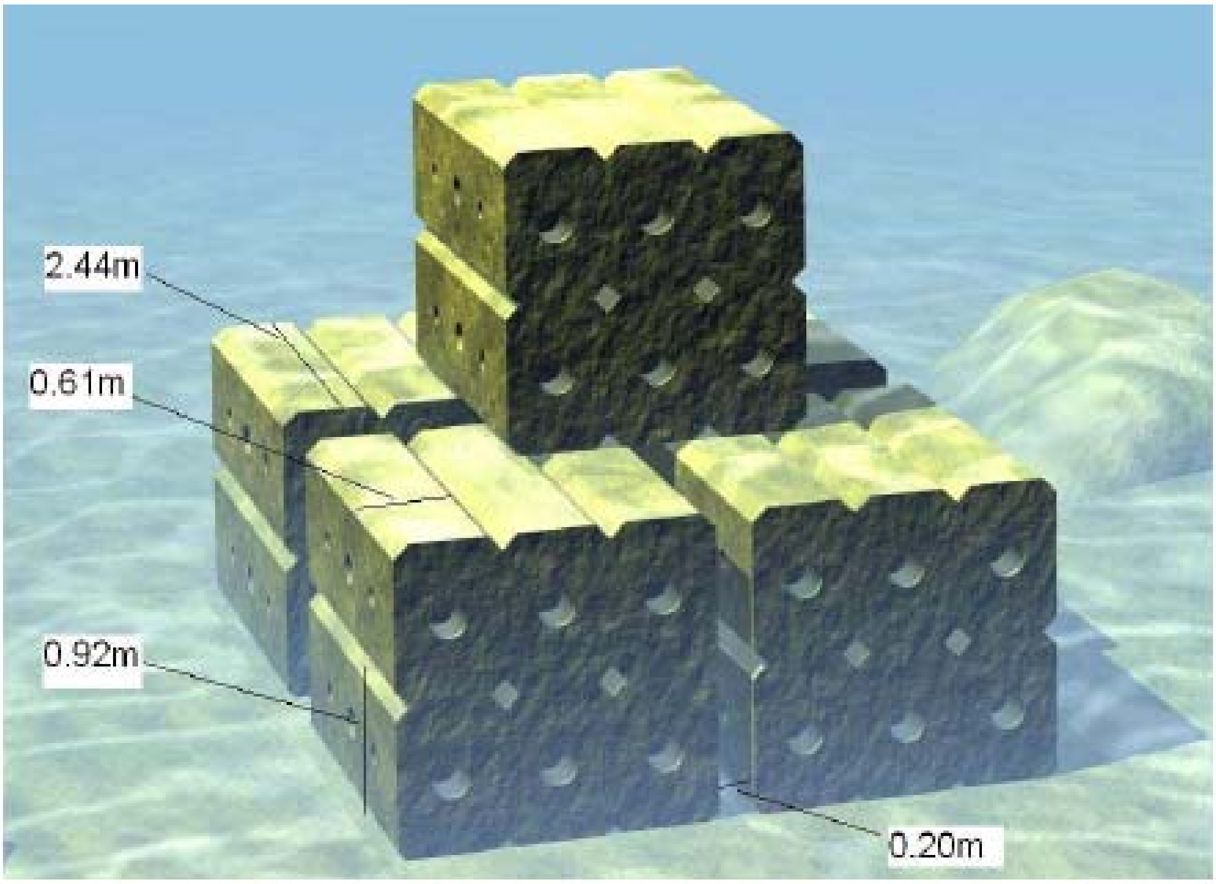

Figure 1. **Artist's design showing the proposed configuration of the artificial reef following assembly of the component modules. Each reef unit has a pyramidal conformation and consists of five sub-units (4 units at the base and one on top). Each of the five sub-units in turn consists of 6 reef blocks each measuring 0.61 m wide x 0.92 m high x 2.44 m long (the total volume of a single block is 1.37m^3).**

It was planned to site the artificial reefs on a bare sand bottom in waters having a depth of around 40 m off St Julians Bay (Figures 2 & 3). Such a depth would ensure that the reefs would be distant enough from the shore to reduce disturbance by anthropogenic activities to a minimum, while also allowing easy access for study using SCUBA diving, and for potential future visits by SCUBA divers for recreational purposes. Locating the artificial reefs on bare sand ensured that no sensitive habitats, namely seagrass beds and infralittoral algal forests, are impacted adversely, while it is also known that 'bare sand' habitats are resilient to disturbance. Nevertheless, another main aim of the project was to investigate any potential effects of the artificial reefs on 'bare sand' habitat.

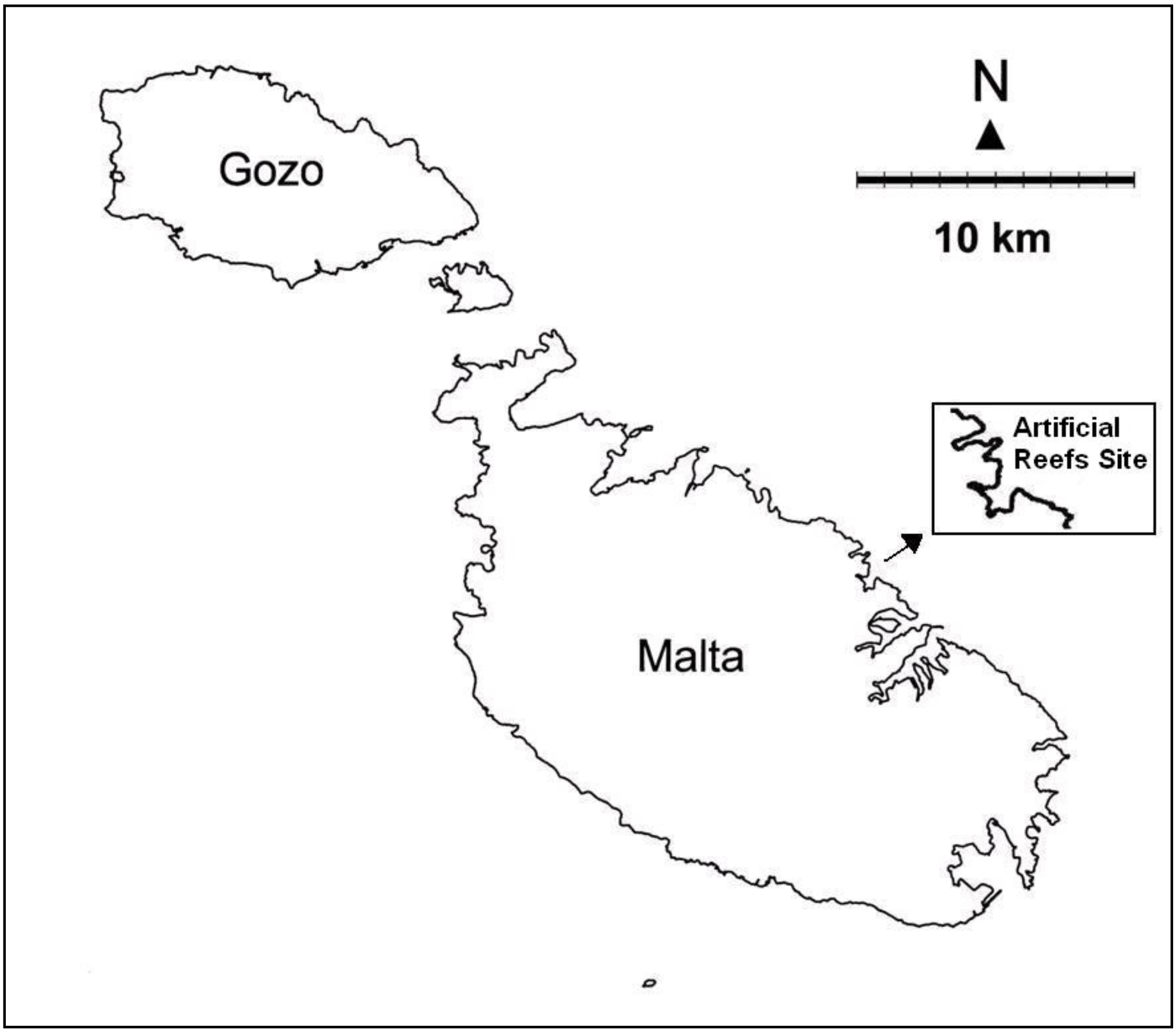

Figure 2. Map of the Maltese islands showing the location of the artificial reefs site, off the coast of St Julians Bay.

The design, size, number and location of the reef modules were selected such that a controlled experiment could be carried out and adequately monitored. The experimental design used is based on the 'Before-After' (BA) protocol (Underwood, 1997), which allows testing of a number of hypotheses and enables comparison between data collected before deployment of the reefs to that collected after. Using this protocol, it was planned to have a replicated design that had two sets of artificial reefs, with two reef units per set (Figure 3). To ensure that all reef units were sited in waters having broadly similar environmental conditions, the selected sites had a similar exposure, bathymetry and bottom type. Furthermore, two 'sandy bottom' and two 'rocky bottom' control sites, all of which were located at the same water depth as the artificial reefs, were incorporated in the experimental design (Figure 3). The codes used for the four artificial reef units and control sites are given in Table 1.

Since it was desirable to have minimal disturbance to reef units during the project studies, a conservation area was established centred on the artificial reefs, as indicated by the geographical coordinates given in Table 2[6].

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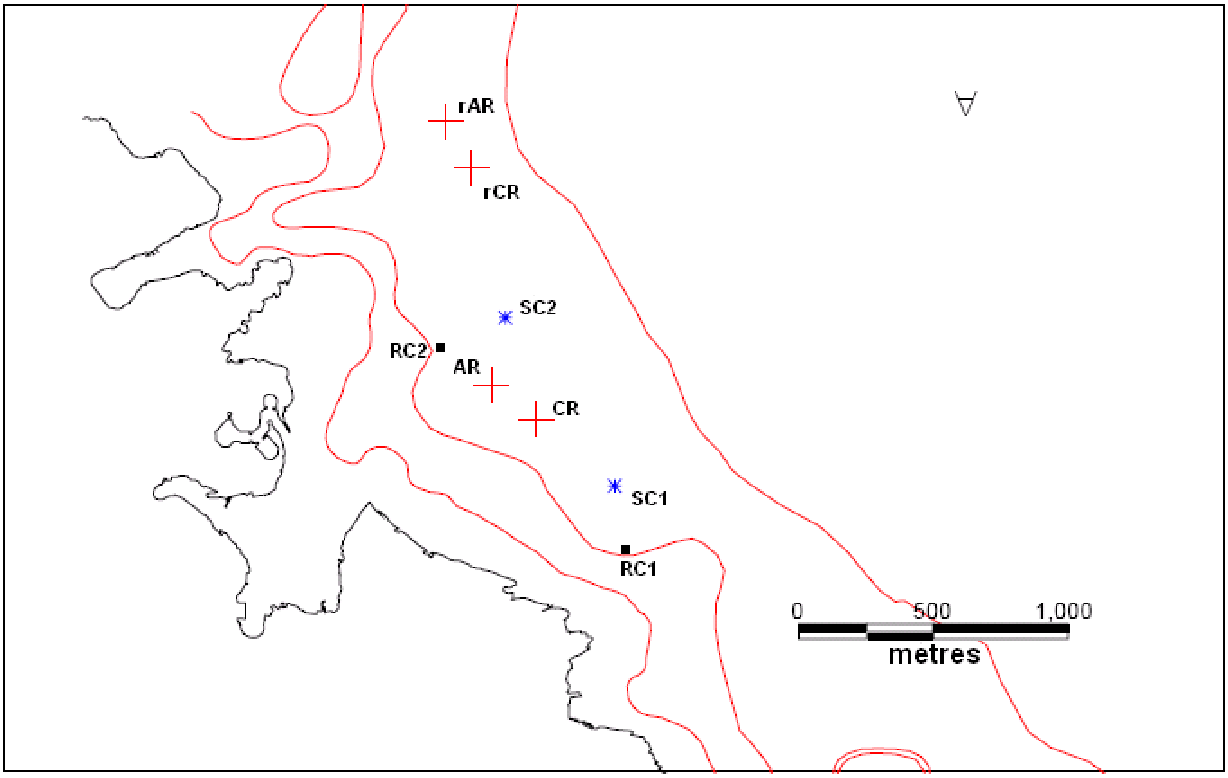

Figure 3. **Map showing the location of the four artificial reef units (AR, CR, rAR and rCR), the sand control sites (SC1 and SC2), and the rock control sites (RC1 and RC2). See Table 1 for a key to the codes used in the map. The red lines represent (outer to inner) the -50m, -20m and -10m depth contours.**

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[6] Notice to Mariners No 5 of 2008 [Malta Government Gazette 22 Jan 2008].

Table 1
Codes for the various artificial reefs used in Figure 3 and in the text of the present report.

Reef	Code
Concrete Artificial Reef	AR
Globigerina Control Reef	CR
Replicate Concrete Reef	rAR
Replicate Globigerina Reef	rCR
Rock Control 1	RC1
Rock Control 2	RC2
Sand Control 1	SC1
Sand Control 2	SC2

Table 2
Geographical positions (based on WGS84 chart datum) delineating the conservation area established at the artificial reefs site.

Points	Latitude (N)	Longitude (E)
Point A	35˚56’.090	14˚30.082
Point B	35˚55’.186	14˚30'.485
Point C	35˚55’.443	14˚30.054

1.5 Project aims

The Artificial Reefs Project has three main study components:

1. Investigation of the effects of the artificial reefs on sediments and sediment biota present in their vicinity;
2. Investigation of the fish fauna associated with the reefs;
3. Investigation of the colonisation of the reef by epifauna.

As this is the first time that such a project has been undertaken locally, it is meant to serve as a pilot study on which larger scale projects may be based, if successful. Additionally, it is meant to provide basic scientific information that is essential for the formulation of a national artificial reefs policy by the Malta Environment and Planning Authority, since no such information is available to date.

In summary, the main aims (some of which have been discussed in detail above) of the Artificial Reef Project are to:

- Construct and deploy experimental artificial reefs under controlled conditions in order to scientifically assess the impact of these structures on the marine environment, in particular the benthic biota and fishes present at the sites of reef deployment, and to monitor and quantify colonisation by marine benthic organisms and fish;
- Test different materials for the construction of the reefs and determine the environmental acceptability of using Maltese limestone in the construction of local artificial reefs;

- Assess the suitability of artificial reefs, made of concrete using a mixture containing Globigerina rock, as a diving attraction;
- Assess the suitability of a specific reef design and construction to support marine species and for long-term structural stability;
- Provide scientific data on the habitat potential of artificial reefs in local waters; such data are presently non-existent but are essential for the formulation of an artificial reefs policy.

The scientific programme had a pre-deployment and a post-deployment phase. In the pre-deployment phase the marine environment was studied in an identical way to the studies that were programmed to be made after deployment of the reefs in order to provide a baseline against which to compare any changes in conditions following deployment.

The present submission constitutes the report of studies concerning two of the three components of the project: (i) investigation of the effects of the artificial reefs on sediments and on the sediment biota present in their vicinity; and (ii) investigation of the fish fauna associated with the reefs. The third study component - investigation of the colonisation of the reef by epifauna – was still ongoing at the time of writing of this report and will therefore not be covered here but will be the subject of a separate report to be issued in the near future.

2. METHODOLOGY

2.1 Site selection and reconnaissance survey

The first part of the project entailed establishing the occurrence and distribution of marine benthic assemblages and habitats at the proposed locality, and finding an adequately sized and suitable area where the artificial reefs could be deployed, keeping in mind the restrictions posed by the scientific design. Accordingly, the physical and biological characteristics of the infralittoral zone in area located off the St Julian’s bay/Sliema area (Figure 2) were surveyed.

Four 400m-long transects, located at four different points within the study area, were surveyed by SCUBA diving in August 2002. Detailed data was collected on: bathymetry of the study area; size and location of areas with a sandy seabed and the water depth at which the latter occurred; location and the spatial extent of areas with rock rubble or rocky outcrops; and the location of the rock-sand boundary (information on which was pertinent to the study given the intention of deploying the artificial reefs on sand, hence the importance to measure the distance of the reefs from the nearest natural rocky substratum which would be the potential source of recruitment for the artificial reefs). In all four different sites were required to fulfil the proposed study design of the present project:

- 4 stations with bare sand for deployment of the artificial reefs;
- 2 stations with bare sand to serve as the sand control sites; and
- 2 stations with rocky outcrops to serve as the natural reef control sites

Boat-dives were made in February 2003 to determine the position of the rock-sand boundary. A side-scan sonar map of the seabed in the area of interest (GAS/MEPA, 2003), which was made available by MEPA, was used as reference such that most of the fieldwork concerned ground-truthing of the data shown on the map. To help cover large distances underwater, the SCUBA divers used Diver Propulsion Vehicles (DPVs). During fieldwork, the divers were transported by boat to an offshore site located well beyond the 40 m depth contour. Following their descent to the seabed, the divers swam underwater along a bearing that led to the rock-sand boundary closer to the shore. At the boundary, a delayed marker buoy was inflated and released to the surface, and the respective geographical coordinates were recorded using a GPS set[7]. Three such positions were recorded and plotted on the side-scan sonar base map of the seabed.

A bathymetric survey was also undertaken within the area of interest between March and May 2003. Spot depths and respective geographical coordinates were recorded along the 25, 30, 35, 40 and 45m depth contours using a boat mounted GPS set and depth sounder. The data collected were then used to produce a map showing the bathymetry of the study area.

The results from the site selection and reconnaissance field surveys indicated that, in many places, there was close agreement between the base map data and GPS coordinates recorded during the surveys. However, in some places, the results of the field surveys indicated the presence of several patches with rock rubble which were shown on the side-scan sonar map as sand. The data collected from the field surveys were used to help determine the final locations of the artificial reefs control sites. The following criteria were used in deciding the artificial reef locations (see Figure 3 and Table 3):

- Substratum, which had to be bare gravel-sand, possibly without any anthropogenic material and/or detached macrophyte debris;
- Distance from shore in relation to the rock-sand boundary;
- Distance from the rock-sand boundary, which had to be at least 100m;
- Distance between the replicate reef units and between the artificial reef units and control sites, which was set at a minimum of 200m;
- Water depth at the artificial reef and control sites, which was set at around 40 m to enable access by SCUBA diving using normal compressed air, while permitting enough time for sample/data collection (at least 20 minutes bottom time).

The distance between the two artificial reefs (concrete and Globigerina) was set at approximately 200m, while the locations of the two reef pairs were set to around 100m from the rock-sand boundary and 450m from the shore (see Figure 3). The locations of the sand control sites are shown in Figure 3. One of the rock control sites (RC1) consisted of a circular patch of rock rubble with boulders measuring some 30 m in diameter, surrounded by coarse sand, while the other rock control site (RC2) consisted of a rocky outcrop situated close to the rock-sand boundary. All proposed locations of the artificial reef and control sites were at a water depth of approximately 40m.

Finally, inspection surveys to ascertain the suitability of all predetermined artificial reef and control site locations for the present project (see Figure 3 and Tables 1 & 3) were made.

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[7] GPS set to WGS84 chart datum.

2.2 Deployment of the artificial reefs

The artificial reefs were deployed during September 2004, following the ‘before’ surveys concerning the sediment biota and fish fauna components, during which data was collected to provide baseline information on the situation prior to deployment of the reefs. Each reef was transported by barge to the deployment site and then lowered into the sea by means of a floating crane. Placement of the reef sub-units on the seabed and assembly was carried out with the help of SCUBA divers. The final coordinates of the reef units and corresponding water depth at the respective locations are given in Table 3. Figure 4 shows a photograph of one of the artificial reefs on the seabed at one of the reef sites soon after deployment.

Table 3
Geographical coordinates and corresponding water depth (m) of the four artificial reefs, and of the two sandy bottom and two rocky bottom control sites.

Site		Latitude/Longitude	Depth (m)
Concrete Artificial Reef	AR	N 35.92283 / E 14.50389	38
Globigerina Control Reef	CR	N 35.92172 / E 14.50569	40
Replicate Concrete Reef	rAR	N 35.93151 / E 14.50200	40
Replicate Globigerina Reef	rCR	N 35.92994 / E 14.50307	42
Sand Control 1	SC1	N 35.92126 / E 14.50956	41
Sand Control 2	SC2	N 35.92680 / E 14.50503	40
Rock Control Site 1	RC1	N 35.91881 / E 14.50889	39
Rock Control Site 2	RC2	N 35.92494 / E 14.50094	40

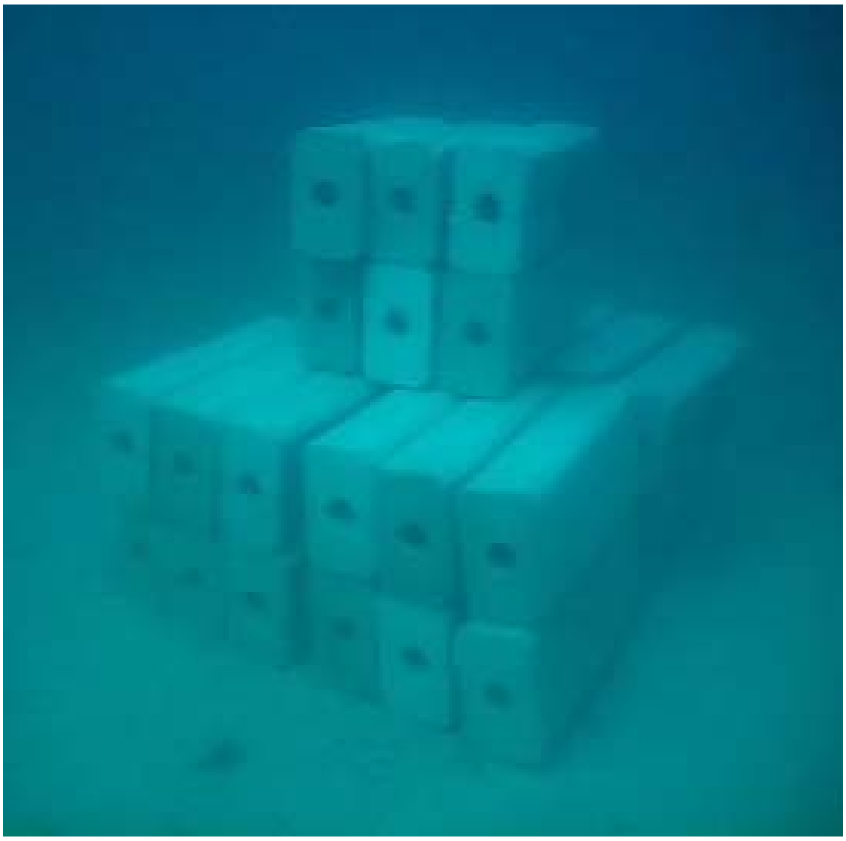

Figure 4. Photograph of one of the artificial reefs, taken just after deployment (September 2004).

2.3 Sediment and sediment biota study

2.3.1 Sampling and laboratory analysis

The main aim of the sediment and sediment biota study component was to investigate the influence of the artificial reefs on the sandy bottom present in their vicinity. To achieve this, the biota and physical parameters of the sandy bottom present in the immediate vicinity of the artificial reefs were sampled before and following deployment. Due to logistic limitations, only one of the two pairs of artificial reefs was investigated as part of this study component: one Concrete Artificial Reef (henceforth AR) and one Globigerina Control Reef (henceforth CR); see Figure 3. For ease of reference, the sandy bottom present in the vicinity of AR will be referred to as Reef Area 1, whilst that in the vicinity of CR will be referred to as Reef Area 2. As part of this study component, physical and biological attributes at the AR and CR sites were compared with those of two control sites SC1 and SC2 (which had similar environmental conditions but where no artificial reefs were deployed) before (henceforth 'pre-deployment') and after deployment (henceforth post-deployment) of the artificial reefs.

The pre-deployment sediment and sediment biota sampling session was carried out during the period December 2003 to February 2004, while the post-deployment session was carried out during the period February 2005 to April 2005. During fieldwork, SCUBA divers were transported to each sampling site by boat; the specific reef and control sites were located using the boat's depth sounder and GPS set (accurate to 15 m). Samples were collected at each site along two transects that extended out on opposite sides of each of the two reef deployment positions[8]; one transect was located on the western side and the other on its eastern side (see Figure 5).

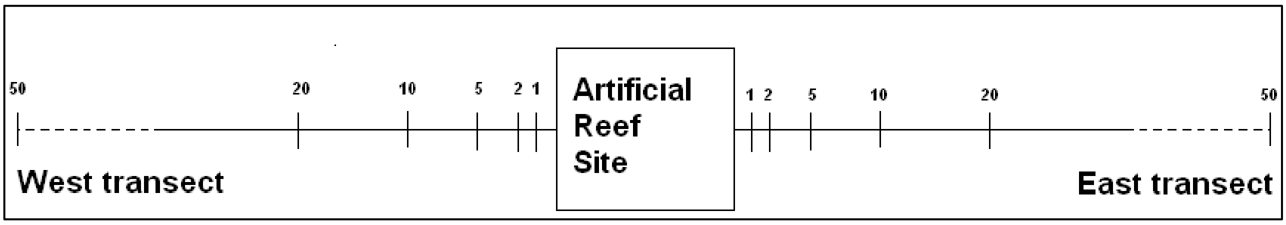

Figure 5. Sketch showing the location of the two transects located on the western and eastern sides of the artificial reef sites, along which sampling stations were located. The numbers indicate the distance in metres with zero being at the boundary of the reef site.

Sampling of infauna was carried out using a cylindrical corer having a diameter of 10cm, which had a fine mesh (< 0.5 mm) net over one of its open ends. During sampling, the corer's open end was pushed into the sediment to a depth of 12 cm and, while still in place, the lower (open) end was capped with a snap-on lid. The corer and its contents were then transferred to a mesh bag. Core samples were collected at distances of 1, 2, 5, 10, 20 and 50m from the two reef sites along each of the two transects (Figure 5); five replicate cores were collected at each station such that

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[8] For the pre-deployment samples, the 'reef site' was that area where the reefs were projected to the deployed. After placement of the artificial reefs at the site, the lower edge of the artificial reefs was taken to be the boundary of the reef site.

there were 24 sampling stations in total. A single station at each of the two sand control sites were sampled likewise, such that five replicate cores were taken from each control location at distances of 1, 2, 5, 10, 20 and 50m from the centre of the control site.

In order to investigate the physical properties of the soft sediment, namely mean grain-size and organic carbon content, additional sediment samples were taken at each artificial reef and control site station, using the 5 cm diameter corer and with three replicate cores taken at each of the 24 sampling stations and the two control sites.

Each of the pre- and post-deployment sampling sessions required a total of 48 dives to complete; the considerable depth at which the artificial reefs were located and other limiting factors, such as diving restrictions and weather conditions at the time of sampling, resulted in a number of difficulties including limitations on the amount of work that could be carried out during each dive. A total of 130 core samples for benthic infaunal analysis were collected from the two artificial reefs and the two control sites during the pre-deployment sediment biota study.

In the laboratory, each core was transferred to labelled buckets and the sediment left to soak in 7% magnesium sulphate for over an hour in order to relax the organisms before fixation. Each core was then preserved in 10% formalin in seawater for later analysis. Subsequently, each core was first thoroughly washed with fresh water to remove the preservative, then sieved through a 0.5 mm sieve to remove the fine sediment (< 0.5mm fraction) and finally sorted to separate out all macrofauna (animals larger than 0.5 mm). The macrofauna was stored in 70% ethanol.

The macrofauna was identified as far as possible and counted. Where identification to species level was not possible, the different species present were labelled using an alphabetical code (e.g. Syllidae sp. A etc). In particular, identification of polychaetes to the species level presented special difficulties given the lack of local taxonomic expertise for this group and of good identification keys for Mediterranean Polychaeta. The total abundance and total number of species were also calculated for each station.

Sediment samples collected for granulometric and organic carbon content analyses were taken to the laboratory and each sample was transferred to a labelled bucket. Each sample was then mixed well and a sub-sample was then transferred to a labelled plastic bag for future analysis. Sub-samples were stored in freezer at -20°C prior to analysis. The remaining sediment in the bucket was then air-dried and transferred to a labelled plastic bag for granulometric analysis.

In the laboratory, the dried samples were thoroughly mixed and 50g sub-samples were weighed out. Granulometry was determined according to the method given in Buchanan (1984) by fractionating each sample using nested 4mm, 2mm, 1mm, 500µm, 250µm, 125µm and 63µm Endecott test-sieves on a mechanical sieve-shaker for 15 minutes, at moderate amplitude. Each fraction was then weighed. The sediment passing through the 63µm sieve, which constitutes the mud fraction, was not analysed further.

The frozen sediment samples for organic carbon analysis were allowed to thaw at room temperature and 5g sub-samples were weighed out and analysed according to the Walkley & Black method as given in Buchanan (1984). In view of the high proportion of carbonaceous material present in local marine sediments, all samples were pre-treated by digesting with acid to remove any inorganic carbon that could interfere with the analytical method (see Hedges & Stern, 1983).

2.3.2 Statistical analysis

A one-way analysis of variance (ANOVA) with α set at the 0.05 level of significance was carried out on the physico-chemical (mean sediment grain size and percentage organic carbon content) and biological attributes (total abundance and total number of species) to test for significant differences between Sand Control 1 (SC1) and Sand Control 2 (SC2), before deployment of the artificial reefs. The factor used was 'Site', which had two levels, ('Site 1' and 'Site 2') and was random. One-way ANOVA was also used to test for significant differences in the same four attributes for each of SC1 and SC2 before and after deployment of the artificial reefs. The factor used was 'Time', which had two levels, ('Before' and 'After') and was fixed.

Two-way (2 factor) ANOVA with α set at the 0.05 level of significance was carried out on the physico-chemical (mean sediment grain size and percentage organic carbon content) and biological attributes (total abundance and total number of species) to test for significant differences between Reef Area 1 and Reef Area 2, and between these and the Sand Controls, before deployment. The two factors used in the model were 'Site' with two levels ('Site 1' and 'Site 2') and 'Station' with twelve stations nested in each 'Site'.

Three-way (3 factor) ANOVA with α set at the 0.05 level of significance was carried out on physico-chemical (mean sediment grain size and percentage organic carbon content) and biological attributes (total abundance and total number of species) to test for significant differences between the situation before and after deployment for Reef Area 1 and Reef Area 2. The 'before' data were obtained from the pre-deployment (2004) session and the 'after' data from the post-deployment (2005) session.

The three factors used in the model were: 'Time', for which there were 2 levels, 'before' and 'after'; 'Transect', for which there were 2 levels, 'West' and 'East', nested in 'Time'; and 'Stations', for which there were 6 levels, nested in 'Time' and 'Transect'

Prior to the analyses, the data sets were checked for homogeneity of variances using Cochran's test (Underwood, 1997) and, where necessary, appropriate transformation was carried out. Where the transformations still showed that Cochran's test was significant, ANOVA was still carried out, since it is considered to be quite robust (Green, 1979). Where significant differences were detected, Student-Newman-Keuls (SNK) tests were carried out to identify the source of difference (Underwood, 1997).

Multivariate analyses, namely agglomerative group average linkage hierarchical cluster analysis and non-metric multidimensional scaling (NMDS), were carried out to test for patterns of similarity among the species assemblages at the four sites: AR, CR, SC1 and SC2, 'before' and 'after' deployment of the reef modules. Cluster analysis aims to identify 'natural groupings' of samples such that samples within a cluster are more similar to each other in terms of species composition and abundance compared to samples in different clusters. In the NMDS, each sample is treated individually, with the distance between samples representing the dissimilarity between them. In both analyses, the Bray-Curtis measure was used to generate a matrix of similarities between each possible pair of samples. Where appropriate, similarity percentage (SIMPER) tests were carried out to identify the species that contributed most to the similarities within samples and dissimilarities between samples. SIMPER indicates which species are principally responsible either for an observed clustering pattern or for differences between sets of samples that differ in assemblage structure. No truncation of data was made prior to the analyses. Since transformation of data decreases the differences in abundance and hence increases the importance of moderately abundant species in the calculation of similarities (Micallef & Schembri, 1998), where necessary, logarithmic transformation *Log(X+1)* was applied to the mean species abundance data in order to minimize the 'noise' caused by rare species.

2.4 Fish fauna

2.4.1 Design and sampling

The main aim of the fish fauna study component was to investigate colonisation of the artificial reefs by demersal fish. To achieve this, the investigation incorporated: (i) comparison of the pre-deployment situation with the post-deployment one; (ii) assessment of the colonisation patterns on all the artificial reefs with time following deployment of the artificial reefs; and (iii) comparing the fish assemblages of the artificial reefs with those on existing natural rocky substrata and control sites in the study area. The sampling design for this study component included all four artificial reefs: AR, CR, the Replicate Concrete Artificial Reef (rAR) and the Replicate Globigerina Control Reef (rCR); see Figure 4 and Table 3.

The sampling protocol used in this study component was designed to achieve the most complete fish inventory possible within the counting area, considering that different species have different behaviour (mobility, cryptic behaviour, etc.). Data from previous studies (e.g. Ody, 1987; Charbonnel *et al*., 1997) indicate that certain fish (e.g. some Pomacentridae) are attracted to divers and their activities. This could lead to bias since the fish accumulate in greater numbers than when undisturbed, and may also hinder other species from being observed or from moving into the area where fish counts are being made. Other fish (e.g. Sparidae) avoid divers. Therefore, the sampling design of the fish fauna study component took into account these factors. The belt transect method, which was introduced by Brock (1954), has been shown to provide similar estimates of precision and accuracy to other methods (Samoilys & Carlos, 1992) and was selected for the present study.

During fieldwork, SCUBA divers were transported to each artificial reef and control site by boat; the specific stations (totalling 8; see Table 1) were located using the boat's depth sounder and GPS set (accurate to 15 m). Fish counts were made at each reef and control site along two transects that were roughly parallel to the rock-sand boundary, and which extended out on opposite sides of each reef; one transect was located on the western side and the other on its eastern side. Each 80m transect was further divided into 20 virtual segments, each 4m long, 4m wide and 4m high and therefore having a volume of (4m x 4m x 4m =) 64m^3. Distances were determined by laying a tape measure on the seabed. Fish counts were carried out in each segment This 64m^3 sample unit was chosen as it was a small enough to enable easy location of the boundaries of each segment while allowing a sufficiently large area to be sampled; in fish visual counts, one or a few large sampling areas are much harder to search than many small units, and the efficiency of searching may decrease with increase in the sample unit size (Mapstone & Ayling, 1993). Transect length also reduces the efficiency of counting with an increase in distance, since the mental concentration of the diver tends to diminish. Kingsford (1989) concluded that for planktivorous fish, counts made using a 25m x 10m transect gave more precise estimates than a 50m x 10m transect. Furthermore, increased transect length will increase bottom time such that the divers will increase their decompression time. When swimming underwater along a transect, the divers swam at a constant swimming rate and at least 50cm above the bottom to ensure minimum disturbance of the sediment which in turn may disturb the fish. On initiation of a fish count in a given 4m x 4m x 4m segment, the most mobile species were counted and recorded first, and progressively less mobile species were then recorded. Fish entering a transect segment during or after that segment was sampled were not included in that count.

Supplementary 'point counts' centred on the artificial reefs were carried out during the post-deployment sessions only. First, fish counts were made for a period of 1 minute for species observed swimming over the artificial reef and in a virtual area extending 1m around the reef. The cavities and crevices of the reef blocks were then closely examined to detect small, cryptic and sedentary species. The data collected were fish abundance and estimated total length for each recorded species.

All fish censuses were made by the same observer to ensure consistency, and counts were made between 0800h and 1500h on any given day of fieldwork. The latter helps avoid error that may be introduced as a result of sampling during periods of high activity, particularly early morning and late afternoon (Bayle-Sempre *et al*., 1994; Renones, 1998). Pre-defined abundance classes for the fish fauna were used to enhance the efficiency of making counts. Counting ability in humans is known to be reduced when the number of objects is above 20 (Bevan *et al.*, 1963). Therefore, during fieldwork, up to a maximum of 17 fish were counted individually in any one census, but above this, the following abundance classes were used: 17-30; 31-50; 51-100; 101-500; 500-1000; >1000. The total length of fish that occurred individually and of others that occurred in small shoals was estimated *in situ* using a graduated T-bar as a scale. In the case of large shoals, an average value for the body length was recorded. Large and small schools of fish in which individuals were smaller than 2cm were recorded as 'fry' since identification was not possible unless destructive sampling was carried out.

Three sampling sessions were held during each of the following periods: October 2003, April-June 2004, May-June 2005, and August-September 2005, the first two representing the pre-deployment autumn and summer sessions, and the latter two the post-deployment autumn and summer sessions. The area of bottom covered per transect was 320m^2 and the respective volume of water was 1280m^3. A total of 96 dives were required to complete fieldwork in relation to this study component.

Estimates of values of total abundance, total number of species and Shannon-Wiener diversity were made for each of the eight sites.

2.4.2 Statistical analysis

Data analysis was based on three attributes: species richness, total abundance, and abundance of the more common species. A four-factor ANOVA with α set at 0.05 was carried using the data sets for each of these three attributes, while also considering the factor 'time' (pre-deployment versus post-deployment, and season). The four factors used in the model were: 'Time', for which there were two levels: 'before' and 'after'; 'Season', for which there were two levels: 'spring' and 'summer'; 'Substratum', for which there were four levels: 'artificial reef', 'control reef', 'sand control' and 'rock control'; and 'Station' (= transect), for which there were two levels nested in 'Substratum'.

Prior to analyses, the data sets were checked for homogeneity of variances using Cochran's test (Underwood, 1997) and, where necessary, an appropriate transformation was made. Where the transformations still indicated that Cochran's test was significant, ANOVA was still carried out, since the analysis is considered to be quite robust (Green, 1979). Where appropriate, ANOVA results were followed by Student-Newman-Keuls (SNK) tests to identify the source of significant difference (Underwood, 1997).

Multivariate analyses were carried out on the full fish data set, excluding fry. The analyses consisted of agglomerative group average linkage hierarchical cluster analysis and non-metric multidimensional scaling (NMDS) ordination, both of which were made on a similarity matrix generated using the Bray-Curtis similarity coefficient. Due to the presence of several highly abundant taxa, a square-root transformation was applied to the data to reduce the contribution of such taxa to the similarity and bring it level with that of the less common species. The SIMPER (similarity percentage) analysis was used to identify the discriminating taxa between the groupings resulting from the cluster analysis and NMDS ordination.

3. RESULTS

3.1 Sediment and sediment biota study

3.1.1 Pre-deployment (2004) session

3.1.1.1 Physico-chemical attributes

Overall, there were differences in the sediment type classification between sediment samples collected from Reef Area 1, Reef Area 2, Sand Control 1 (SC1) and Sand Control 2 (SC2) during the pre-deployment (2004) session; sediments varied from gravelly sand to slightly gravelly muddy sand. Values of mean sediment grain size (expressed as moment measures in phi; see Linholm, 1987) for each of the 26 sampling stations are shown graphically in Figure 6. The soft sediment at Reef Area 1 was homogenous such that samples from all stations there were classified as slightly gravelly muddy sand. On the other hand, the soft sediment present at Reef Area 2 varied between fine sand and coarse sand and was therefore rather heterogeneous. This is reflected in the sediment type classification which varied from gravelly sand, to slightly gravelly sand to slightly gravelly muddy sand. Sediments at SC1 and SC2 were classified as slightly gravelly muddy sand, however, the sediment at the sand controls was, overall, coarser than the sediment at Reef Area 1 (see Figure 6).

Values of mean percentage organic carbon of the sediment for each of 26 sampling stations sampled during the pre-deployment session (2004) are shown graphically in Figure 7. Overall, values of organic carbon content were less than 0.2%. The highest value (0.180%) and the lowest value (0.066%) were both recorded from Reef Area 2, again showing that the bottom at Reef Area 2 is rather heterogeneous. Mean percentage organic carbon values recorded from Reef Area 1 were overall similar to one another, but higher than those recorded for both sand controls (Figure 7).

One-factor ANOVA indicated that for the pre-deployment (2004) session there were no significant differences in percentage organic carbon between Sand Control 1 (SC1) and Sand Control 2 (SC2), however there was a significant difference ($p < 0.05$) for the factor Site for mean sediment grain size.

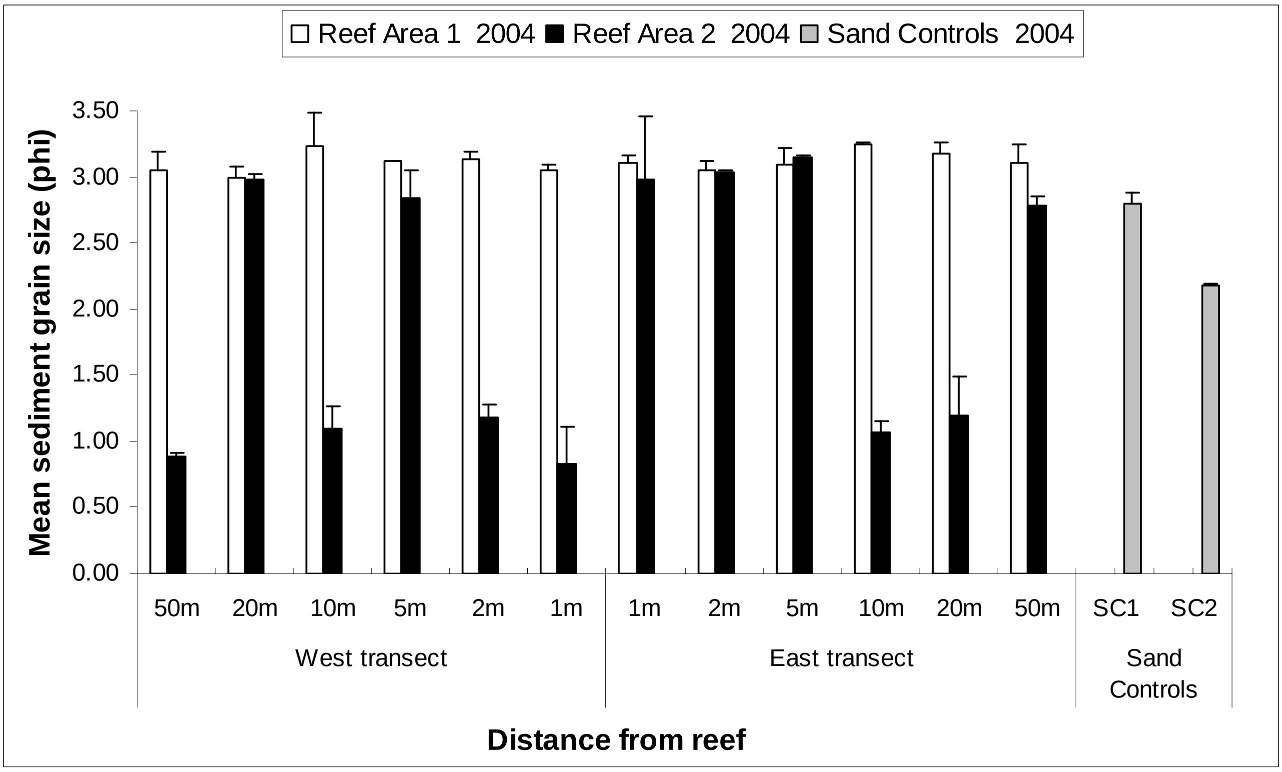

Figure 6. **Mean sediment grain size values (in phi) recorded from Reef Area 1, Reef Area 2, Sand Control 1 and Sand Control 2, during the 2004 (pre-deployment) sampling session. Error bars represent +1 SD**.

Two-factor ANOVA indicated that for the pre-deployment (2004) session there were:

- No significant differences in percentage organic carbon content of the sediment between Reef Area 1 and Reef Area 2. However, there was a significant difference ($p < 0.01$) for the factor Site for mean sediment grain size values;
- Significant differences in percentage organic carbon content of the sediment and mean sediment grain sizes between Reef Area 1 and the two sand controls (SC1 and SC2).
- No significant difference in percentage organic carbon between Reef Area 2 and SC1. However, there were a significant difference ($p < 0.01$ respectively) in mean sediment grain size between Reef Area 2 and SC1.
- No significant differences in mean sediment grain size between Reef Area 2 and SC2, however, there was a significant difference ($p < 0.001$) in percentage organic carbon content between Reef Area 2 and SC2.

3.1.1.2 Benthic biota

The study area supported an assemblage of ‘bare sand’. A total of 7,685 individuals comprising 165 species were recorded for the pre-deployment (2004) session. Values of relative abundance of major taxa recorded are shown in Figure 8. Polychaetes were most abundant (79 %), followed by crustaceans (15 %), sipunculans (1%), molluscs (1 %) and others (4 %). The total number of species was also highest for the Polychaeta (74 species); hence this group dominated the bare sand assemblage, both in terms of number of species and abundance. Values of mean total abundance and mean total number of species recorded from Reef Area 1, Reef Area 2 and the two sand controls (SC1 and SC2) during the pre-deployment session are shown graphically in Figures 9 and 10 respectively. Overall, Reef Area 1 had a higher mean total abundance compared to both Reef Area 2 and the two sand controls. Values of mean total number of species were relatively similar between Reef Area 1, Reef Area 2 and SC 2, and highest at SC1.

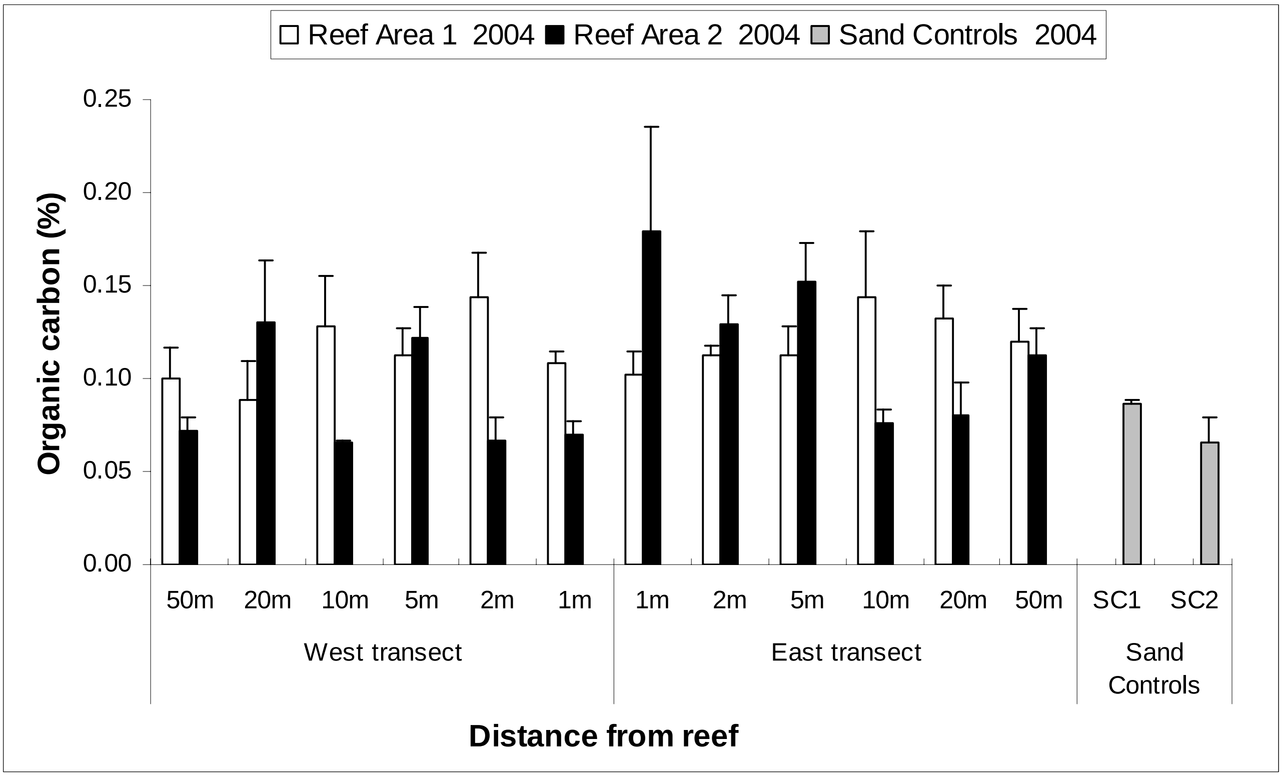

Figure 7. **Values of mean % organic carbon content recorded from Reef Area 1, Reef Area 2, Sand Control 1 and Sand Control 2, during the 2004 (pre-deployment) sampling session. Error bars represent +1 SD.**

The one-factor ANOVA indicated that for the pre-deployment (2004) session, there were no significant differences in total abundance between Sand Control 1 (SC1) and Sand Control 2 (SC2); however, there was a significant difference ($p < 0.05$) for the factor Site for total number of species.

The two-factor ANOVA indicated that for the pre-deployment (2004) session there were:

- No significant differences in total number of species between Reef Area 1 and Reef Area 2. However, there was a significant difference ($p < 0.01$) for the factor Site for total abundance.
- Significant differences ($p < 0.01$) for total abundance and total number of species between Reef Area 1 and the two sand controls (SC1 and SC2).
- No significant differences in total abundance between Reef Area 2 and SC1, however, total number of species was significantly different ($p < 0.001$).
- No significant differences in total number of species and mean sediment grain size between Reef Area 2 and SC2, however, total abundance and percentage organic carbon were both statistically significant at the $p < 0.05$ and $p < 0.001$ levels, respectively.

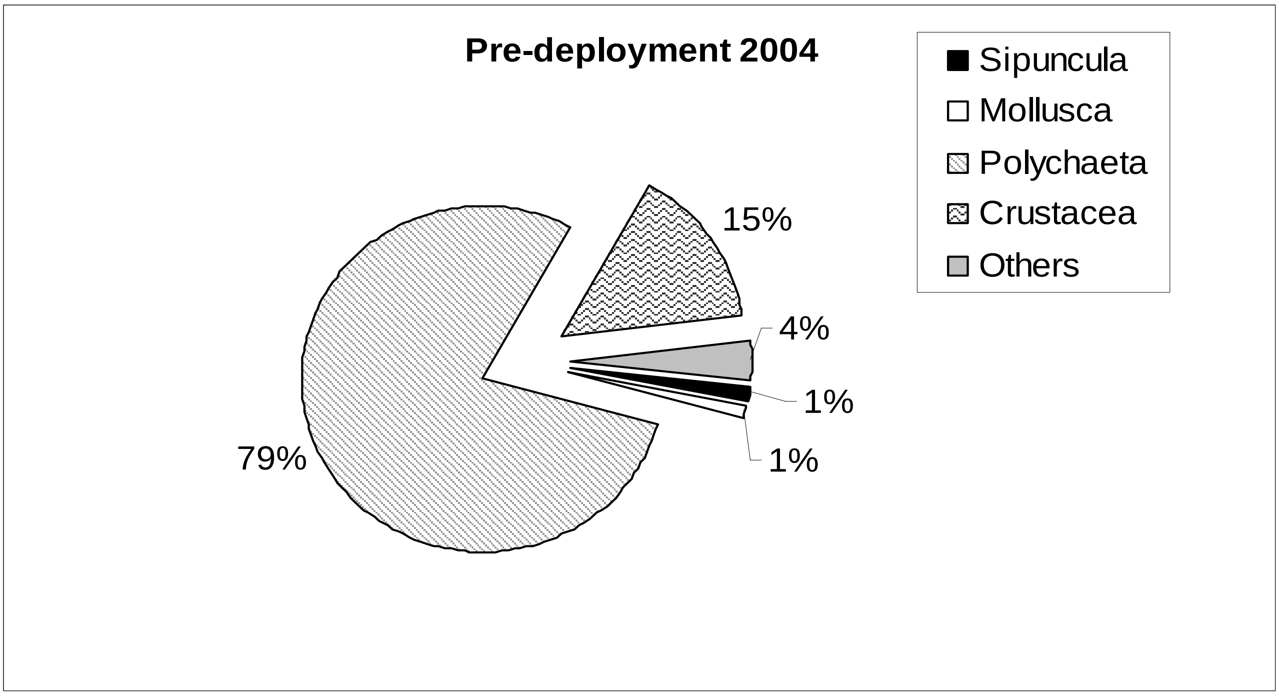

Figure 8. **Relative abundance of the major taxa collected during the pre-deployment (2004) sampling session.**

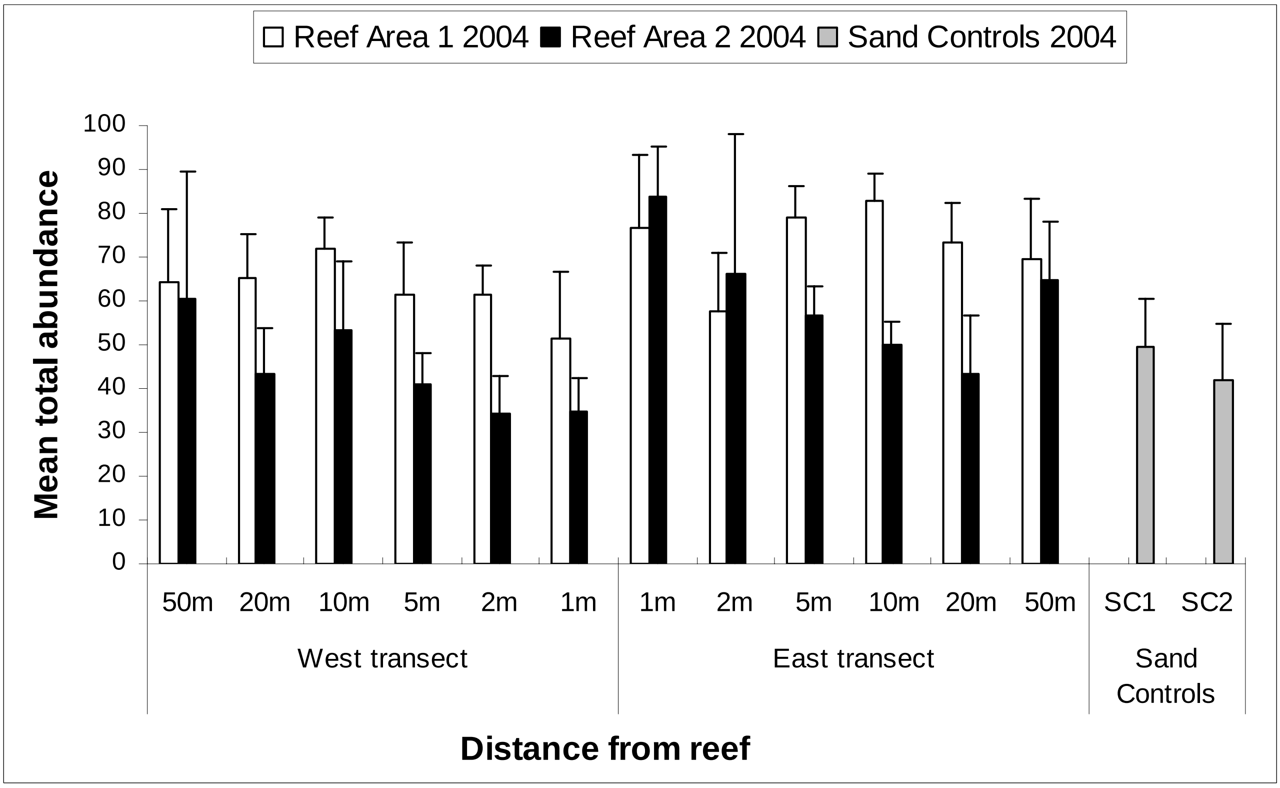

Figure 9. **Values of mean total abundance recorded from Reef Area 1, Reef Area 2, Sand Control 1 and Sand Control 2, during the pre-deployment (2004) sampling session. Error bars represent +1 SD.**

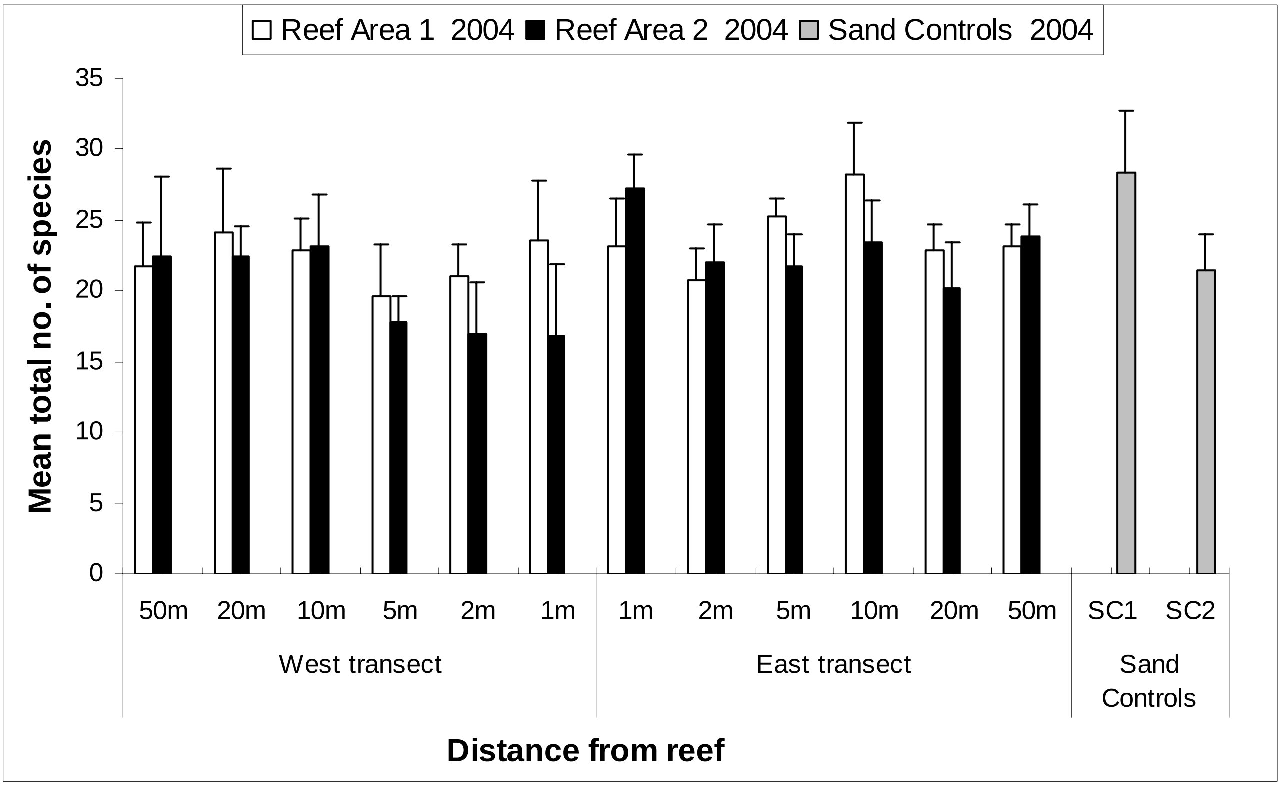

Figure 10. **Values of mean total number of species recorded from Reef Area 1, Reef Area 2, Sand Control 1 and Sand Control 2, during the pre-deployment (2004) sampling session. Error bars represent +1 SD.**

The results of both the NMDS and the cluster analyses showed differences in the benthic assemblages between: Reef Area 1 and Reef Area 2; Reef Area 1 and the two sand control sites (SC1 and SC2); Reef Area 2 and SC2; and Reef Area 2 and SC1. The results of the SIMPER analysis showed that the amphipod Aoridae sp. A and the polychaete Dorvillidae sp. A were present at SC2 only but completely absent from SC1, indicating differences in the species composition of the benthic assemblages at the two sites.

3.1.2 Post-deployment (2005) session

3.1.2.1 Physico-chemical attributes

Only small differences in the sediment type classification were recorded between sediment samples collected from Reef Area 1, Reef Area 2, Sand Control 1 (SC1) and Sand Control 2 (SC2) during the post-deployment session. The sediment was overall classified as slightly gravelly muddy sand. Values of mean sediment grain size (expressed as moment measures in phi; see Linholm, 1987) for the four sites sampled before and after deployment are shown graphically in Figures 11 and 12.

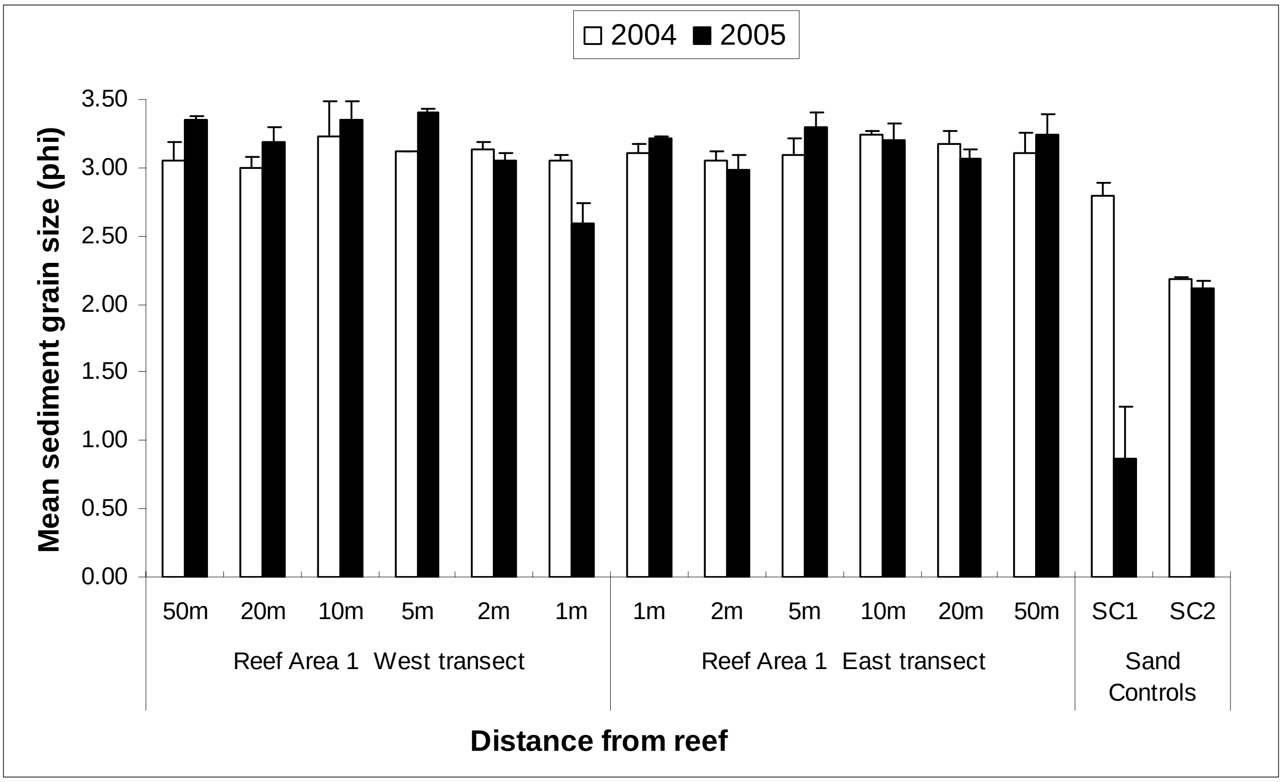

Figure 11. **Mean sediment grain size values (phi) recorded from Reef Area 1, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

The results show that, following deployment of the artificial reefs at Reef Area 1, there was an overall slight increase in mean sediment grain size (in terms of phi values) at stations located at a distance from the structure, while there was a general decrease (in terms of phi values) at stations close to the reef, namely stations located at distances of 1m and 2m from the reef. On the other hand, due to the heterogeneity of the bottom at Reef Area 2, when comparing the stations at this site before and after reef deployment (see Figure 12), no trend could be identified, although stations located close to the Reef, namely those at 1m and 2m from the reef, had a lower mean sediment grain size compared with the other stations.

Figures 12 and 13 also show that while there was only a slight decrease in mean sediment grain size at SC2, there was a major decrease at SC1, meaning that the sediment at the latter site during the post-deployment session was much coarser.

Values of mean percentage organic carbon content of the sediment for the four sites sampled before and after deployment are shown graphically in Figures 13 and 14. Overall, values of organic carbon content in the sediment recorded during the post-deployment were less than 0.2%. The highest value (0.181%) and the lowest one (0.072%) were both recorded from Reef Area 2. The results show that, following deployment of the reefs, there was an overall increase in percentage organic carbon content in the sediment at Reef Area 1. On the other hand, no pattern of increase/decrease in percentage sediment organic carbon was discernible for Reef Area 2. The results also show a slight decrease in mean percentage sediment organic carbon at SC1 and an increase at SC2. However, overall, values recorded from the sand control sites were lower than those recorded from Reef Area 1 and Reef Area 2.

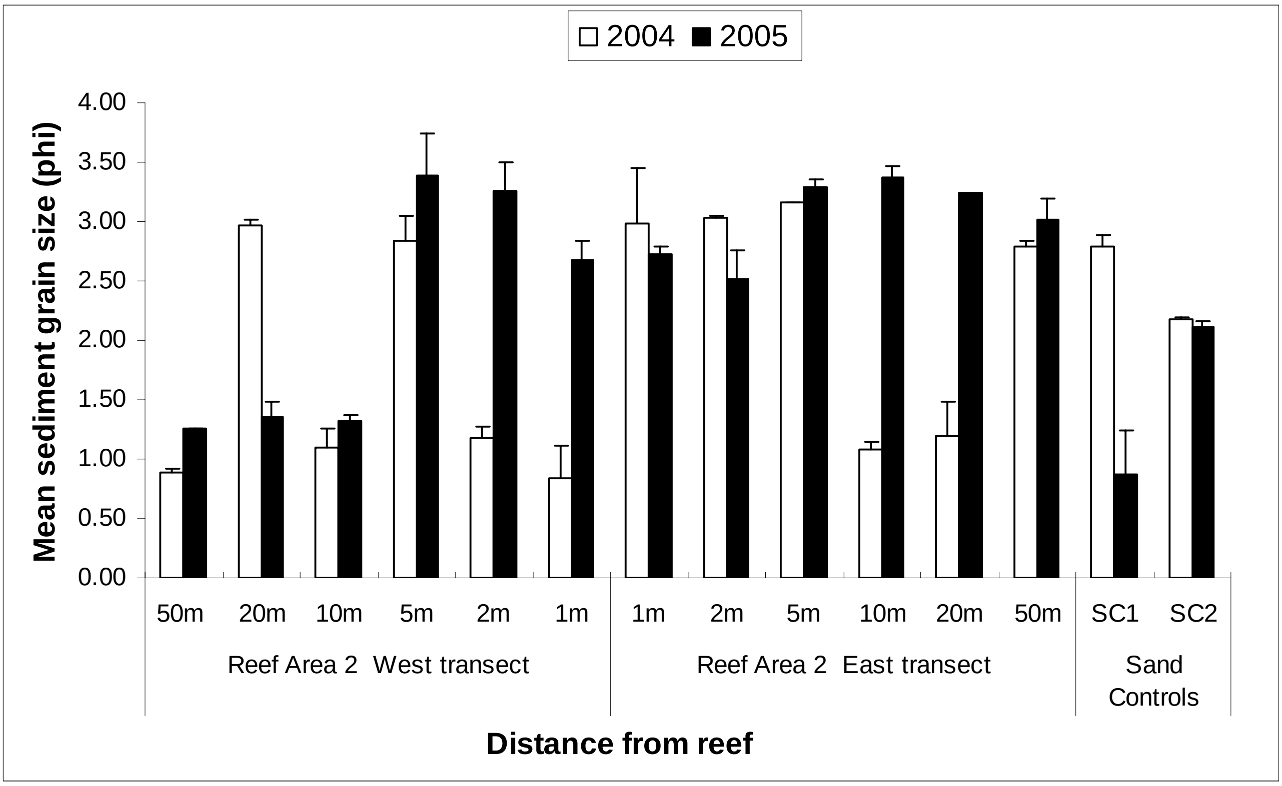

Figure 12. **Mean sediment grain size values (phi) recorded from Reef Area 2, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

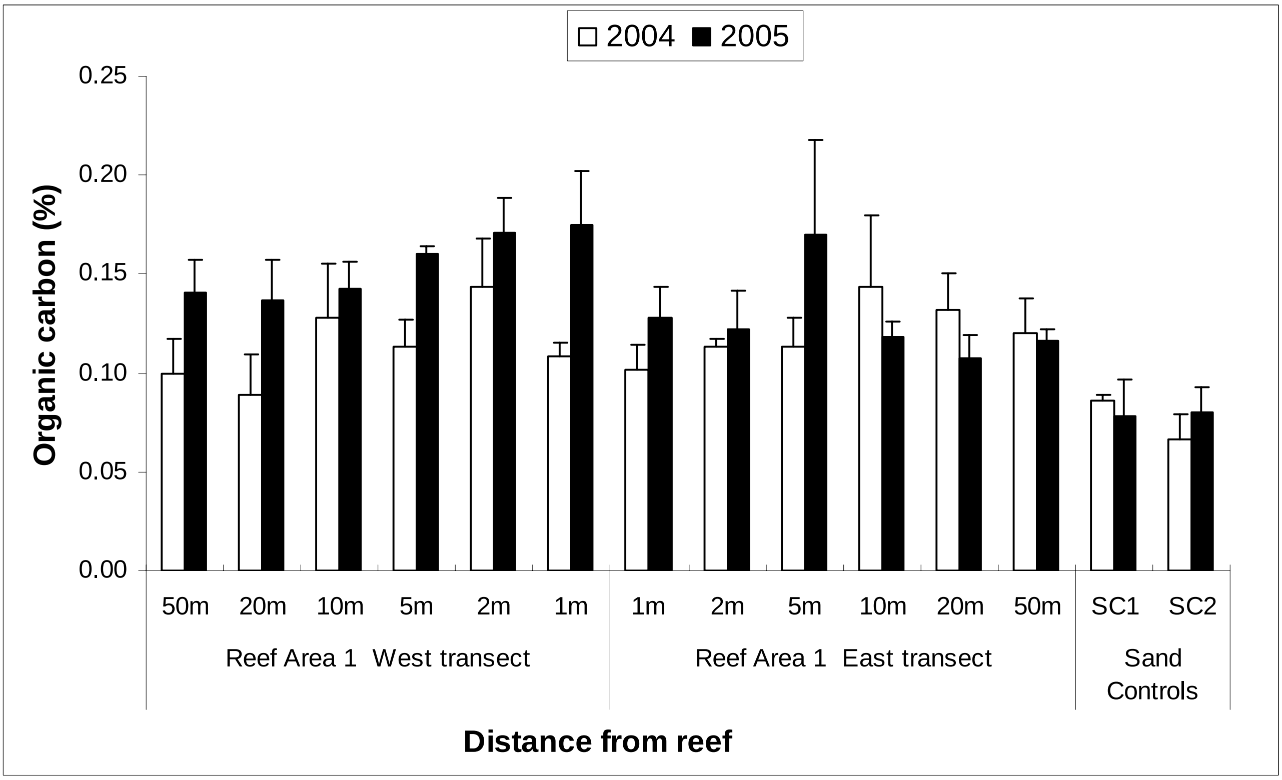

Figure 13 **Mean sediment organic carbon content (%) recorded from Reef Area 1, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

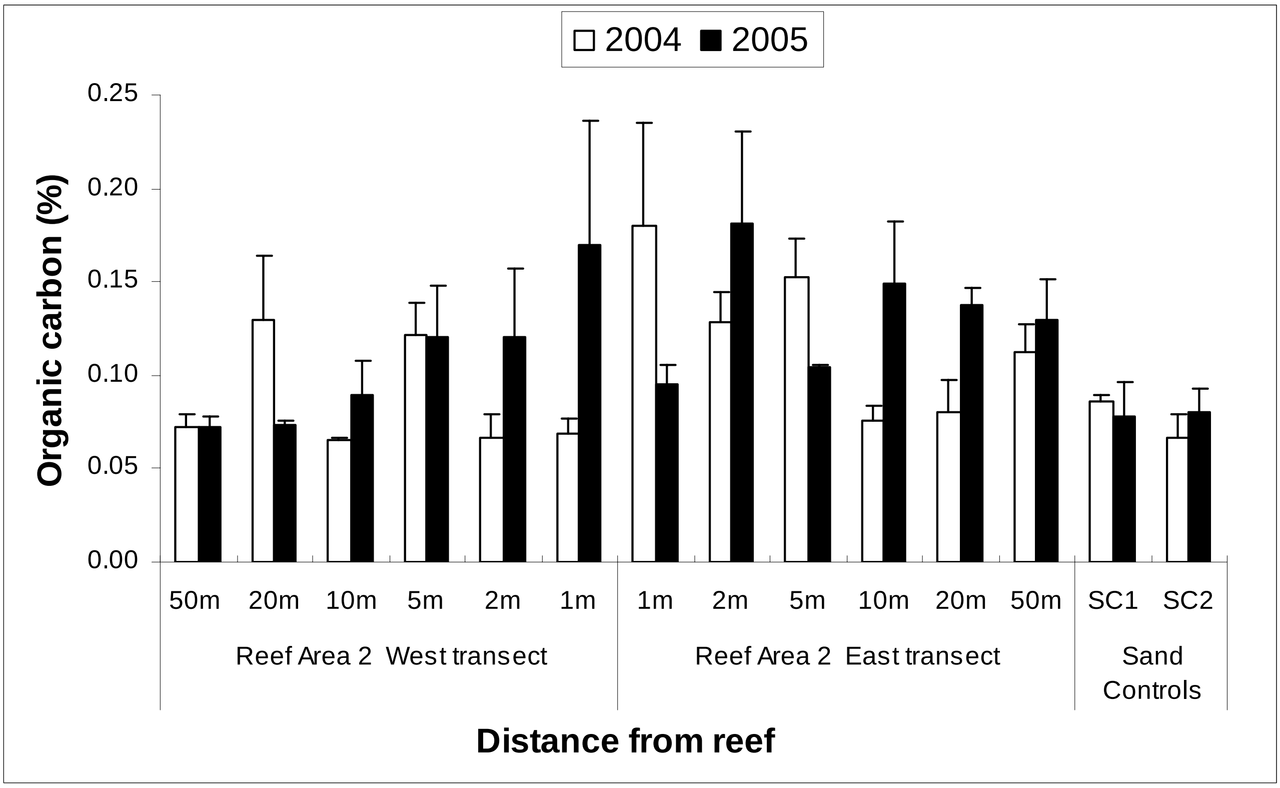

Figure 14 **Mean sediment organic carbon content (%) recorded from Reef Area 2, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

The one-factor ANOVA indicated that there were no significant differences in percentage organic carbon content of the sediment between samples collected from SC1 during the (2004) pre-deployment session and samples collected from the same site during 2005 (post-deployment session); however, there was a significant difference ($p < 0.05$) for the factor Time in mean sediment grain size.

The one-way ANOVA also indicated that there were no significant differences in mean sediment grain size and percentage organic carbon content between samples collected from SC2 during the (2004) pre-deployment session and samples collected from the same site during 2005 (post-deployment session).

The three-factor ANOVA indicated that there was no significant difference for the factor Time (‘before’ vs ‘after’) in mean sediment grain size and percentage sediment organic carbon at Reef Area 1 and Reef Area 2.

3.1.2.2 Benthic biota

A total of 8,754 individuals comprising 187 different species were collected and identified. Figure 15 shows the relative abundance of the major taxa collected. The most abundant group was the Polychaeta (75 %), followed by the Crustacea (21 %), Sipuncula (1%), Mollusca (1 %), and others (2%). The total number of species was also highest for the Polychaeta (78 species), therefore, this group dominated the bare sand assemblage, both in terms of number of species and in abundance.

In all, a total of 16,439 individuals comprising 216 different species were collected from the pre-deployment and post-deployment sessions considered collectively. Figure 16 shows the total number of Polychaeta and Crustacea – the two most abundant taxa – recorded from the pre- and post-deployment sessions. Clearly, a higher total abundance for these two groups was recorded in the post-deployment session.

Values of mean total abundance and mean total number of species recorded from Reef Area 1 and the two sand controls before and after reef deployment are shown graphically in Figures 17 and 18 respectively. A general increase in mean total abundance and mean total number of species was recorded during the post-deployment session from stations located along the western transect. Along the East Transect, the largest increase in mean total abundance recorded from the post-deployment session was noted for stations located closest to the reef (i.e. the 1m and 2m stations). Furthermore, with the exception of the 5m and 10m stations, a general increase in mean total number of species at stations located along the eastern transect was recorded in the post-deployment session.

Values of mean total abundance and mean total number of species recorded from Reef Area 2 and from the two sand controls before and after reef deployment, are shown graphically in Figures 19 and 20. Overall, values of mean total abundance and mean total number of species recorded from the transect stations increased with distance from the reef. Furthermore, higher values of mean total abundance were recorded from SC1 during the post-deployment (2005) session, while slightly lower values of this attribute were recorded from SC2 during the same session. Higher values of total number of species were recorded from SC2 during the post-deployment session, while values of this attribute were similar at SC1 between the pre- and post-deployment sessions.

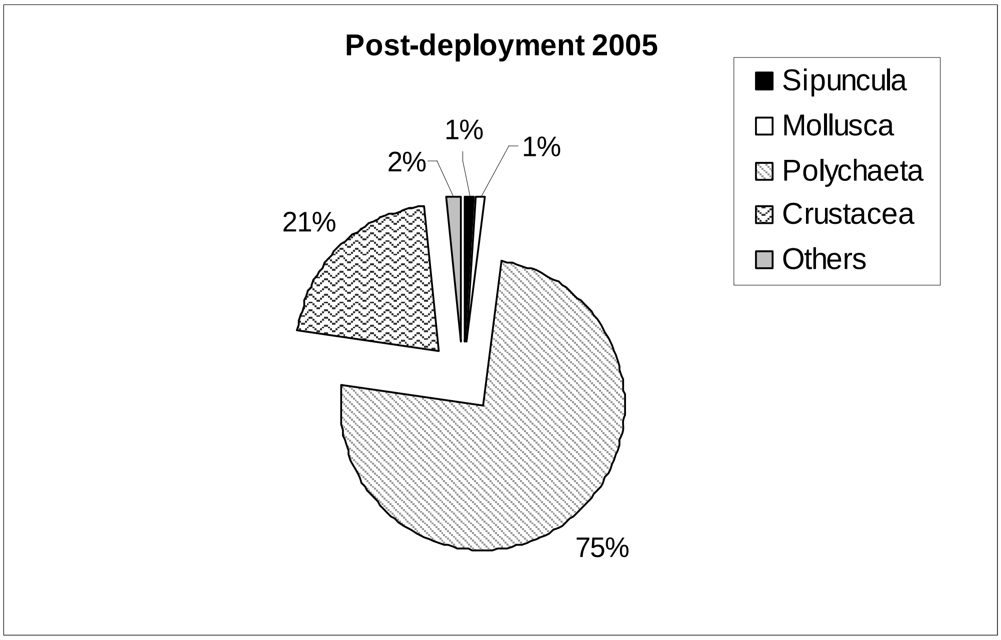

Figure 15. **Relative abundance of the major taxa collected during the post-deployment session (2005).**

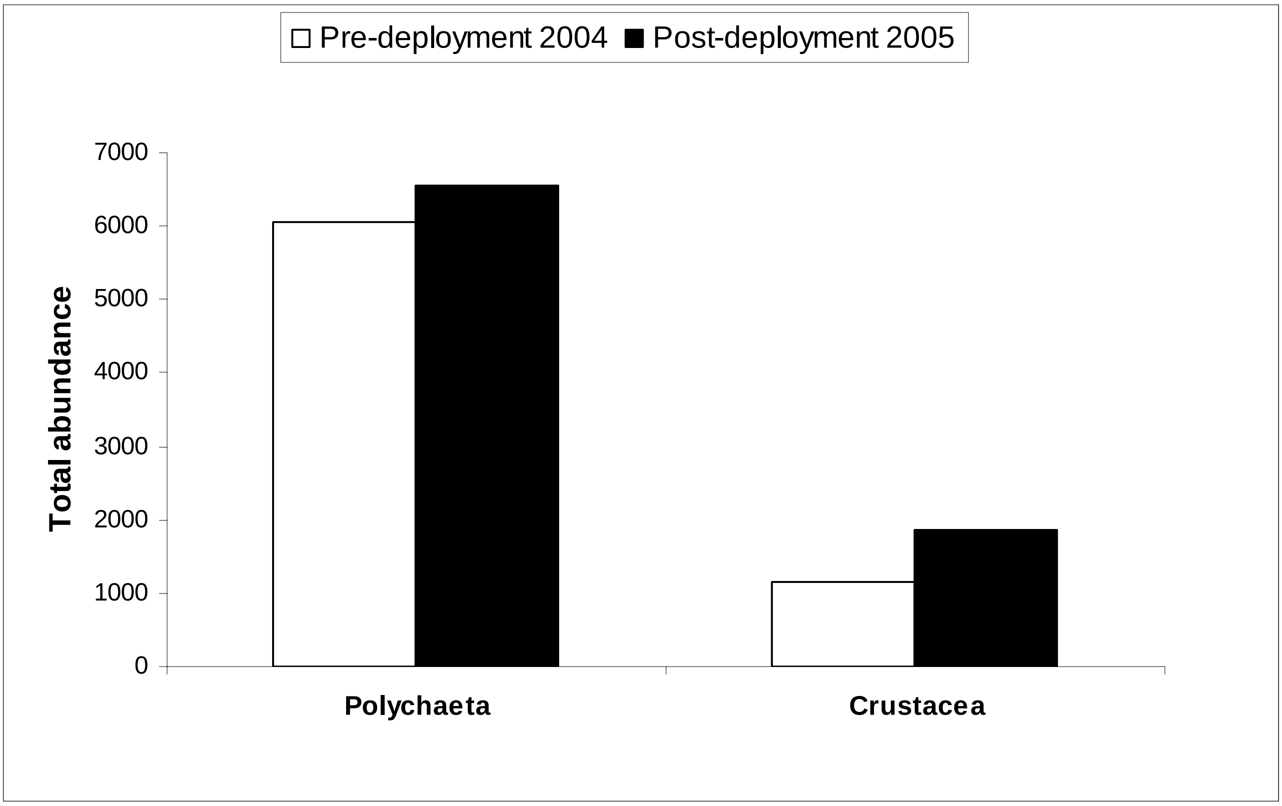

Figure 16. Values of total abundance of Polychaeta and Crustacea collected during the pre-deployment and post-deployment sessions.

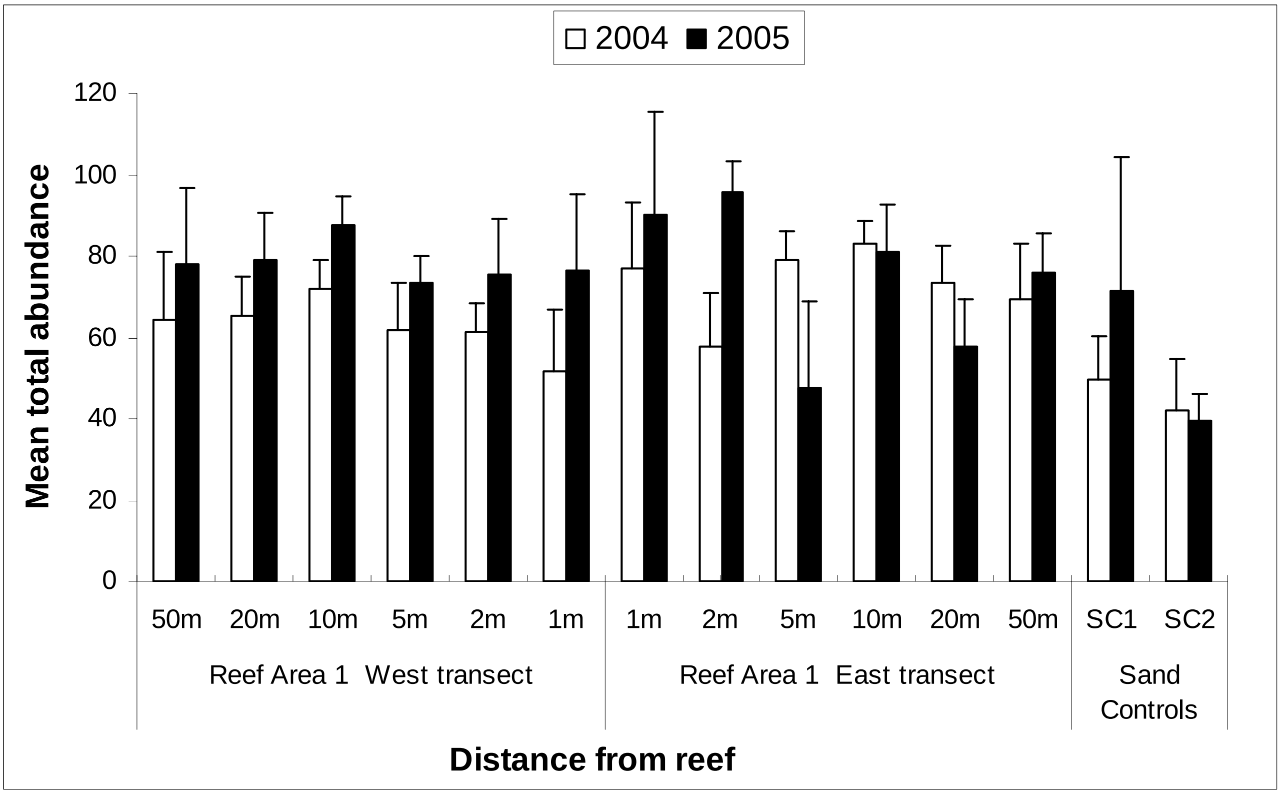

Figure 17. Values of mean total abundance recorded from Reef Area 1, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.

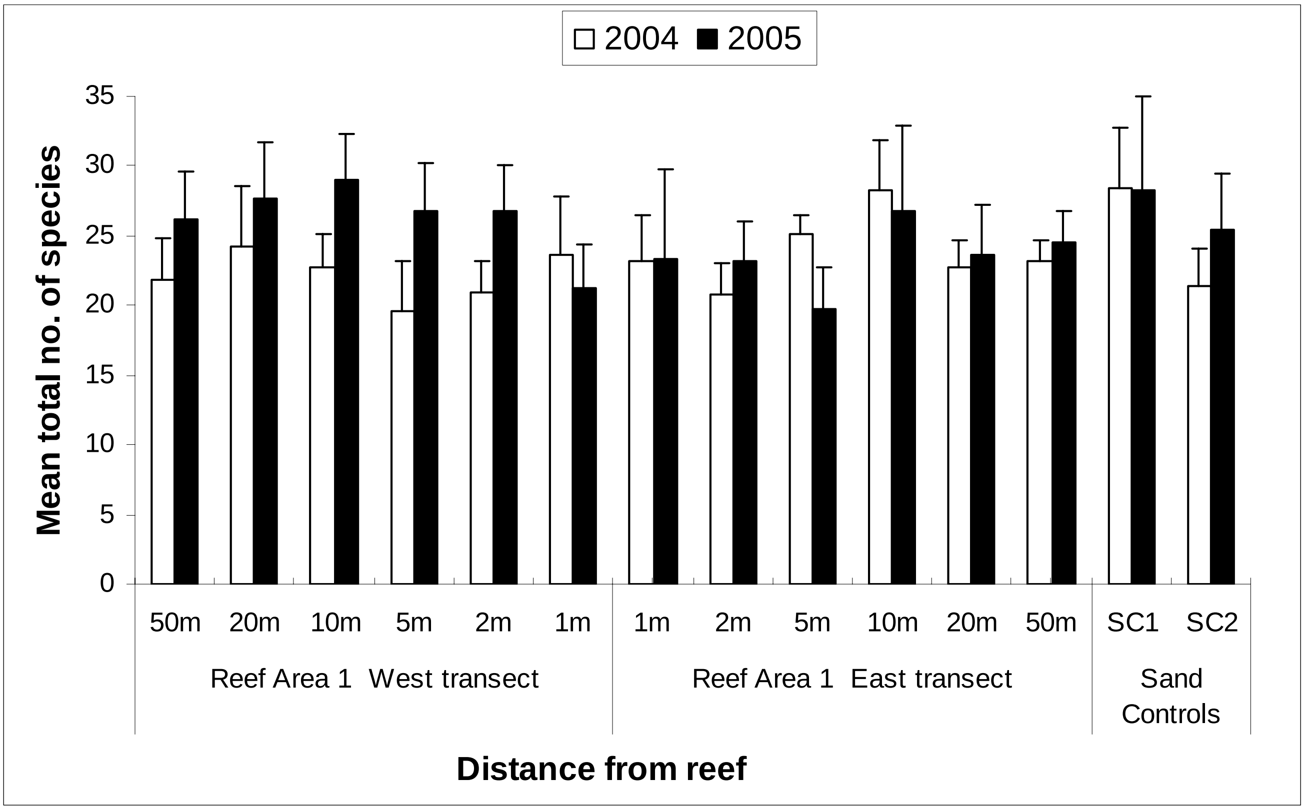

Figure 18. **Mean total number of species recorded from Reef Area 1, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

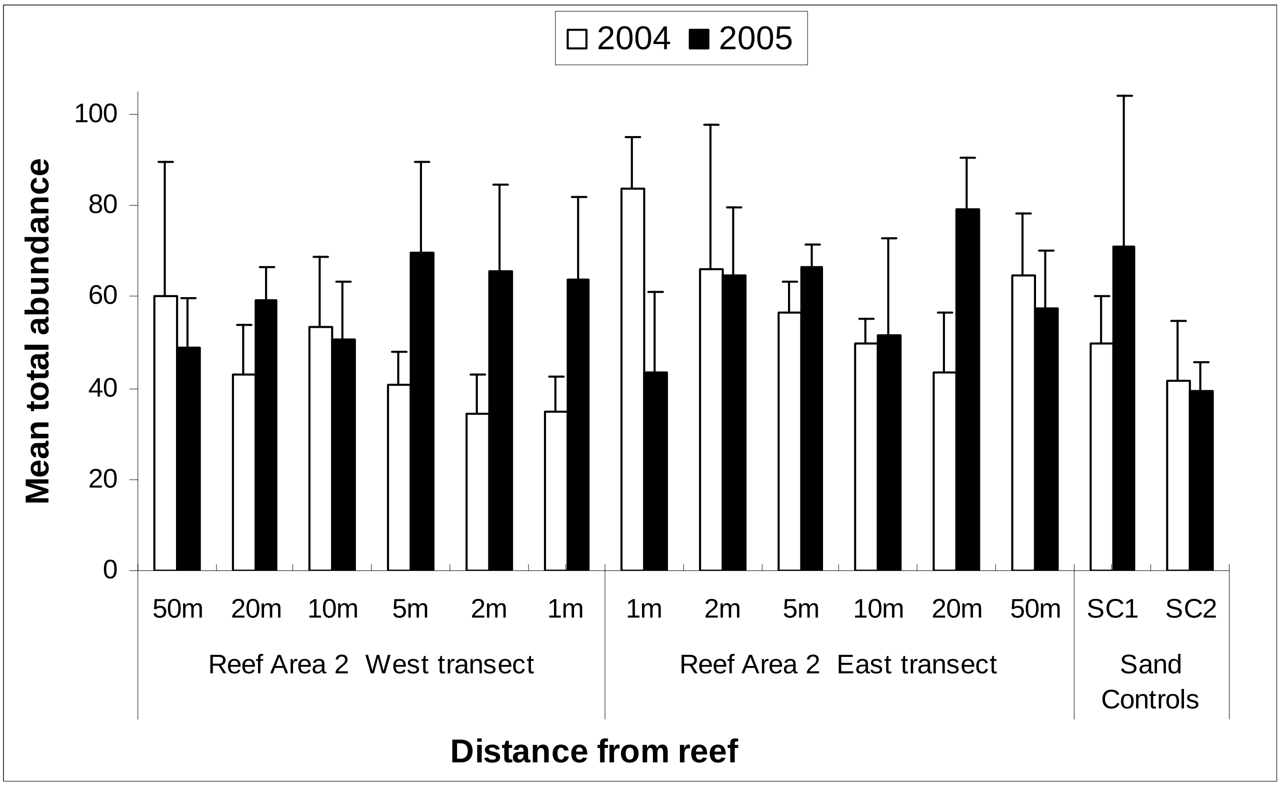

Figure 19. **Values of mean total abundance recorded from Reef Area 2, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

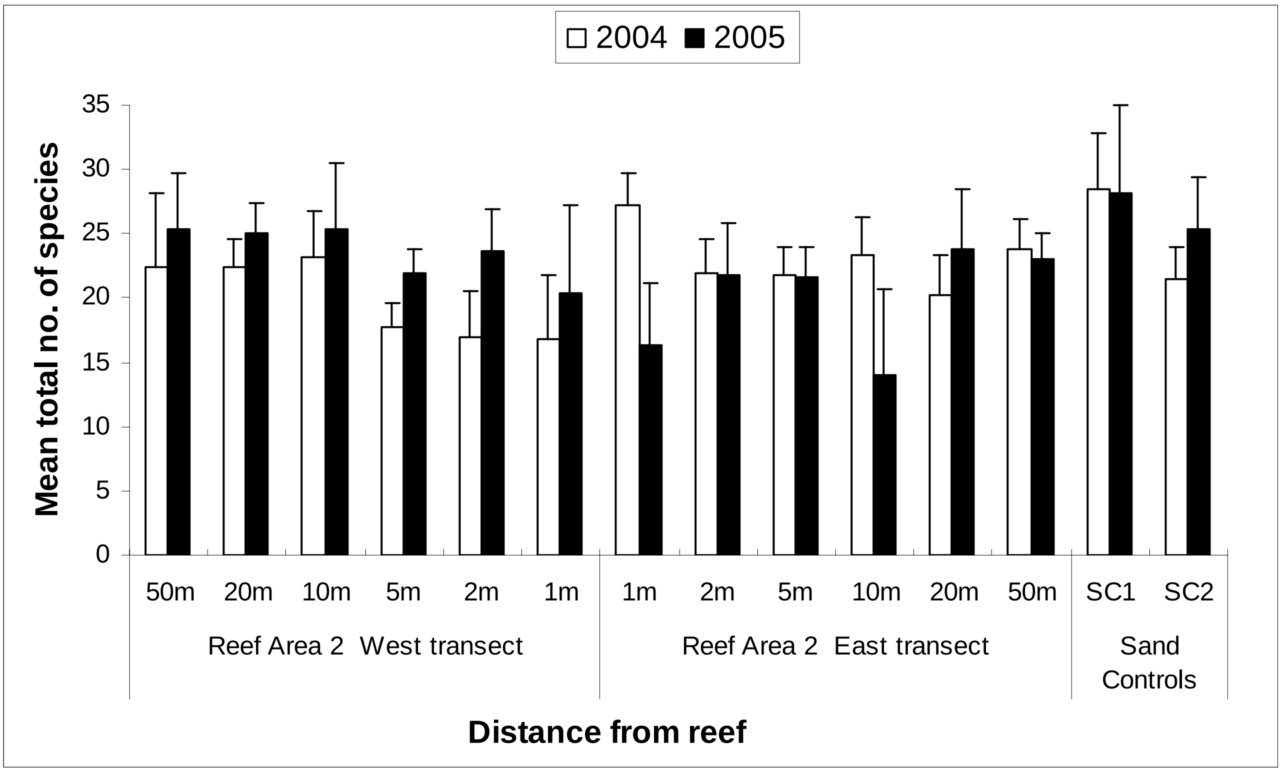

Figure 20. **Values of mean total number of species recorded from Reef Area 2, Sand Control 1 and Sand Control 2, during the pre-deployment and post-deployment sessions. Error bars represent +1 SD.**

Figure 21. **Photograph of the seabed and the artificial reef at Reef Area 2 showing accumulations of detached Posidonia oceanica rhizomes and leaf litter in the proximity of the reef. The photograph was taken in May 2005, eight months after deployment.**

Figure 22. Photograph of the seabed and the artificial reef at Reef Area 2, showing hollows in the soft sediment (arrows) produced by scouring and collapse of some of the units. The photograph was taken in May 2005, eight months after deployment.

The one-factor ANOVA indicated that there were no significant differences in total abundance and total number of species at SC1 and SC2 between the pre-deployment (2004) session and the post-deployment (2005) session

The three-factor ANOVA indicated that there were no significant differences in total abundance and total number of species for the factor 'Time' at Reef Area 1 and Reef Area 2 between the pre- and post deployment sessions.

The results of the multivariate analyses indicated differences in the benthic assemblages at Reef Area 1 and Reef Area 2 between the pre-deployment (2004) session and the post-deployment (2005) sessions. The results of the SIMPER analysis showed that the polychaete *Aricidea* sp. A contributed most to these differences; other species that contributed to these differences included the polychaetes *Aricidea* sp. B, Sabellidae sp. A, and Cirratulidae sp. A, and the amphipod *Bathyporeia* sp. Closer examination of abundance data for these species indicated differences in their pattern of abundance along the transects at Reef Area 1 and Reef Area 2; a higher mean total abundance of *Aricidea* sp. A was recorded during the post-deployment session at Reef Area 1. Furthermore, this species contributed to differences between stations along the same transects; the mean abundance of this species decreased with distance from the reef, as did that of *Aricidea* sp. B, Sabellidae sp. A and Cirratulidae sp. On the other hand, abundance values of the amphipod *Bathyporeia* sp. A increased with distance from the reef. In the case of Reef Area 2, stations closest to the reef had lower values of mean total abundance of *Aricidea* sp. A, *Urothoe* sp. B, *Aricidea* sp. B, and *Urothoe* sp. A, compared with the rest of the stations. Overall, values of mean total abundance of these four species increased with distance from the reef.

The results of multivariate analyses also showed some differences in the benthic assemblages at SC1 between the pre-deployment (2004) session and the post-deployment (2005) session, but not for SC2 for the same (before-after) comparison. The SIMPER analysis indicated that the crustacean *Gammarella fucicola* and the polychaetes Syllidae sp. B and Syllidae sp. F were recorded from SC1 during the post-deployment session only, but were completely absent from the pre-deployment samples, hence accounting for the observed differences at this study site between the pre- and post-deployment sessions. Moreover, there was a large increase in the abundance of the sipunculan *Aspidosiphon muelleri* at SC1 in the post-deployment session.

3.1.2.3 Additional observations

Detached *Posidonia oceanica* rhizomes and leaf litter was observed at both Reef Area 1 and Reef Area 2 during the post-deployment fieldwork (Figure 21). At Reef Area 1, the seagrass litter was present in small amounts at a single station (the 5m station on the eastern transect). At Reef Area 2, several stations, notably those in the vicinity of the reef, had considerable amounts of detached seagrass rhizomes and leaf litter.

Scouring of sediment was observed in the immediate vicinity of the two artificial reefs such that hollows in the sand were clearly visible, while some of the reef units had collapsed (Figure 22).

3.1 Fish fauna

Adults of species such as *C. chromis* and *S. cabrilla*, which may be classified as 'permanent residents' of rocky bottom habitats, were observed in the vicinity of the artificial reefs following deployment. Such species were recorded during each post-deployment session at all four artificial reef sites. Furthermore, juveniles of these two species were recorded from the artificial reef sites, as were juveniles of the Dusky Grouper *Epinephelus guaza*. Serranids and labrids were recorded frequently during censuses at the artificial reef sites, however, no scorpaenids or carangids were recorded. The Pomacentridae (damselfishes) were very abundant on all artificial reefs. Some adult fish species were noted to take refuge in the spaces and holes present within the artificial reef structures. Furthermore, some species, for example, *Murena helena*, *Epinephelus* spp., *S. cabrilla*, and *A. imberbis*, were recorded from the same spot within a specific reef during consecutive survey sessions. Based on body size characteristics, it is highly probable that the same individuals were being recorded on different occasions. Individuals of the Mediterranean Moray Eel *M. helena* were recorded on the artificial reef at reef area 3, while a large (total length ca 50cm) individual of the White Grouper *Epinephelus aeneus* was also observed more than once in the vicinity of the artificial reef at reef area 4.

Some species demonstrated a distinct pattern of occurrence on the artificial reefs. For example, individuals of the most abundant species, *C. chromis*, were always observed outside the reef crevices and on the upper parts of the artificial reefs. However, juveniles of the same species were recorded seeking refuge inside the spaces and holes within the reef structure. *C. julis* and *M. surmuletus* were usually observed in shoals on the upper sides of the reef blocks. *Gobius cruentatus* was always recorded underneath the lower reef subunits, seeking refuge inside crevices formed between the subunits and the sand. On the other hand, *G. bucchichi* was always recorded at distances of 10cm and more away from the reef blocks.

Excluding fry (which amounted to around 198,000 individuals, i.e. 91.15% of the total number of fish recorded), a total of 19,225 live individuals, comprising 27 species from 16 families, were recorded during the study. Twelve species were recorded during the pre-deployment session, compared to 19 species recorded in the post-deployment session. Mean values of total species richness and abundance recorded from the eight study sites in the pre- and post-deployment sessions (values for spring and summer are combined) are shown respectively in Figures 23 and 24. Overall, values of mean species richness and total abundance recorded during the post-deployment sessions were higher (Figures 23 and 24). The most abundant species was the goby *Gobius bucchichi*, which was recorded both pre- and post-deployment (Figure 25).

Fry comprised the bulk of the fish populations recorded during the study (Figure 26). This was particularly true at RA4 (concrete reef) where values of mean abundance exceeded 19,000 individuals per transect.

Values of the Shannon-Wiener diversity index calculated for the eight sites for the pre- and post-deployment sessions and in the two different seasons are shown in Figure 27.

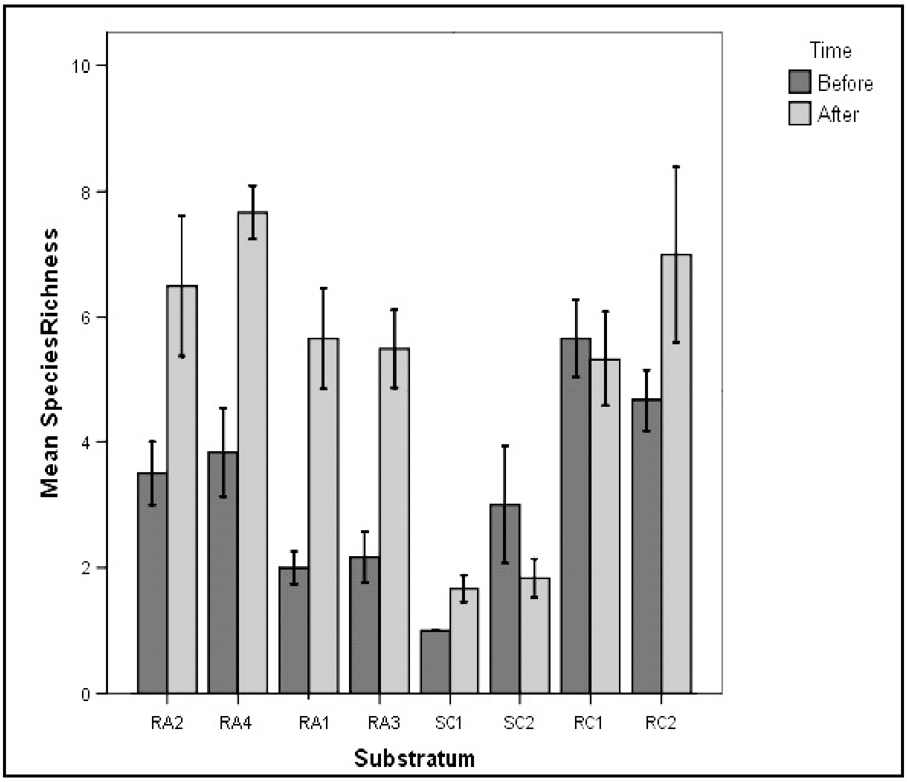

Figure 23. **Values of mean species richness recorded from the eight study sites during the pre-deployment ('before') and post-deployment ('after') sessions. Error bars represent ±1 SD.**

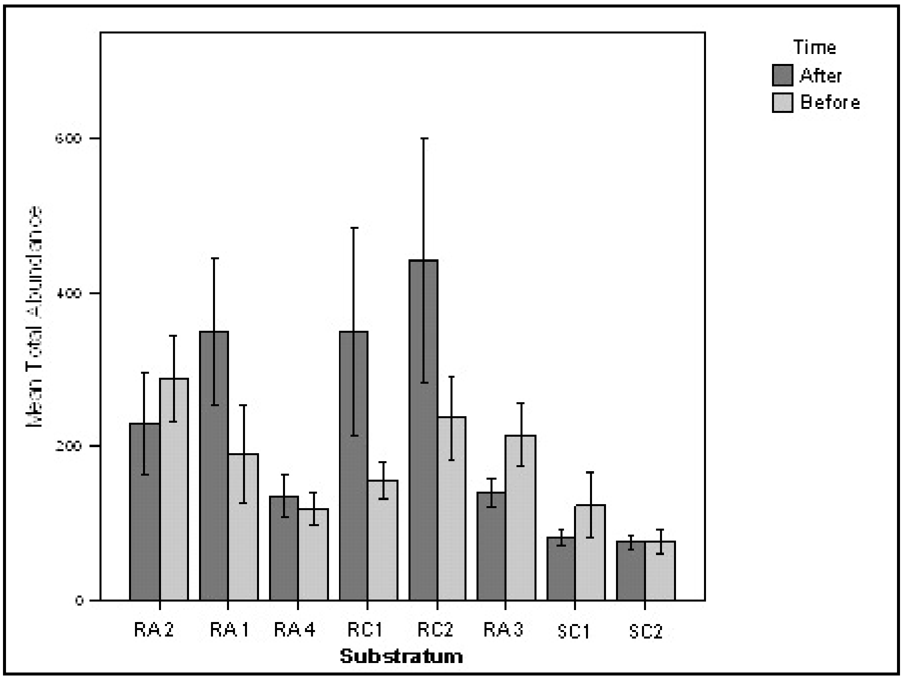

Figure 24. Values of mean total abundance recorded from the eight study sites during the pre-deployment ('before') and post-deployment ('after') sessions. Error bars represent ±1 SD.

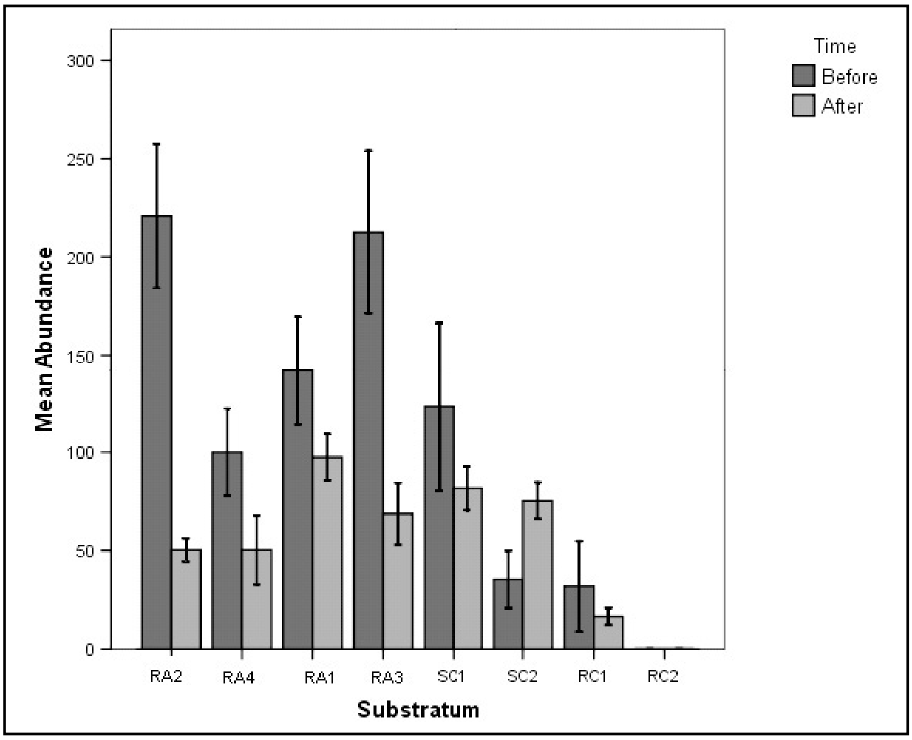

Figure 25. Values of mean total abundance of the goby *Gobius bucchichi* recorded from the eight study sites during the pre-deployment ('before') and post-deployment ('after') sessions. Error bars represent ±1 SD.

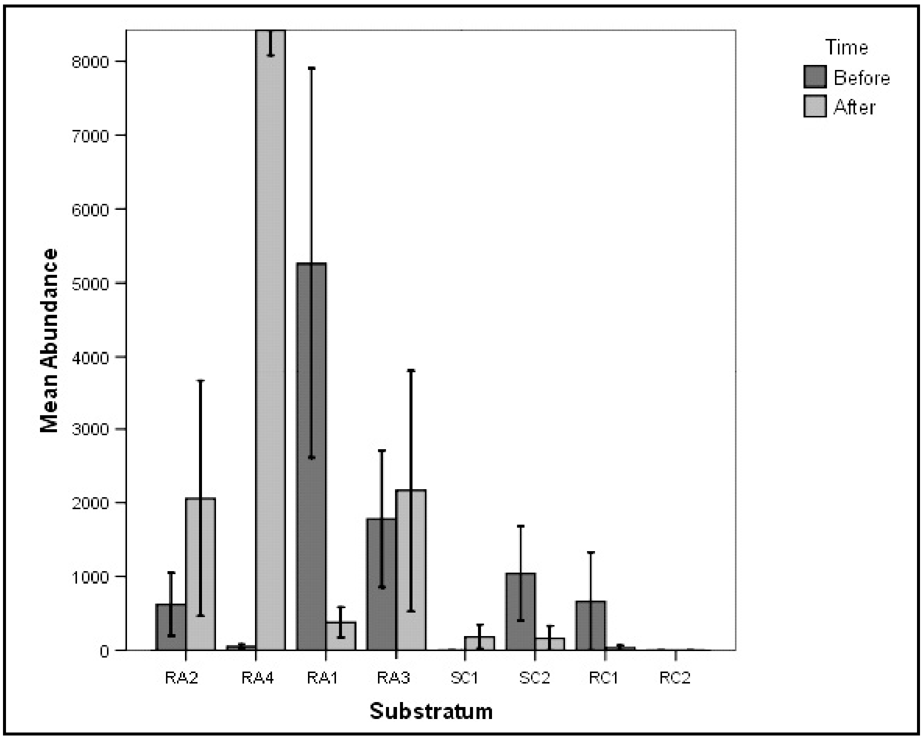

Figure 26. **Values of mean total abundance of fry recorded from the eight study sites during the pre-deployment ('before') and post-deployment ('after') sessions. The value of mean total abundance recorded at RA4 during the post-deployment session is truncated; the actual value is 19,167 individuals/320m^2. Error bars represent ±1 SD.**

The results of the ANOVA indicated that species richness was significantly higher during the post-deployment sessions compared to the pre-deployment sessions at all artificial reef sites; the highest mean value was recorded from the replicate concrete reef (RA4). No significant differences in species richness were recorded from the sand and rock control sites between the pre- and post-deployment sessions. Overall, values of species richness recorded from the various reef sites were similar. ANOVA indicated a significantly lower species richness at the sand control sites compared to the artificial reef sites and the rock control sites. A higher total abundance was recorded at the artificial reef sites during the post-deployment sessions compared to the pre-deployment values; however, the results of ANOVA did not indicate that this difference was significant, except in the case of the Globigerina artificial reef (RA1) for which total abundance was significantly higher during the post-deployment summer survey. Significant differences in total abundance were also recorded from the rock control sites during the post-deployment sessions (spring and summer), compared with the pre-deployment sessions.

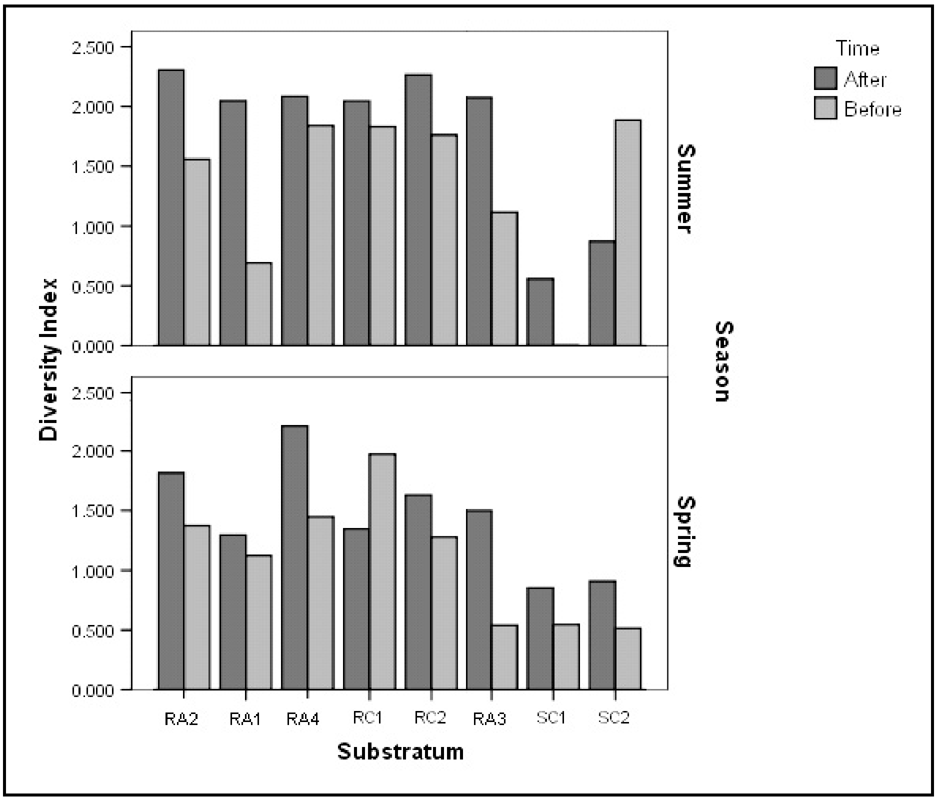

Figure 27. **Values of the Shannon-Wiener diversity index recorded from the pre-deployment ('before') and post-deployment ('after') sessions.**

Total abundance of *G. bucchichi* recorded during the pre-deployment survey was significantly higher at the concrete artificial reef sites and at the Globigerina control reef sites compared to the sand control sites. Total abundance values of this species were not significantly different between the concrete artificial reef sites and Globigerina control reef sites during the pre-deployment survey, while a significant difference in this attribute was recorded during the same session between the sand control sites and the artificial reef sites. ANOVA also indicated a significant decrease in the abundance of *G. bucchichi* at the artificial reef sites following deployment. On the other hand, the abundance of this species increased significantly at one of the sand control sites (SC2) during the post-deployment session.

Overall, the results of multivariate analyses (NDMS and cluster analysis) indicated separation of samples by habitat type and season, indicating that the fish assemblage structure was influenced by these two factors. Cluster analysis indicated separation of samples into two large clusters, which represented distinct fish assemblages occurring at: (i) the sand control and artificial reefs sites (for samples collected during the pre-deployment survey only); and (ii) the rock control sites (for samples collected during both pre- and post-deployment sessions) and the artificial reef sites (for samples collected during post-deployment session only).

The results of SIMPER analysis indicated that the species *Gobius bucchichi* contributed most to the similarity between the soft sediment sampling sites, while the damselfish *Chromis chromis* contributed most to the similarity between the hard substratum sampling sites. The results of SIMPER analysis also showed that *C. chromis* and *Coris julis* were the species that contributed most to the similarity between the rock control sites. The two species that contributed most to the similarity between samples collected from the two rock control sites and the artificial reef sites during the pre- and post-deployment surveys were *C. julis* and *Gobius bucchichi*.

4. DISCUSSION

4.1 Sediment and sediment biota study

The benthic biotic assemblages recorded from the sites surveyed during the sediment and sediment biota study component consisted of a ‘bare sand’ assemblage that is typical of the lower infralittoral and upper circalittoral off the northeastern coast of the Maltese islands at the recorded depths (Borg *et al*., 1998). Such an assemblage type is characterised by an impoverished epifauna, and two typical megafaunal species: the anemone *Condylactis aurantiaca* and the sea urchin *Spatangus purpureus*. On the other hand, such assemblage types are known to support a rich infauna consisting of species that are typical of lower infralittoral and upper circalittoral muddy sand assemblages, which include numerous polychaetes, crustaceans, molluscs and echinoderms (Borg *et al*., 1998).

Overall, the results of univariate and multivariate analyses of data on the sediment and sediment biota collected during the pre-deployment session indicate some differences in the physical and biological characteristics between Reef Area 1, Reef Area 2, Sand Control 1 and Sand Control 2. While the sediment characterising the site at Reef Area 1 consisted primarily of fine sand (generally classified as ‘slightly gravelly muddy sand’) and very low values of percentage organic carbon content, the sediment at Reef Area 2 varied between fine sand and coarser sand. At Reef Area 2, stations having coarser sediment had lower values of percentage organic carbon compared to Reef Area 1. The higher proportion of fine sand and organic carbon recorded from the seabed at Reef Area 1 is indicative of a low-energy environment, while the bottom at Reef Area 2, with its higher proportion of coarse sediment and lower amount of organic content, appears to be located in a higher energy environment, probably resulting from the presence of strong currents. The sediment at the sand control sites was classified as ‘slightly gravelly muddy sand’; however, values of mean sediment grain size and percentage organic carbon content were lower than values recorded at Reef Area 1, which seems to indicate that the former sites are also located in high-energy environments, as in the case of Reef Area 2. Of the two sand control sites, Sand Control 2 had lower values of sediment grain size and organic carbon.

The results of univariate analysis of data from the pre-deployment sessions indicated significant differences in mean total abundance and mean total number of species between Reef Area 1, Reef Area 2, Sand Control 1 and Sand Control 2. Given the results of the analyses of the physico-chemical attributes of the sediments, these findings are expected since soft sediment benthic macrofaunal assemblages respond to differences in sediment characteristics, such as grain-size, which is considered to be one to the most important factors influencing such benthic assemblage types (Gray, 1981). Sediment-related variables, such as sediment grain-size distribution, vary in time and space. Such variations may in turn contribute to spatial variability in the biological attributes of infaunal assemblages (Bishop, 2005). Polychaetes belonging to the families Syllidae and Dorvillidae, together with the cephalochordate *Branchiostoma lanceolatum* were present only at the ‘coarse sediment’ stations at Reef Area 2, while they were nearly completely absent from Reef Area 1 and the ‘fine sediment’ stations at Reef Area 2. Syllid and dorvillid polychaetes have a preference for gravel and shell fragments (Fauvel, 1969), while *Branchiostoma lanceolatum* also prefers coarse sediments (Degraer *et al*., 2006). This probably accounts for the presence of these species only at Reef Area 2, which was characterised by coarse sediments. Spatial heterogeneity in the physico-chemical characteristics of sediments at Reef Area 2 is also probably responsible for the variation in the structure of benthic assemblages recorded between this site and the two sand controls, as indicated by the results of the multivariate analyses. This same observation also applies the two Sand Controls 1 and 2 which had different mean sediment grain size characteristics that seem to have resulted in differences in the structure of benthic assemblages between the two sites. For example, the amphipod Aoridae sp. A and the polychaete Dorvillidae sp. A were present, albeit in low abundance, in the Sand Control 2 samples, but were not recorded from the Sand Control 1. We deem this to possibly result from preference of these two species for relatively fine sandy bottoms.

The results of the univariate analyses also indicated an alteration of sediment grain size characteristics at some stations following deployment of the reef structures; along the West Transect of Reef Area 1, mean sediment grain size decreased at stations located closest to the reef, while it increased at stations located distantly from the reef. The same was observed at Reef Area 2; stations there located close to the reef had significantly coarser sediment compared to stations located at a distance from the reef. It appears that bottom currents are likely to be responsible for the alteration of mean sediment grain size recorded in the immediate vicinity of both artificial reefs. The presence of the artificial structures may have caused a localised change in the bottom current regime that led to scouring of the sediment in their immediate vicinity, leading to transport of the finer sediment fraction and deposition at stations located distantly from the reef. Localised loss of fine sediment in the immediate vicinity of the reef would contribute to a prevalence of coarse sediments there, as has been observed in the present study. The effects of scouring in the vicinity of the artificial reefs were well visible, since scour troughs developed at both reef edges, while these probably also contributed to subsidence and subsequent collapse of some of the reef units. The sediments in the immediate vicinity of the artificial reefs may also have become coarser due to the addition of shell fragments and other calcareous remains from the organisms colonising the reef; within a relatively short period of six months from deployment of the reefs, substantial colonisation of the reef units by sessile biota, especially by calcareous organisms that are very fragile and which can break off easily, had occurred. However, changes in mean sediment grain size were also noted for one of the sand control sites following deployment of the artificial reefs; a significantly lower mean sediment grain size (in term of Phi values), hence significantly coarser sediment, was recorded from Sand Control 1. Such a change probably resulted from natural factors.

Following deployment of the artificial reefs, values of mean percentage organic carbon content of the sediment at Reef Area 1 increased, albeit not significantly, for all stations, except those located furthest from the reef along the East Transect. The observed increase in sediment organic carbon may have resulted from organic input originating from reef-associated organisms. Such a notion is corroborated by the observed progressive decrease in values of organic carbon content with increasing distance from the reef at both Reef Area 1 and Reef Area 2. Furthermore, it appears that accumulations of detached shoots and leaf litter of *Posidonia oceanica* present in the vicinity of Reef Area 2 contributed to organic enrichment of the sediments in the vicinity the reef. The results of univariate analyses indicated that values of percentage organic carbon content of the sediment at the two sand control sites did not differ significantly between the preand post-deployment sampling sessions. Therefore, the increased content of organic carbon in the sediments in the vicinity of the reefs may be attributed to enrichment by organic matter originating from the biota that colonised the reefs and, where present, from accumulations of detached seagrass rhizomes and leaf litter.

Benthic macrofaunal assemblages are influenced by the physical characteristics of the sediment in which they live. Since changes in both the mean sediment grain-size and organic carbon content of the sediment were recorded during the post-deployment session, a corresponding change in the structure of benthic assemblages would be expected. The results from the present study indicate that the benthic assemblage structure at Reef Area 1 differed between the pre-deployment and post-deployment sessions; an overall increase in values of mean total abundance and mean total number of species was recorded during the post-deployment session from stations located along the two transects. This increase may be attributed to the observed increase in organic carbon content of the sediment, and decrease in mean sediment grain size, recorded during the post-deployment survey. As the sediment became finer and richer in organic material, the habitat favoured species that prefer these conditions, such as the polychaete *Aricidea* sp. A. On other hand, data from the present study also indicate localised effects of the reef on the sediment and biota present in the immediate vicinity (1-2m) of the artificial structure. For example, at Reef Area 1, an 'infaunal halo' of decreasing abundance with increasing distance from the reef is apparent for the polychaetes *Aricidea* sp. A, *Aricidea* sp. B, Sabellidae sp. A and Cirratulidae sp. A. Conversely, for the amphipod *Bathyporeia* sp., an 'infaunal halo' of increasing abundance with distance from the reef is apparent. *Bathyporeia* sp. prefers fine sand (Ruffo, 1989), therefore, the coarser sediment recorded near the reef during the post-deployment survey probably resulted in a less suitable habitat for this species. On the other hand, this cannot be generalised to other species; for example, although the polychaetes *Aricidea* spp. also prefer fine sand (Guzman-Alvis and Diaz, 1996), and hence were expected to be less abundant closer to the reef, the results indicated increased abundance values for these species. This suggests that the infauna are responding to more than simple changes in sediment characteristics caused by the reef, and most likely to a multitude of interacting factors. Increased turbulence near the reefs might have increased the density and type of suspended particles that serve as food for suspension feeders. Alternatively, the abundance of the polychaetes may have increased due to an increase in the organic content of sediments. For other species, such as the amphipod *Dexamine spinosa*, no particular trend of change in abundance with distance from the reef was evident, however, elevated values of abundance were noted at stations where detached *P. oceanica* rhizomes and leaf litter was present. *D. spinosa* is well known for its association with seagrass material (Gallmetzer et al., 2005).

Overall, similar results to those observed for Reef Area 1 were noted for Reef Area 2. The benthic assemblage structure recorded during the post-deployment survey at Reef Area 2 was different when compared to that recorded during the pre-deployment survey, as was evident from the results of the multivariate analysis. A significant decrease in values of total abundance and total number of species was recorded between the 1m station along the East Transect and the other stations. The decreased total abundance and species richness at this station probably resulted from the change to coarser sediment that occurred there. Multivariate analysis also grouped samples from the 1m station along the West Transect separately from the rest of the stations, but also separately from the 1m station on the East Transect, showing that the benthic assemblages found at these two stations were different from each other. While the amphipod *Dexamine spinosa* was absent from the 1m station on the East Transect, the highest abundance for this amphipod was recorded at the 1m station on the West Transect, where accumulations of detached *P. oceanica* shoots and leaf litter was present. The source of the seagrass litter at the two Reef Areas could either be meadows of the seagrass present in the area between the shore and the artificial reefs, or banquettes removed from beaches during beach cleaning operations, which were dumped offshore in the vicinity of the study area[9]. *P. oceanica* litter may have then accumulated near the reefs, mostly at Reef Area 2, as a result of a reduction in current velocities around the reef edges (Wilding, 2005). Low abundance values were recorded for the polychaetes *Aricidea* sp. A and *Aricidea* sp. B, and the amphipods *Urothoe* sp. A and *Urothoe* sp. B, in the immediate vicinity of the reef at Reef Area 2, while there was an increase in the abundance of these species with increasing distance from the reef. The reduction in abundance in the immediate vicinity of the reef may have resulted from foraging by reef-associated predators, or to changes in habitat characteristics near the reef, such as those involving alterations to the physico-chemical characteristics of the sediments as described above, rendering the habitat less suitable for the species.

The results of both univariate and multivariate analyses indicated that there was no change in the benthic assemblage structure at the Sand Control 2 following deployment of the reef modules. On the other hand, changes in the physico-chemical attributes (namely the change to coarser sediment) of the seabed at Sand Control 1 appear to have resulted in an increased mean total abundance of benthic macrofauna at this site. For example, an increased abundance of some amphipod species, namely *Ceradocus semiserratus* and *Gammarella fucicola*, was recorded from this site during the post-deployment session, while the species Syllidae sp. F, *Gammarella fucicola* and Syllidae sp. B were recorded from the same site during the pre-deployment session but were completely absent from samples collected during the post-deployment session.

An unexpected finding was the opposed trend of abundance of *Aricidea* sp. between Reef Area 1 and Reef Area 2; while at Reef Area 1 the abundance of this polychaete was higher close to the reef, an 'infaunal halo' of increasing abundance with distance from the reef was recorded for the same species at Reef Area 2. Changes in the physical characteristics of the sediments, along with higher predation in the vicinity of the reef may have been contributed to the observed 'infaunal halo' effect at Reef Area 2. However, the change in granulometric characteristics of the sediments recorded in the vicinity of Reef Area 1 does not explain the increase in abundance of *Aricidea* sp. A there, nor does higher predation. It would therefore seem that some of the findings from the present study cannot be attributed to one or few factors, but possibly to a multitude of interlinked factors, leading to potentially different situations in space and time.

The results of similar studies on the impacts of artificial reefs on soft sediment benthic assemblages carried out elsewhere indicated that the structure of soft sediment macrofaunal assemblages was, in most cases, influenced by the proximity of the sampling stations to the reefs (e.g. Barros *et al*., 2001), while the scale of the impact of artificial reefs on the biota was limited to a small area near the reef (Ambrose and Anderson, 1990; Nelson *et al*., 1994). Such findings are similar to those of the present study. On the other hand, some workers noted that the impact extended several tens of metres from the reef (e.g. Davis *et al*., 1982; Posey and Ambrose, 1994). Changes to the infaunal assemblage structure were attributed to physical (Ambrose and Anderson, 1990; Fabi *et al*., 2002) or biological factors (e.g. predation; Posey and Ambrose, 1994; Langlois *et al*., 2005), or to a combination of several factors acting together.

Soft sediment habitats are often considered to be biotically impoverished, hence the name 'bare sand'. Such habitats are not considered to be 'structured' and are assumed to be inhospitable to most epifaunal organisms due to the relatively unstable substratum. However, while this may

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[9] Such dumping was observed during a field session.

hold true for the epifauna, ‘bare sand’ habitats support a diverse infauna which sustain key ecosystem services (Snelgrove, 1999). From this study, a total of 16,439 individuals comprising 216 species were recorded from two sampling sessions. This indicates an infaunal density exceeding 67,000 individuals per m^3 of sediment (considering the first 12 cm layer of sediment only) and strengthens the notion that ‘bare sand’ habitats are not impoverished with respect to the infauna, while they also contribute to a high biomass, which in turn can support fauna at higher trophic levels, including many species of fish and invertebrates.

4.2 Fish fauna

The goby *Gobius bucchichi* was the most abundant fish recorded from the soft sediment seabed in the study area. The second most abundant fish, *Mullus surmuletus*, recorded from the study area had very high densities during the summer pre-deployment session, but no individuals of this species were recorded during subsequent sessions. Other fish species that were noted to be characteristic of the soft bottom habitat in the study area included *Echiichthys vipera*, *Xyrichthys novacula*, *Trigloporus lastoviza*, and *Dasyatis pastinica*. However, the occurrence of these species was rather sporadic.

The occurrence of certain species on the reef such as *C. chromis* and *S. cabrilla*, which may be classified as ‘permanent residents’, together with juveniles of these two species and of the Dusky Grouper *Epinephelus guaza* indicate that, after less than a year, the artificial reefs were potentially being used as recruitment and nursery sites by such species. Furthermore, several species recorded from the artificial reefs are of high economic importance, namely species belonging to the family Serranidae. In the Mediterranean Sea, serranids and other commercially important fishes, such as some Sparidae, Labridae, Scorpaenidae, Carangidae, and Scombridae, are amongst the most frequent colonisers of artificial reefs (Santos *et al.*, 1997). The Pomacentridae (Damselfishes) appeared to be the most abundant fishes on all artificial reefs, indicating their high thigmotactic behaviour, which led to rapid colonisation of the reef units. The recurrence of adult fish of *Murena helena*, *Epinephelus* spp., *S. cabrilla*, and *A. imberbis* in crevices and holes within the artificial reefs indicate that such species were using the structures as a permanent habitat.

Values of the Shannon-Wiener diversity index recorded from the bare sand habitat were rather low. The more structurally complex a habitat is, the more different species of fish it can support, and therefore the higher the diversity (Gratwicke and Speight, 2005). Bare sand habitats have a relatively low above-ground structural complexity compared to, for example, vegetated habitats and to natural reefs, which have a complex surface topography; as a result bare sand supports a relatively low species richness and abundance of fish fauna. This was reflected in the results obtained from the multivariate analysis. As expected, low species diversity values were recorded from the artificial reef sites during the pre-deployment survey. However, once the artificial reefs were deployed, higher values of species diversity were recorded at the reef sites within a relatively short time, while values of the same attribute remained unchanged at the sand control sites, indicating that this effect had only occurred in the vicinity of the reefs.

The rock control sites (RC1 and RC2) were characterized by species that are typical of rocky habitats, such as *Chromis chromis*, *Serranus cabrilla* and *Coris julis*, and by other less abundant species but which again are typical of rocky habitats, such as *Apogon imberbis*, *Symphodus* spp., and *Parablennius rouxi*. Due to the particular physical characteristics of one of the rock control stations (RC1: which comprised a small patch of rock rubble on sand), some species that are more typical of bare sandy habitat, for example *G. bucchichi*, were recorded there. This resulted in *G. bucchichi* being one of the species that contributed significantly to the similarity between the rock control sites and the artificial reef sites. Values of species richness and Shannon-Wiener diversity were always relatively high at the two rock control sites during both pre- and post-deployment sessions, but lower values were recorded from RC2 during the spring sampling session. Compared with bare sand substrata, natural reefs comprise habitats that have a high structural complexity and provide shelter and food for several fish species, which explains the higher values of species diversity recorded at the rock control sites. One of the principal aims of the study was to determine to what extent the artificial reefs mimic natural rocky reefs and which fish assemblages will become associated with the artificial reefs. Observations from the present study indicate that a number of species which are usually associated with natural reefs, but which are rare or completely absent from bare sandy bottoms, were recorded at the artificial reef sites during the post-deployment session. This in itself indicates habitat similarities between the artificial structures and natural reefs.

The results indicate that the number of species increased at all artificial reef sites following deployment. Values of species richness increased from a maximum of 13 recorded during the pre-deployment survey to over 20 recorded during the post-deployment survey. This increase in species richness at the artificial reef sites was concomitant with an increase in values of Shannon-Wiener diversity. The recorded values of species richness were similar between different substrata during the pre-deployment surveys; the only significant difference in this attribute was recorded between the Globigerina control reef sites (RA1 & RA3) and the rock control sites (RC1 and RC2). Values of this attribute recorded during the post-deployment surveys were similar between different sites characterised by hard substrata, whether natural or artificial. On the other hand, values of species richness recorded from the sand control sites (SC1 and SC2) were lower and significantly different from those recorded from the artificial reef and natural reef sites.

Fry were very abundant during some of the sampling sessions, with a high variability in abundance and occurrence between different sessions. Fish abundance at the artificial reefs was higher than at the sand control sites, but slightly lower than at the rock controls. Overall, a higher total fish abundance was recorded during the post-deployment sessions, compared to values recorded during the pre-deployment sessions, however, the difference was not significant. When considering the individual artificial reef sites, no trend in the effects of the structures on the total abundance for the respective site was noted. The only significantly higher values of total abundance were recorded at the Globigerina artificial reefs (RA1 & RA 3) during summer; for these, abundance values recorded during the summer post-deployment session were some of the highest recorded. The most notable decrease in the abundance of the sand dwelling goby *G. bucchichi* was recorded in the first 20m of seabed in the vicinity of the artificial reefs. This may have resulted from predation by reef-associating predator species, such as the grouper *Epinephelus* spp., which may be feeding on the sand-associated species present in the vicinity of the artificial reef. The decrease may also have resulted from changes to the hydrodynamic regime and granulometric characteristics of sediments, hence alteration of habitat characteristics, in the vicinity of the artificial reefs. Despite the observed decrease, the abundance of *G. bucchichi* recorded in the vicinity of the artificial reef stations was, overall, not very different from that recorded at the sand control sites. Following deployment of the artificial reefs, a significant increase in total fish abundance and species richness was recorded from the rock controls in summer, and a slight non-significant decrease in spring. However, this increase in fish abundance cannot be attributed to deployment of the artificial reefs, given the large distance between these and the rock controls.

Numerous adult fish were recorded in the vicinity of artificial reefs. These had a body size which indicated recruitment from nearby areas, as has been noted by other workers (e.g. Froese and Pauly, 2006). Therefore, although the artificial reefs were potentially serving as nursery areas and contributing to production, as indicated by the numerous shoals of fry that were recorded in their vicinity, they were also attracting fish from similar habitat types located elsewhere.

Overall, no significant trend in values of abundance and species richness was detected that would indicate different influences of the two artificial reef materials (i.e. concrete versus Globigerina) on these attributes.

The results obtained indicated a significantly higher species richness and total abundance during summer, compared to values of these attributes recorded in spring. Such seasonal differences are expected. On the other hand, no significant seasonal differences in species richness and total abundance were recorded for the bare sand controls.

5. GENERAL CONCLUSIONS

The placement of artificial structures on soft sediment bottoms is often considered to enhance what is otherwise regarded to be an ‘impoverished habitat’, at least in terms of epifauna, because of the provision of a habitat for “desirable” species (Davis *et al*., 1982). However, several studies have shown that such structures do have effects on the surrounding sediments and associated benthic assemblages. Therefore, any decisions to construct artificial reefs should consider possible effects on the biota of the seabed on which they are placed.

Both reef structures at Reef Area 1 (CR) and Reef Area 2 (AR) had an influence on the adjacent benthic biotic assemblages; however, this impact was localised to the area in the immediate vicinity of the reefs. The recorded impacts were not the same at the two reefs, but this could not be attributed to the type of material used to construct the reefs but rather to some differences in the physico-chemical characteristics of the seabed between the reef sites. A significant change in the benthic assemblage structure was also detected during the post-deployment sessions at one of the sand controls, indicating natural spatial and temporal variations in physico-chemical and biological characteristics of the marine environment in the general area.

The fish fauna inhabiting the sandy bottom in the area where the artificial reefs were deployed was significantly affected by the presence of the reefs. The observed change mainly consisted of a decrease in the abundance of the sand-dwelling goby *G. bucchichi*, which would seem to indicate a negative influence by the reefs on the fish fauna living on the sandy bottom, at least in the immediate vicinity of the reef structures. On the other hand, increased values of species richness and abundance for fish that are typical of rocky bottom habitats were recorded in the vicinity of the artificial reefs during the post-deployment sessions. An increase in total fish abundance was also recorded at the rock control sites during the post-deployment survey. However, this change is not likely to be related to the deployment of the artificial reefs, given the considerable distance between the reef sites and the rock control sites. Such a change is deemed to have resulted from natural temporal changes.

The pattern of colonisation of the artificial reefs constructed using the two different materials (Globigerina concrete and native Globigerina rock) was similar, while values of species richness and abundance of fish fauna were also similar between the two reef types, hence indicating that the type of material used to construct artificial reefs does not have an influence on colonisation by fishes.

Large changes to the structural integrity of the artificial reef at Reef Area 4 may have resulted in the observed lower species diversity recorded during the summer post-deployment session at that site, compared to values of this attribute recorded from the other three artificial reef sites. However, further studies are required to confirm the validity of this notion.

While the results from the present study give an indication of the ecological processes occurring at the artificial reefs, these findings should be considered as preliminary, especially since the period over which the investigations were made is somewhat short. Future studies, undertaken after several years have elapsed since deployment, should give a better indication of the ecological process operating at the reef sites, since the ecosystem would have attained more stability. The present results also show that, if properly designed and managed, artificial reefs can potentially enhance production, at least in terms of the fish fauna, while also potentially serving as an attraction for SCUBA divers.

In conclusion, the results of the sediment and benthic biota study components indicate that:

- The Artificial Reefs had an influence on the benthic biotic assemblages and fish fauna associated with the soft sediment seabed in their vicinity. However, this influence was localised to the area in the immediate vicinity (circa 20 m) of the reefs. Some differences in the observed changes were noted for the different artificial reef sites, but these should not be attributed to the structures *per se*, but to natural spatial variation of physico-chemical features of the seabed in the study area.
- Observations made during the fish study component indicate that the artificial reefs attract fishes from rocky bottom habitats located at a distance from the reefs, while also potentially serving as nursery sites and to enhance production.
- There were no indications that the two different materials (Globigerina concrete and native Globigerina rock) used to construct the two different reef types had any effects on colonisation of the reefs by fish fauna. There were also no apparent differences in the influence of the two different reef types on the sediment and benthic assemblages in their vicinity.
- The artificial reefs were colonised by a high species diversity of fish, which included large fishes (e.g. groupers and moray eels) that may serve as an attraction for SCUBA divers.
- Changes to the structural integrity of the artificial reefs occurred within a relatively short time of deployment, however, these do not appear to have had large adverse effects on colonisation of the reefs by biota.
- Overall, artificial reefs such as those studied here appear to have the potential of serving as a habitat for a large variety of fish and other biota, but careful planning of aspects of their design, deployment and management are crucial for a successful positive outcome of any artificial reef programme.

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APPENDIX A

Classified species list of the macrofaunal species recorded from the sediment and benthic fauna study component.

ANTHOZOA
Edwardsia sp.

SIPUNCULA
Aspidosiphon muelleri
Sipuncula sp.

MOLLUSCA
Polyplacophora
Leptochiton africanus

Gastropoda
Bittium latreillii
Cerithidium submamillatum
Cylichna cylindracea
Mangelia smithii
Nassarius mutabilis
Ocinebrina (cf) *aciculata*
Parvioris anderswareni
Retusa sp.
Rhizorus acuminatus
Turbonilla sp.A
Turbonilla sp.B

Bivalvia
Abra alba
Abra prismatica
Arcopagia balaustina
Corbula gibba
Ctena decussata
Loripes lacteus
Lucinella divaricata
Lyonsia norwegica
Nuculana pella
Phaxas pellucidus
Pitar rudis
Solemya togata
Spisula subtruncata
Tellina balaustina
Tellina donacina
Timoclea ovata

Scaphopoda
Cadulus politus
Fustiaria rubescens

NEMERTEA
Nemertea sp.

POLYCHAETA
Ampharetidae sp.A
Ampharetidae sp.B
Aphroditidae sp.A
Aphroditidae sp.B
Aphroditidae sp.C
Aphroditidae sp.D
Aphroditidae sp.E
Arabella sp.
Aricidea sp.A
Aricidea sp.B
Capitellidae sp.A
Capitellidae sp.B
Capitellidae sp.C
Cirratulidae sp.A
Cirratulidae sp.B
Dorvillidae sp.A
Dorvillidae sp.B
Dorvillidae sp.C
Dorvillidae sp.D
Dorvillidae sp.E
Eunice sp.
Glycera sp.
Goniada sp.
Lumbrineridae sp.A
Lumbrineridae sp.B
Lumbrineridae sp.C
Lumbrineridae sp.D
Lysidice sp.
Magelona sp.
? Magelonidae sp.
Maldanidae sp.A
Maldanidae sp.B
Maldanidae sp.C
Marphysa sp.
Nematonereis unicornis
Nephtyidae sp.A
Nephtyidae sp.B
Nephtyidae sp.C
Nephtyidae sp.D
Nephtyidae sp.E
Nereis rava

Appendix A (continued)

Classified species list of the macrofaunal species recorded from the sediment and benthic fauna study component.

POLYCHAETA
Notomastus ? *latericeus*
Onuphiidae sp.A
Onuphiidae sp.B
Opheliidae sp.
Orbiniidae sp.
Paraonis sp.A
Paraonis sp.B
Phyllodocidae sp.A
Phyllodocidae sp.B
Phyllodocidae sp.C
Phyllodocidae sp.D
? Phyllodocidae sp.E
Piromis eruca
Poecilochaetidae sp.
Polychaeta sp.A
Polychaeta sp.B
Polyophthalmus sp.
Sabellidae sp.A
Sabellidae sp.B
Sabellidae sp.C
Sabellidae sp.D
Sabellidae sp.E
Sabellidae sp.F
Scalibregmidae sp.
Serpulidae sp.
Spionidae sp.A
Spionidae sp.B
Spionidae sp.C
Spionidae sp.D
? Spionidae sp.E
Sthenelais sp.
Syllidae sp.A
Syllidae sp.B
Syllidae sp.C
Syllidae sp.D
Syllidae sp.E
Syllidae sp.F
Syllidae sp.G
? Syllidae sp.H
Terebellidae sp.A
Terebellidae sp.B
Terebellidae sp.C
Terebellidae sp.D

CRUSTACEA
Decapoda
Anapagurus sp.
Cestopagurus sp.
Ebalia sp.
Galathea intermedia
Liocarcinus sp.
Liocarcinus sp.B
Pagurus sp.
Palicus caronii
Philoceras bispinosus
Processa sp.
Thalassinidae sp.

Leptostraca
Nebalia bipes

Mysidacea
Gastrosaccus sp.A
Gastrosaccus sp.B
Mysidacea sp.

Tanaidacea
Apseudes talpa
Leptochelia savignyi

Isopoda
Anthuridae sp.
Eurydice sp.
Gnathia sp.
Idotea balthica
Zenobiana prismatica

Amphipoda
Ampelisca sp.A
Ampelisca sp.B
Amphilocus sp.
Amphithoe sp.A
Amphithoe sp.B
Amphithoe sp.C
Aoridae sp.A
Aoridae sp.B
Aoridae sp.C
Aoridae sp.D
Aoridae sp.E

Appendix A (continued)

Classified species list of the macrofaunal species recorded from the sediment and benthic fauna study component.

Amphipoda
Aoridae sp.F
Aoridae sp.G
Apherusa sp.
Atylus sp.
Bathyporeia sp.A
Bathyporeia sp.B
Caprellidae sp.
Ceradocus orchestiipes
Ceradocus semiserratus
Cheirocratus sundevalli
Corophium sp.A
Corophium sp.B
Dexamine spinosa
? Dexaminidae sp.
Elasmopus sp.
Gammarella fucicola
? Gammaridaea sp.
Gammarus sp.
Harpinia sp.A
Harpinia sp.B
Hippomedon sp.
Hyale sp.
Iphimedia sp.
Lepidepecreum sp.
Leptocheirus sp.
Leucothoe sp.
Lysianassa sp.
Lysianassidae sp.
Maera sp.
Monoculodes sp.A
Monoculodes sp.B
Monoculodes sp.C
Monoculodes sp.D
Monoculodes sp.E
? *Neogammarus* sp.
Orchomene sp.
? *Orchomene* sp.
Photis sp.A
Photis sp.B
Photis sp.C
Photis sp.D
Photis sp.E
? *Photis* sp.F
Phoxocephalidae sp.
Socarnes filicornis
Stenothoe sp.
Urothoe sp.A
Urothoe sp.B
Urothoe sp.C

PYCNOGONIDA
Pycnogonida sp.

ECHINODERMATA

Ophiuroidea
Amphipholis squamata
Amphiura (Acrocnida) brachiata
Amphiura chiajei
Amphiura sp.
Astropecten sp.
Ophiopsila aranea
Ophiura albida
Ophiura grubei
Ophiura texturata

Echinoidea
Echinocyamus pusillus
Spatangus purpureus
Schizaster canaliferus

Holothuroidea
Cucumariidae sp.

CEPHALOCHORDATA
Branchiostoma lanceolatum

ACTINOPTERYGII
ANGUILLIFORMES
Ophichthidae
Apterichtus anguiformis

APPENDIX B

Table showing the scientific and common Maltese and English names of the fish species recorded from the fish study component.

Latin name	**Maltese name**	**English name**
Apogon imberbis	Sultan tac-cawl	Cardinal fish
Boops boops	Vopa	Bogue
Chromis chromis	Cawla	Damsel fish
Coris julis	Gharusa	Rainbow wrasse
Dasyatis pastinaca	Boll komuni	Common stingray
Diplodus annularis	Sparlu	Annular sea bream
Diplodus sargus	Sargu komuni	White sea bream
Diplodus vulgaris	Xirghien	Common two banded sea bream
Echiichthys vipera	Sawt	Lesser weever
Epinephelus aeneus	Dott tal-faxxi	White grouper
Epinephelus guaza	Cerna	Dusky grouper
FRY	Recently hatched fish; species not identified	
Gobius bucchichi	Mazzun kannella	Bucchich's goby
Gobius cruentatus	Mazzun tad-demm	Red-mouthed goby
Gobius geniporus	Mazzun irqiq	Slender goby
Mullus surmuletus	Trilja tal-faxxi	Striped red mullet
Muraena helena	Morina	Mediterranean moray
Pagrus pagrus	Pagru	Common sea bream
Parablennius rouxi	Budakkra	Blenny

Appendix B continued….

Table showing the scientific and common Maltese and English names of the fish species recorded from the fish study component.

Phycis phycis	Lipp tal-qawwi	Forkbeard
Sciaena umbra	Gurbell tork	Brown meagre
Serranus cabrilla	Sirran	Comber
Serranus scriba	Burqax	Painted comber
Solea sp.	Lingwata	Sole
Spicara maena	Arznella tat-tikek	Blotched picarel
Symphodus sp.	Tirda	Wrasse
Chelidonichthys lastoviza *(= Trigloporus lastoviza)*	Gallinetta tar-rigi	Streaked gurnard
Xyrichthys novacula	Ruzetta	Pearly razorfish